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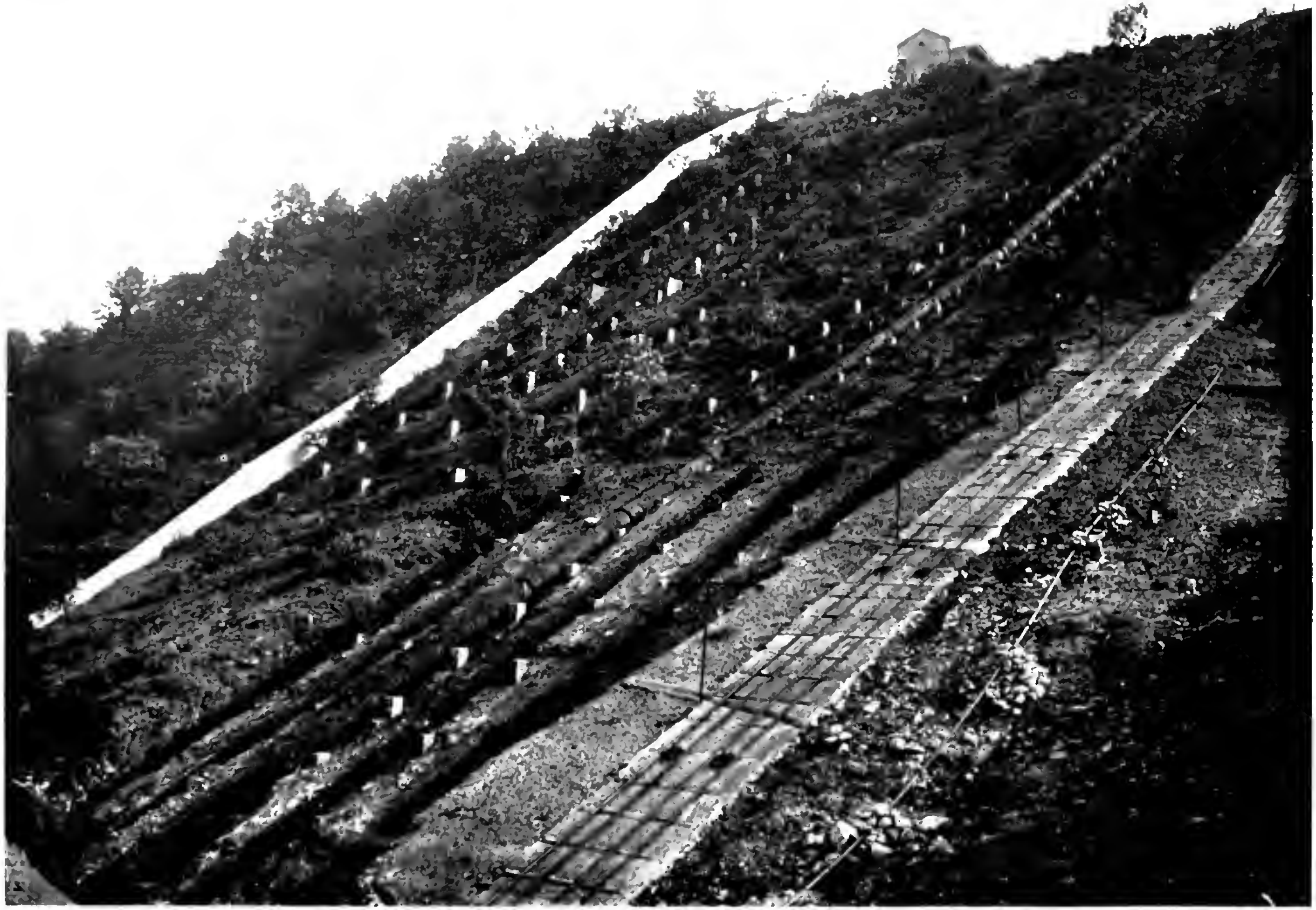

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GENERAL ELECTRIC REVIEW

With the present issue, the REVIEW enters upon the third year of its circulation outside of the organization of the General Electric Company. Its reception by the electrical fraternity at large, and the support it has received have been most gratifying. With the new year more space will be devoted to distinctly practical articles, while theoretical articles will be restricted to those that have a direct bearing upon everyday practical engineering. The latest developments in the electrical engineering practice, new machinery, discoveries and inventions will be described and illustrated.

A modern manufacturing concern of the magnitude of the General Electric Company is a distinctly educational institution and partakes of many of the more important characteristics of a university. First, there are the student courses composed largely of graduates of technical schools and colleges who attend for the purpose of obtaining a practical knowledge of actual operating conditions with a greater variety of commercial apparatus than was possible with the comparatively limited equipment of the college laboratory.

The second feature of similarity lies in the research work that is carried on in the various laboratories. Few, indeed, are the universities that can devote such enormous sums as are annually expended by a large manufacturing company in purely scientific research, and there are few where the technical work is of a higher order. Many of the investigations carried on in laboratories of manufacturing plants would, if pursued in those of a university, entitle the investigator to the higher graduate degrees.

A third feature of similarity to the university is the dissemination of information in printed form. As the large university prints its theses, monographs and pamphlets, so the manufacturing concern publishes the results of recent development and improvements in engineering methods and practice, describing new apparatus which must be brought to the attention of the engineering fraternity, and setting forth its use, its characteristics, and its advantages. Herein lies the function of the GENERAL ELECTRIC REVIEW—it is the medium for disseminating this information to the engineering profession.

Being in close touch with the experts of the General Electric Company, each of whom is in advance of the latest developments in his own line, the REVIEW possesses exceptional opportunities for securing early and accurate information in practically every branch of electrical activity. For this reason, it can furnish information a year or more in advance of its appearance in the text books and elsewhere.

Of the series of articles on practical subjects scheduled for the coming year, one in particular, on the diagnosis and remedy of troubles with alternating current apparatus, should be of special value to the construction engineer, to the operator, to the central station man, the consulting engineer, and the student. Little has been written on this important subject, and that little is mostly scattered through various domestic and foreign magazines and books. We hope to make this series complete and to so arrange it that if a piece of alternating current apparatus goes wrong, the difficulty can be immediately located.

Mr. E. B. Raymond, General Superintendent of the Schenectady Works, will leave the employ of the General Electric Company on January 31st to accept the position of Second Vice President of the Pittsburg Plate Glass Company, and take charge of their manufacturing.

Mr. Raymond was born in Somerville, Massachusetts, and pursued his preparatory education in the High School of that place. He received his university education at the Massachusetts Institute of Technology, from which institution he was graduated in 1890, and the same year entered the employ of the Thomson-Houston Company, at Lynn, where he devoted two years to practical work and then entered the Railway Department to take charge of experimental railway work. Mr. Raymond later entered the Calculating Department, under Mr. H. F. Parshall, and when that department was discontinued at the time of the combination of the Thomson-Houston and Edison companies, became Assistant Engineer of the Chicago office where he was engaged in construction work and in investigating operating troubles.

In the spring of 1895, Mr. Raymond came to Schenectady in the capacity of General Foreman of the department attending to erecting, testing, and the preparation of apparatus for shipment. Mr. Raymond was appointed to his present position of General Superintendent of the Schenectady Works in 1903, at which time the position was created. The duties in this position are defined in the following notice which was published at that time:

"In the absence of the Manager, the General Superintendent will be the ranking officer in charge of the works.

"Foreman will report to and be governed by instructions from the General Superintendent's office in matters pertaining to electrical and mechanical testing and inspection of apparatus and materials, corrections of defects that develop in manufacture, suggested changes in methods or design of apparatus, operation of machine tools, readjustment of facilities and help, as requirements may arise, shop discipline and other matters relating to the economical operation or general condition of departments."

With the departure of Mr. Raymond, the General Electric Company will lose one of the most able and popular members of its technical staff. While a rigid disciplinarian, he commands both the respect and affection of his men, all of whom have learned that with the General Superintendent they are always sure of a square deal.

Mr. Raymond is the author of a number of monographs on electrical and mechanical subjects, besides two text books that are used in various technical colleges.

Dr. Ernst Julius Berg, who for a number of years has been recognized as one of the leading engineers of the General Electric Company, recently accepted the position of Professor of Electrical Engineering and Head of the Department at the University of Illinois.

Dr. Berg was born at Ostersund, Sweden, in which country he resided until he reached his majority. His early education was received in the High School of his native town, and his technical education at the Royal Institute of Technology in Stockholm, from which he was graduated in 1892 with the degree of Mechanical Engineer. Upon completing his university course, Dr. Berg came to America and shortly thereafter entered the employ of the Thomson-Houston Company. Here his technical knowledge and manifest ability as an engineer was immediately recognized, and from a relatively subordinate position, he rapidly advanced to that of Dr. Steinmetz's assistant and chief coadjutor.

In the design and development of alternators, motors, rotary converters, and other alternating current apparatus: and in the solution of such problems as those arising from the use of the alternating current for railway operation, the parallel operation of alternators, the hunting of rotaries, etc., etc., Dr. Berg rendered particularly effective and valuable work. He contributed largely to the successful development of the steam turbine. For a number of years Dr. Berg has acted in the capacity of Consulting Engineer with the General Electric Company. To him were taken many of the more intricate and difficult problems.

Dr. Berg is the author of numerous papers on engineering subjects, and his treatise on the transmission and utilization of electrical energy is a recognized standard. He also collaborated with Dr. Steinmetz in the preparation of the latter's well known "Alternating Current Phenomena." For the past two years he has held the position of Consulting Professor of Electrical Engineering at Union University and recently received the degree of Sc. D. from that institution.

A first-class practical engineer is a man diligently sought after in these days; first-class theoretical men who understand the mathematical theory of the science are more infrequently met, but the man who can combine these gifts—who is both a high grade practical engineer and a mathematical technician,—and who can use his theory in the practical engineering work is exceptional indeed. Finally, the one who, while possessing these characteristics of theoretical knowledge combined with practical engineering ability, can convey his information to others—who in other words possesses the qualifications of a teacher—is a *rara avis*. Such a one is Dr. Berg.

THE FIRST IMPORTANT HYDRO-ELECTRICAL DEVELOPMENT IN SOUTHERN ASIA

By H. P. Gibbs, M.A.I E.E.

The Undertaking

In 1899, having decided to develop hydraulic power in the vicinity of the old village of Sivasamudram for the supply of electric current to the several gold mining companies on the Kolar gold field ninety-two miles away, the Government of Mysore despatched Capt. A. Joly de Lothbiniere, Royal Engineer (loaned to the State of Mysore by the Imperial Government), to Europe and America for the purpose of arranging suitable contracts for the equipment and erection of the power plant, and for the utilization of the available power.

As such work was an entirely new departure in India, Capt. Lothbiniere first made a tour of Europe and America, visiting the plants of numerous manufacturers to ascertain which company, in the matter of experience and facilities, was best qualified to carry through such a contract. A decision was made in favor of the General Electric Company of America for the complete electrical work,

Fig. 1. The Cauvery Falls

including generation, transmission and distribution, and Escher Wyss, of Zurich, for the hydraulic turbires. Each of these companies agreed to install its portion and complete one year's successful operation prior to accepanete on the part of the Government.

Fig. 2. Bridge at Sivasamudram

Arrangement was made with the firm of Messrs. John Taylor and Sons, on behalf of the several mining companies, for the consumption of a little over 4000 horse-power.

The Head Works

At a point approximately two miles above the Cauvery Falls and well above the swiftly descending rapids, a low diverting dam 4.2 ft. in height and 390 ft. in length was built of granite masonry, on a river bed of hard dolerite trap rock. This dam was built for the express purpose of diverting the entire supply of water to the channels during low water periods.

Intake Channels

The entrance to the two channels is equipped with suitable gates for regulating the flow of water, and, in addition, with a scouring sluice for preventing an undue accumulation of silt in front of the channel openings.

Channels

There are two parallel channels which follow the natural contour of the country, so that, although the distance down the river from head works to power house is but

2.65 miles, the channels are 3.375 miles in length. These two channels, when filled to a depth of 6.3 ft., pass 560 cubic feet of water per second, which quantity is sufficient to develop 18,750 h.p. at the turbine shafts. The normal gradient of the channels is 0.2 ft. in 1000 ft. For a distance of 1400 feet, the channels were cut through a spur of hornblende shist and were narrowed to a width of 12 feet with vertical sides, the slope or gradient being increased to 0.6 in 1000.

Fig. 3. Penstock Forebays

Forebays

The two channels terminate in a forebay which is built in two sections, one for the original installation of 6000 h.p. and the other for the first extension of 5000 h.p. Recently a second extension has been made, increasing the capacity of the plant by 2000 h.p., and making a total of 13000 installed electrical horse-power in generators.

The intake chambers for the penstocks are protected from debris by the usual iron rack and are regulated by gates of sheet iron on angle frames operated by hand wheels.

Penstocks

Each penstock is equipped at the top with an ordinary gate valve for individual control. Each pipe has two expansion joints and is supported at the bottom by a firmly anchored thrust block located just outside of the power house wall.

For the original plant, three penstocks were installed, each supplying two 1250 h.p. turbines, while subsequently each turbine has been supplied from a separate pipe. The penstocks are located on an incline having a slope of 1 in 2 for about half way, and 1 in 3 for the remainder of the distance. The average length of the penstocks is 920 feet, with an effective head of 382.5 feet.

The larger pipes are built in three sections, with diameters of 48, 45 and 42 ins. and respective thicknesses of $\frac{3}{16}$, $\frac{1}{4}$ and $\frac{5}{16}$ in. The smaller pipes are built in four sections, the different sections having diameters of 36, 33, 30 and 27 ins., and respective thicknesses of $\frac{7}{32}$, $\frac{1}{4}$, $\frac{1}{4}$ and $\frac{9}{32}$ in. The velocity of flow at the thrust blocks under normal full load conditions is 7.33 feet per second.

Fig. 4. Channels Through Rock Cutting

Turbines

As stated before, the turbines were built by Messrs. Escher Wyss, of Zurich, each turbine having a capacity of 1250 h.p. at 300 r.p.m., with a water consumption of 37½ cu. ft. per second. An interconnection between penstocks is made in the power house with a 10 in. pipe, which also serves the purpose of an exciter main. A similar connection from this pipe to the hydraulic regulators is made for use in emergencies, while the ordinary regulator supply is obtained from a separate service main of 10 in. diameter leading from the forebay, at which point settling tanks are provided to supply clear water in order that the wear of regulator valves and moving parts, due to gritty substance usually carried in the river water, may be avoided.

Regulators

Each turbine is equipped with two jaw nozzles, and the regulation is accomplished as follows: Each nozzle tongue is pivoted near its center, and the tendency to open, due to pressure underneath the tongue, is resisted by a corresponding pressure on a piston linked to the end of the tongue on the side of the fulcrum opposite to that on which the first mentioned pressure is exerted. The pressure on the top side of the piston is automatically varied by a regulating valve operated by fly-balls, allowing the nozzles to open and close according to requirements.

Fig. 5. Penstock Gates and Switch House

This regulator works well under conditions of flat load curve, but is naturally slow in responding to large and sudden fluctuations.

The governor is equipped with a hydraulically operated automatic relief valve, so that undue rise of pressure in the system is

Fig. 6. General View of Development at Power House

entirely eliminated when sudden shut-offs occur. This relief system has always proved reliable and efficient.

Exciters

The generating station is equipped with three turbine-driven and two motor-driven exciters, each of 75 kw. capacity, 110/115 volts.

The generators consist of eleven 720 kw. units, and one 1500 kw. unit, all of which are driven at 300 r.p.m. and operated at 2173 volts, full load normal conditions. The stationary armatures are so arranged that they can be conveniently jacked along the base until clear of the revolving field, thus permitting of ready access to all parts. Up to the present, however (seven years' service), it has never been necessary to shift any of them.

Each generator is supplied with a panel equipped with oil switch, ampere meter, and synchronizing lamps. These switches are for use in emergencies only, as ordinarily the operation is handled from the step-up station, 100 feet above and 1200 feet away.

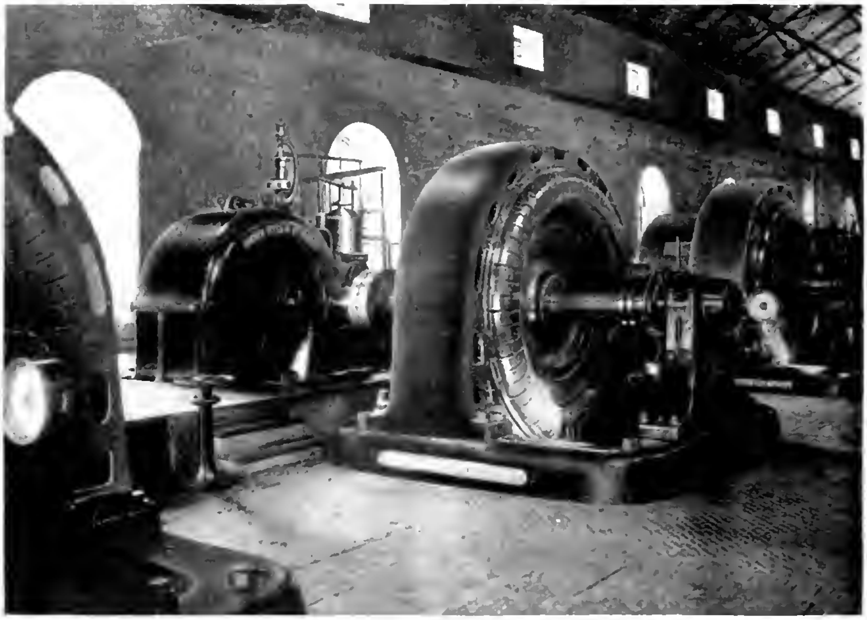


Fig. 7. Generating Units

danger, and now fever cases among the staff are exceptional.

The field and armature cable of each machine are connected by individual cables to the low tension switchboard apparatus above. These cables, which are paper insulated and leaded, are carried on projecting stone shelves at the sides of a ventilated masonry duct. (See illustration page 2.)

Low Tension Work

The low tension switchboard is so arranged that all 2000 volt connections are confined to the basement, while low tension currents only are carried above, where the operator stands on watch.

General Electric Type TA regulators are used to good effect and with satisfactory results for regulating the voltage.

After a thorough system of metering and control, the current is carried along to the low tension side of eleven banks of General Electric transformers; eight of these banks, each consisting of three single-phase 375 kw., 2173/35000 volt, air blast transformers, supplying the Kolar service; two banks,

The separation of the generating station and transformer house was made in accordance with the wishes of Government officers, as it was thought that men working above would be much less subject to malaria than those working in the generating station below. However, it has since been found that such an arrangement was unnecessary.

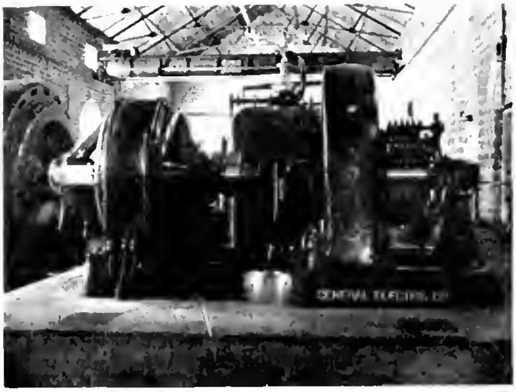


Fig. 8 Motor Driven Exciter

Fig. 9 Turbine Driven Exciter

The entire site was at first very much infested with fever bacteria, but good water supply, drainage, sanitation, and clearing of undergrowth have combined to minimize the each of three 150 kw., 2173/35000 volt, oil cooled transformers, furnishing current for the Bangalore mines; and one bank of 125 kw., 2173/25000 volt, oil cooled transformers, supplying the service at Mysore. It will be noted that the latter bank delivers potential at 25000 volts instead of 35000, as for the other service.

Fig. 10. Step-Up Station

High Tension Work

Each bank of transformers is equipped on the high tension side with a group of three single-pole double break oil switches set in masonry compartments, and can be isolated from the high tension bus-bars by means of knife switches. Each outgoing line is controlled by an automatic motor-operated three-pole switch of the standard General Electric type. These switches have proved provide a convenient means of isolating the latter for examination or adjustment.

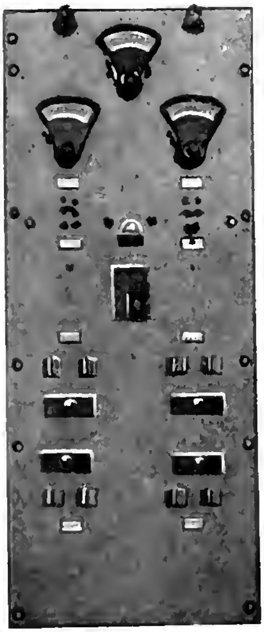


Fig. 11. Exciter Panel

Fig. 12. Low Tension Switch Compartments

entirely satisfactory. Knife switches are installed on both sides of the oil switches to

The lightning arresters are of the standard General Electric multiplex type and are located in the towers of the high tension outgoing lines. Suitable choking coils are also provided.

The lines enter through plate glass set in suitable frames, each glass having a six inch hole in its centre. These entrances have proved very satisfactory.

Fig. 13. Step-Down Station

Line Construction

There are three separate pole lines for the Kolar service. Two of these, as built during the first installation period, are made up of thirteen-foot lengths of extra heavy seven inch hydraulic pipe, and a seven inch square timber top seventeen and a half feet long. The timber is let into the round socket twenty-one inches, and the pole is then set six feet in the ground. This pole is expensive and deteriorates rapidly due to dry rot within the iron socket. These two lines carry No. 0 copper wire supported on single piece, five petticoat, white porcelain insulators made by Richard Ginori of Milan, Italy. The pins are galvanized iron and are secured with portland cement. The distance of transmission is ninety-two miles.

During the third installation period, a third circuit was built of No. 000 copper wire carried on wrought iron poles with angle-iron cross arms and Locke three part brown porcelain insulators.

In special work, spans up to 1620 feet have been built, using standard insulators and 6 strand hard drawn copper cable on a hemp core.

The Kolar gold field transmission lines are equipped with two section stations, dividing the three circuits into nine sections. These section houses are equipped with lightning arresters, and knife and oil switches. Here the lines can be connected straight through, independently or in parallel, and any section can be conveniently cut out for repairs without disturbing the general service. These station sites afford headquarters for the line inspectors and greatly facilitate the location of line trouble.

Fig. 14 High Tension Line Entrances to Step-Up Station

Sub-station

The power is received at the step-down

station at approximately 30000 volts and reduced to 2300 volts, which is the normal pressure of the distributing mains.

The Maharaja of Mysore (on left) and the late Dewar, Sir Sheshadri Iyer

The principal feature of interest in this sub-station is a one-thousand kilowatt synchronous motor running idle with heavily excited field. The leading current provided thereby maintains the power factor at the centre of distribution at from 0.91 to 0.93. Without this machine in circuit, the power factor averages 0.82. The advantage to be derived from this set in the matter of regulation of the system is obvious.

Fig. 15 Special Construction

On the several mining properties of the Kolar gold field, 9000 h.p. from the Cauvery supply is employed in general mining operations, including the driving of air compressors, mills, stone breakers, work-shops, cyanide works, pumps and electrical hoists. The hoists are both above and below ground and are used in sizes up to 400 h.p. These hoists are driven by 3000 volt three-phase induction motors controlled by resistance in the rotor circuit. Their operation has proved to be satisfactory and economical. The principal winding is from a 3000 foot level, carrying a load of rock of 2 1/2 tons at 1000 feet per minute.

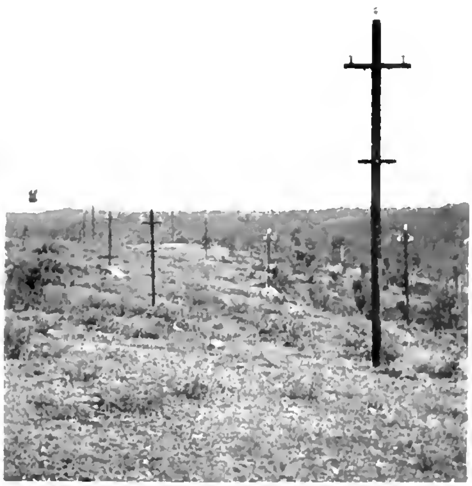


Fig. 16. Standard Construction

Financial

The original arrangement that the Government should install all distribution plants and operate the same for a period of one year prior to acceptance by the mines, applied only to the first installation. This included all distributing lines, motors, compressors, pumps, hoists, belts, ropes, buildings and foundation.

Fig 17. Special Construction

The mining companies agreed to pay for the service on a flat rate, based on the normal full load consumption of motors. Therefore, it is perhaps needless to say that the load factor of the system is a remarkably high one.

The agreement covered ten years payment to be as follows:

First year	£29 per h.p. year	
Three following years	18 " " "	
Fifth year, up to	£24 per h.p. year	
Five following years	10 " " "	

It may here be said that of the first year's payment of £29, £11 was to recoup the Government for its expenditure on the distribution plant; so that the power payment was really £18, as in the second, third and fourth years.

The agreement as regarded the power of the second installation was the same as that of the first, except that the mines installed their own distribution plant and paid at the rate of £18 for the first year's supply. The agreement for the third installation provided for supply at the rate of £10 from the outset.

The result from the Government's point of view is highly satisfactory, although the mining companies concerned have profited to a considerably greater extent, owing to the necessity of an extremely long carriage of an inferior class of coal on which they were previously dependent.

Local Features

During the earlier construction period, work of such description was entirely new to the local people, which fact made it exceedingly difficult for the original construction staff; but the General Electric Company had chosen well, and sent able, hard working men for this special undertaking, with the result that the work was expeditiously carried out in spite of many obstacles.

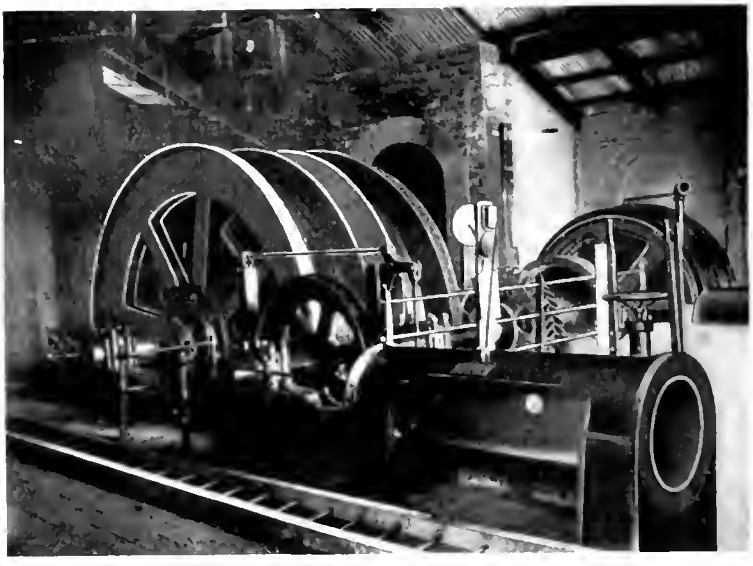


Fig. 18 400 H.P Electrical Hoist at Ovregum

Huge teams of bullocks might be regularly seen slowly wending their way along the hot and dusty 30 mile road, carrying the heavy machinery from the railway to the power house site, while the mighty elephant, ever

Fig. 19. Team of Bullocks

ready, was frequently requisitioned to pull them out of difficult situations.

His Highness, the Maharaja of Mysore, and his able administrators, have often and deservingly been the recipients of congratulation

Fig. 20. The Mighty Elephant

and praise for their pluck and enterprise in carrying out this most successful installation, which was made possible through the far-sightedness and hearty co-operation of the firm of Messrs. John Taylor & Sons, of London, Agents for the Kolar Gold Field Mines.

In closing, it will not be amiss to say that when this development was planned, there were but few similar undertakings on record, so that the credit due to the above mentioned people is undoubtedly greater than would at first appear when considered from a present-day standpoint.

The General Electric Company assumed so large a measure of responsibility that any failure must have been most severely felt by it; but as will be evident from the preceding paragraphs, the entire undertaking has proved a practically unqualified success for all concerned.

POWER FACTOR REGULATORS

By H. A. Laycock

It has become to be generally conceded that in commercial power and lighting work of the present day synchronous condensers are an absolute necessity to the central station manager, in order that the dead loss of power due to wattless current occasioned by heavy inductive loads may be eliminated. For this reason, synchronous motors are being installed on the majority of systems, even though in certain cases they have to run light, as the reduction in the cost of delivering power and the improvement in the voltage regulation of the systems more than compensate for the cost of the machines. However, in order that this regulation may be accurately obtained without the attention of an operator an automatic regulator should be employed. This article describes two forms of regulators that are arranged for power factor work. It does not matter materially whether the synchronous motors are running light, driving direct current or alternating current generators, or being used for power work, as driving conveyors, hoists, etc.

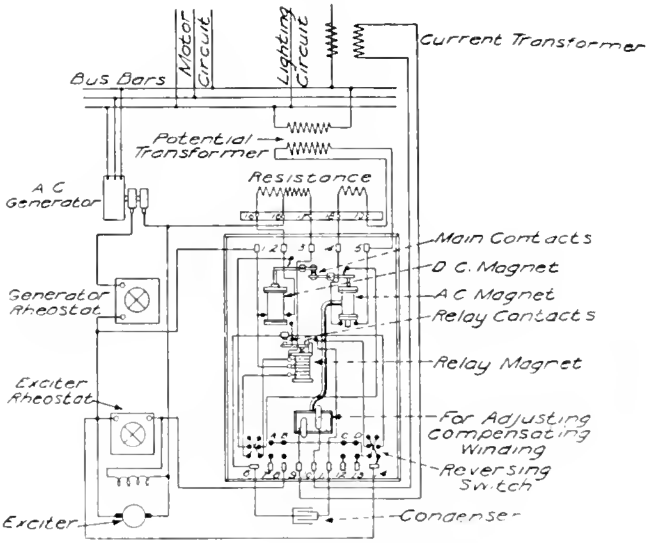


Fig. 1. Connections of Voltage Regulator for Maintaining Constant Power Factor on Line

Plants in which close regulation is desired should always have the generators equipped with voltage regulators; so that the first step is to obtain a constant voltage at the power station and thus relieve the synchronous condenser from doing more work than is necessary. This having been accomplished, the first and simplest method for the installation of a power factor regulator is shown in Fig. 1. This connection is identical with that of a voltage regulator connected to an alternating current generator; in this case, however, one of the standard voltage regulators is connected to a synchronous motor and improves the voltage of the line by increasing or decreasing the excitation on this synchronous machine, the cycle of operation being as follows:

Should the power factor tend to decrease at some point along the line, or at a point where the motor is connected, the voltage will of course have a tendency to fall, due to the low power factor

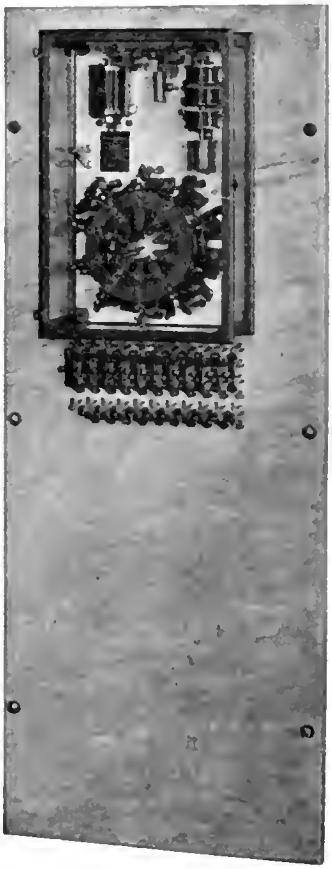


Fig. 2. Power Factor Regulator

conditions. But the alternating current regulating potential magnet is connected across the terminals of the motor, and thus when this voltage tends to fall the floating contacts are closed, which operation in turn closes the relay contacts, and builds up the exciter voltage. This increase in exciter voltage over-excites the fields of the synchronous motor and improves the power factor of the line, so that the voltage is maintained constant at this point.

By referring to connections in Fig. 1, it will be seen that the current transformer can be used if desired to over-compound or over excite the motor still more in order to give the line a lead-

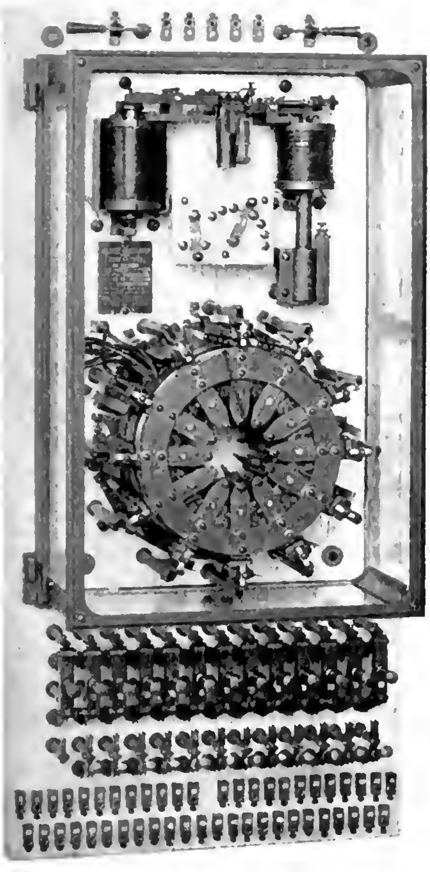


Fig. 3. 12 Relay Voltage Regulator for Power Factor Regulation

ing current. This feature is especially advantageous where heavy fluctuations of inductive load occur between the central station and center of distributi n.

This regulator is designed with a safety stop, so that if desired the amount of excitation current that the motor will receive can

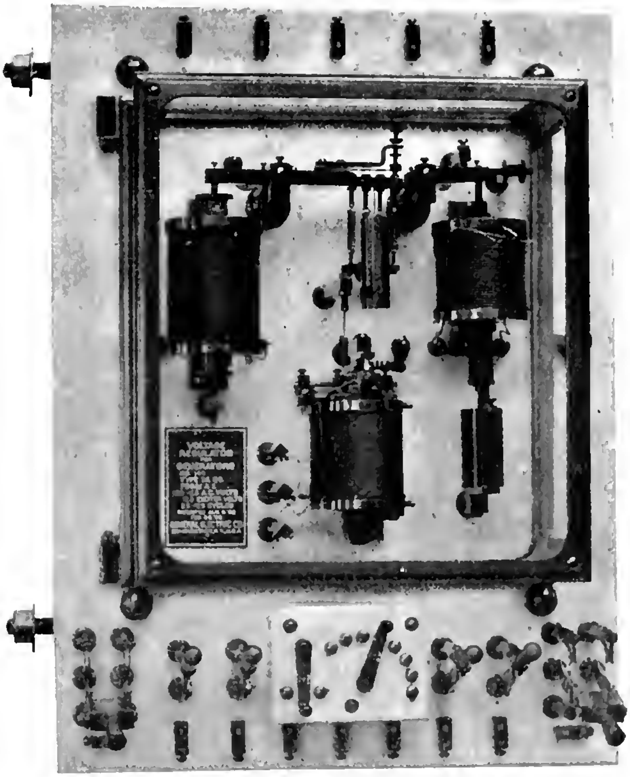


Fig. 4 Single Relay Voltage Regulator for Power Factor Regulation

be limited, thus making the machine safe against injury from excessive excitation.

Almost any number of these motors and regulators can be installed on a transmission line provided they are located far enough apart to secure sufficient reactance between the motors to insure parallel operation without hunting.

Figs. 2, 3 and 4 show the front views of the different types of TA regulators which can be used for improving power factor.

It will be noted that this arrangement of regulation does not hold a constant power factor on the synchronous motor but regulates the motor to help hold a constant power factor on the line.

CONSTANT POWER FACTOR REGULATOR

The appearance of the constant power factor regulator is shown in Fig. 2, while Fig. 5 shows the connections of the apparatus to a synchronous motor and exciter. In this apparatus, the control magnet consists of two stationary potential coils and one movable coil, which, with unity power factor, merely of the voltage regulator, and since the contacts are operated at a high rate of vibration, absolutely perfect results can be obtained within the capacity of the motors and exciters.

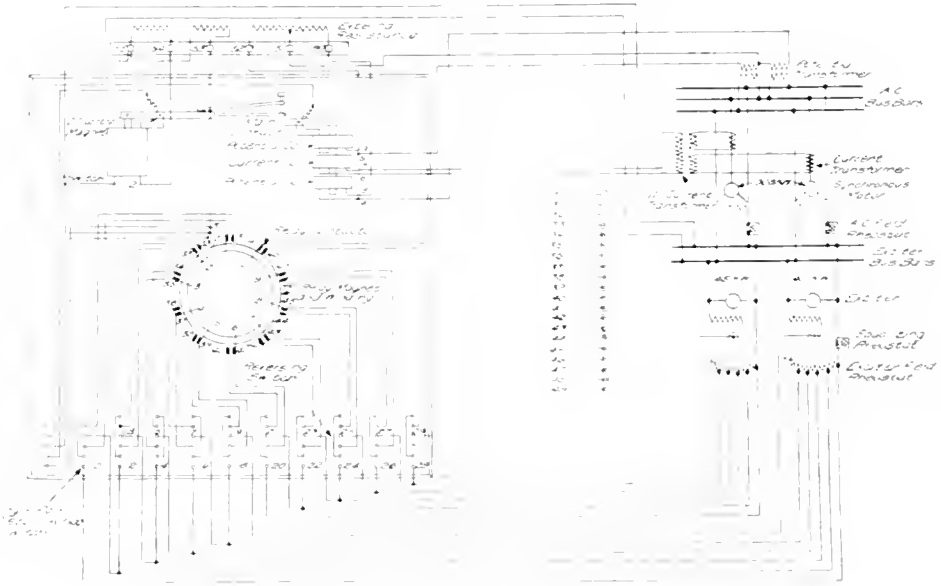


Fig. 5. Connections of Power Factor Regulator

floats between the potential coils, the motor under these circumstances receiving a certain predetermined excitation.

The action of the regulator becomes evident from inspection of the vector diagram, Fig. 6. I_1, I_2, or I_3 is the current per phase, E_1, E_2, or E_3 is the corresponding e.m.f. Assuming that the current coil is in circuit with the phase designated I_1; it is then evident that if the current, for example, lags by the value I_0 or I_ϕ, the phase relations between the current in the current coil and that in the potential coils must necessarily change. A magnetic action is thus set up between the coils to which the movable current coil responds, closing the main contacts. This closing of the main contacts causes the relay contacts to close, thus increasing the excitation of motor and bringing the power factor back to unity, or to the point where the coils are balanced.

If instead of lagging, the current should become leading, the above cycle, of course, will be reversed; the current coil then moving in the opposite direction, opening the main contacts, and thus the relay contacts, and reducing the excitation of the motor.

If the regulator is set for unity power factor, the cycle of operation is similar to that

In addition to maintaining unity power factor, it is also possible, by raising or lowering the current coil and thus changing its relation to one or the other of the potential

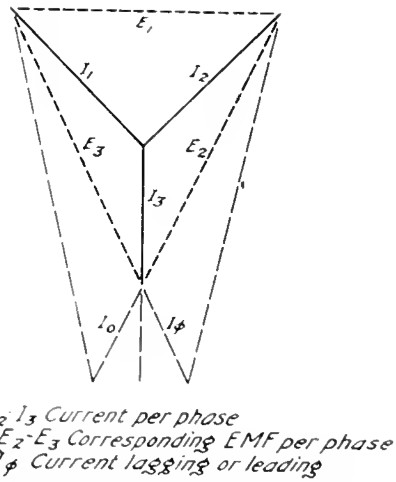


Fig. 6

coils, to hold any per cent. leading or lagging current that may be desired to meet the requirements for which the motors have been designed.

Several installations of power factor regulators have been made in cases where synchronous motors are used for driving railway generators on which the load is subject to violent fluctuations. In such a case without regulator, the sudden changes in load would produce a very bad power factor on the line supplying the motor. Fig. 5 shows a typical installation of this kind. Here the regulator is designed with six relays which operate on two 45 kw. exciters supplying excitation current for two 1000 kw. synchronous motors driving railway generators. Installations of this kind are generally found to require a leading current with a power factor of 80 per cent., and when this is the case the regulator is set for this figure, with a safety device adjusted so that the excitation current is held to a certain predetermined amount, depending upon whether the fields are designed for 125, 250 or other voltage. These regulators, like the voltage regulators, are designed to operate over a range of exciting potential of 100 per cent from minimum to maximum, and if the synchronous motor is properly supplied from the line, the range of excitation potential will be well within these limits. A motor should not receive a greater excitation than a standard alternating current generator, and it is to prevent a possible excess of excitation and consequent injury to motors that the limiting device is used.

COMMERCIAL ELECTRICAL TESTING

Part III

By E. F. Collins
Superintendent of Testing Department

Heating Tests

The test to determine the heating of a machine is a very important one and great care must be taken to obtain reliable temperatures. Any large machine requiring a considerable amount of floor space should have the room temperatures taken at four different points nearby, and at a sufficient distance away from the machine to be unaffected by heat from the latter. Two thermometers, one in air and one in a specially designed metal cup containing oil, are used at each point to measure the room temperature. Before starting a heat run, thermometers should be placed on all important accessible stationary parts, such as series and shunt field spools, pole tips, frame, etc., in the case of a direct current machine. In addition, thermometers should be placed between pole tips to register the temperature of the air thrown off from the surface of the armature and from the air ducts. Each thermometer should be attached with the bulb in contact with the part of which the temperature is required, the bulbs being covered with putty. Thermometers which are to register the temperature of air ducts should be so placed that the bulb cannot make contact with the iron laminations while the machine is running.

The machine should be shielded from currents of air coming from adjacent pulleys and belts. Unreliable temperatures are obtained when the machine is located so that another machine blows air upon it. A very slight current of air will cause great discrepancies in heating; consequently either a suitable canvas screen should be used to shield the machine under test, or the machine causing the draught should be shut down.

Overload heat runs require considerable attention. Where an overload is applied for one or two hours, it should be certain that normal load temperatures have been reached before applying the overload. The overload must be carried only for the specified time, since, in many cases, the temperature rises rapidly throughout the whole period of the overload. Hence lengthening or shortening the overload period a few minutes may make several degrees difference in the overload temperatures obtained. To avoid continuing an overload run for a longer time than that specified, arrangements for a sufficient number of thermometer and resistance measurements must be made well in advance of the end of the run.

During the heat run all conditions should remain normal, and the machine should be watched carefully for any undue heating of bearings or field spools, or for the appearance of defects. The wiring, holding down bolts, belt lacing, etc., must also be watched.

In making heating tests two methods may be used; *i.e., actual load tests* and *equivalent load tests*. Several different means for obtaining actual load tests may be employed, such as "water box," "circulating," "feeding back," "shifting the phase" and "induction generators."

The "water box" method, as the name implies, consists in driving the machine by either a motor or engine and loading it upon a "water box," or rheostat. (Fig. 11.) This method entails considerable expense, since all the power generated is lost. To obviate this loss and reduce the cost of testing, the "feeding back" method is used when possible, especially in the case of large d.c. machines and motor generator sets. In this method the total machine losses are supplied either mechanically or electrically from an external source. In the mechanical loss supply method, two machines of the same size and voltage are belted or direct connected together and driven by a third machine large enough to carry the losses of the set. Connections are made as shown in Fig. 12. If the machines have series fields, these should be connected to boost one another. Both machines should then be started up as generators and thrown together by closing the switch between them when the voltage across this switch is zero. The field of the machine that is to act as motor should then be weakened, which operation throws load on both machines. The speed is held constant by the loss supply motor. After running at the proper load for the specified time, temperatures should be taken and tests finished according to standard requirements.

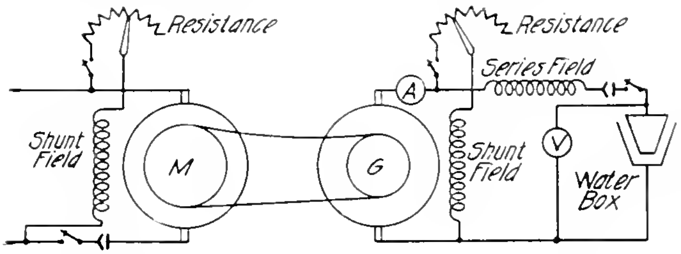


Fig. 11. Connections for Loading a D.C. Generator on a Water Box

If the machines are motors, the same connections should be made and the machines thrown together as before. The voltage of the system must be held by the machine running as generator. The only correct way of obtaining load is by changing the speed of the set, the brushes having previously been set in the running position. Usually the speed will have to be decreased, and the difference between full load and no load speed will be the normal drop in speed for the motors. Cases sometimes occur where the speed of the motor, due to armature reaction, increases with increase of load. In pumping back, this condition is shown by the motors taking an overload at no load speed, in which case the speed of the loss supply must be increased.

In the method of electrical loss supply, two machines are direct connected or belted together and the losses supplied electrically. Should two shunt motors be tested by this method, one machine should be run at normal voltage, current, speed and full field; the other motor to be run as a generator with a little higher current and slightly stronger field than for normal conditions. The fields of the generator may have to be connected in multiple. Connections should be made as in Fig. 13. The motor should be started first from the electrical loss supply circuit and its brushes shifted for commutation and speed. After exciting the field of the generator and adjusting the voltage between the machines to zero, the circuit is closed. The machines are loaded by increasing the field current of the generator. Care should always be exercised when shifting the brushes while the machines are under load, since a slight change in shift will at once change the load. After the heat run has been finished and all motor readings taken, the wiring should be changed and motor readings taken on the machine which ran as a generator.

When compound wound generators are being tested by this method the series field of the motor must be included or the load will be unstable.

Another method of "feeding back," often used, is to feed the entire load back on the

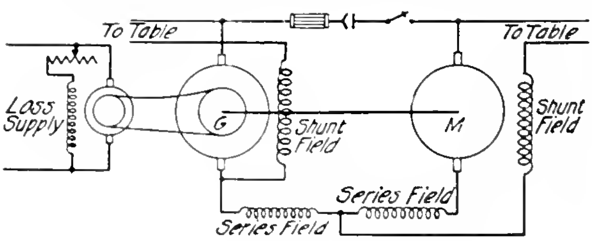


Fig. 12. Connections for Mechanical Loss Supply Pump Back

main supply circuit from which the motor is run that drives the generator under test. If the main supply circuit is likely to vary in voltage, it may be necessary to insert resistances between the generator and supply. It sometimes happens that the no-load voltage of the generator is below that of the supply. As changing the line resistances will have no effect at no-load, the generator voltage must be increased until it is equal to that of the main supply circuit. Having previously calculated the full-load field current from the no-load current and the ratio of compounding voltages, the machines are thrown together and full load put on the generator by cutting out the variable resistance.

Two similar motor generator sets can be tested very readily by the "feeding back" method. As an illustration, suppose each set consists of an induction motor and a d.c. generator. In this case connections are made as in Fig. 14. The a.c. and d.c. ends of the sets are respectively connected together, one set being run normally, and the other inverted. The induction generator feeds back on the induction motor, both taking their exciting current from the alternator (A) which supplies the losses. The sets are started one at a time from the a.c. end, and the d.c. ends paralleled by means of a voltmeter across switch P. The d.c. motor field is weakened until the ammeter in the d.c. line indicates that normal current is flowing. The weakening of the motor field allows the speed of the inverted set to increase just enough to load the induction generator, while it also decreases the counter e.m.f. of the motor a sufficient amount to allow full load current to flow in the d.c. circuit. This load must be closely watched, as it is unstable. Load unstability is a rather common occurrence in "feeding back," due to either variations in shop voltage or speed.

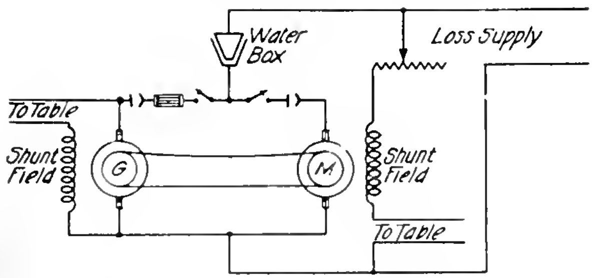


Fig. 13. Connections for Electrical Loss Supply Pump Back

It will be noted in the "feeding back" tests described, that it is necessary to weaken or strengthen one of the fields to obtain the load. To conduct the test with the same field excitation on both machines the armature of a separately excited booster may be connected in series with the armatures of the two machines being tested. The machines, connected so that they run at the same speed, are brought up to normal speed by means of the motor supplying the losses. The connecting switch is then closed

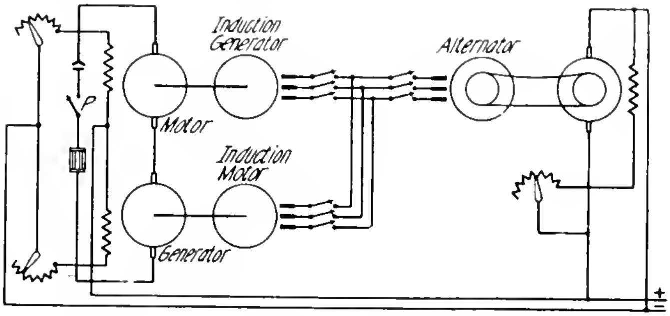


Fig. 14. Connections for Induction Motor Generator Set Pump Back

and the booster field strengthened until normal current flows in the armature circuit, the field current being adjusted to give the same excitation on both fields. The voltage is held across the motor terminals by varying the speed of the loss supply motor. This method, known as the circulating method, is used particularly in the testing of series or railway motors. In the latter case the machines are geared to the same shaft.

Another method known as "shifting the phase" is used in testing two similar alternators or frequency changer sets. Two similar alternators may be direct connected by means of a coupling and driven by a motor to supply the losses. For example, let a three-phase machine be considered, the phases of which are shown diagrammatically in Fig. 15. The machines should be run at normal speed, the fields connected in series and separately excited to a value corresponding to the load at which it is desired to make the test. The value of this excitation should be calculated from the saturation and synchronous impedance curves. With phases A and A′ connected together, the voltage across phases b and b′ is read, the circuit closed, and the value of the current flowing observed. Knowing the voltage between phases a and b, a′ and b′ and b and b′ the angle of phase displacement may be readily obtained. Should the resulting armature current be considerably greater or less than that desired, a further trial will be necessary.

The current value will vary nearly as the angle of displacement, so that an approximate value of the angle desired can be found from the value of current and angle previously ascertained. When the value of this angle has been ascertained, the phase displacement should be changed, so as to obtain

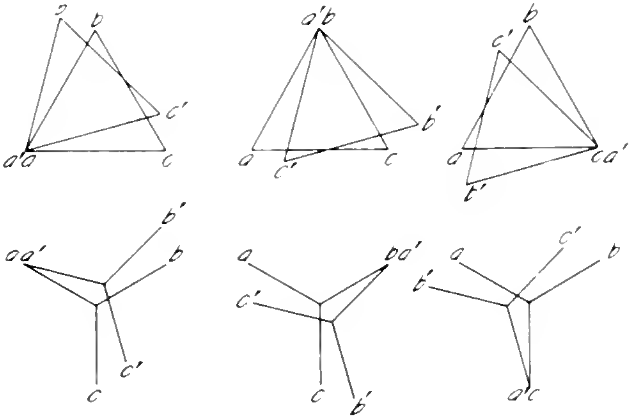


Fig. 15. Shifting of Phases Shown Diagrammatically

as closely as possible the desired value of current. With the machines still connected together as they were originally, the angle of phase displacement previously found will be increased 120 electrical degrees by connecting a′ b. If a′ c are connected, a still further displacement of 120 degrees is obtained. If with any of these connections, the field of one machine be reversed, a still further displacement of 180 degrees is made. With the connection which gives the nearest value of armature current to that required, a further adjustment may be made by shimming the stator of one or both machines up on one side and taking shims out on the other side. The circuits should then be closed and the heat run made for the specified time. Even with the angles of phase displacement possible with the various combinations of connections and field rheostats it may not be practicable to get the desired armature current. In this case, unbolt the coupling and shift the rotor of one machine around one or more bolt holes. The "cut and try" operations should then be repeated.

Although the method employed in this test may seem long and tedious, the results obtained are very satisfactory, especially where it is necessary to make an actual full load test.

The induction generator method is sometimes employed in making full load tests on induction motors. Two similar induction motors are belted together and run in parallel from the same alternator which supplies the losses. (Fig. 16.) In order to get full load on both machines, the diameter of the pulleys must differ by a percentage equal to double the full load per cent. slip.

In starting, the switches A are closed and the motor M allowed to come up to speed, until the speed of the motor running as a generator is above synchronism. The alternator field is opened momentarily, whilst the switches B are closed. The circuit in the alternator field is then closed again, and full load current flows through the two machines. No changes in load can be made without changing the pulley ratio and it is absolutely necessary that this ratio be correct in order to obtain full load.

Equivalent Load Tests

Very often it is found impossible to run actual load tests, especially on large machines, on account of limited facilities. Equivalent load tests have consequently been devised in which the heating of the machine at a certain load may be very closely ascertained without actually loading it. One of five different methods may be employed in making such a test; *viz.*, "open circuit," "short circuit" and "low voltage test," "circulating open delta" or "phase control."

Direct current machines can be satisfactorily tested by short circuiting the armature upon itself, or through the series field, so connected that it will not build up as a series generator. The shunt field is separately excited from an external source, until the required current flows through the armature, or armature and series field. This method is excellent for baking and settling the commutator. Amperes armature and field, and volts field should be read throughout the run.

In the case of alternators, the machine is run open circuited, with a field current that gives a predetermined percentage over normal voltage. The run should be continued until the rise in temperatures above the room temperature is constant, after which the machine is shut down and the final temperatures taken. The armature is then short circuited, the machine started again, and sufficient excitation applied to give a current in the armature of a certain percentage over normal. This run should also be continued until the rise in temperatures above that of the room is constant, after which the final temperatures are taken. The resistance of the field should be carefully measured before and after the open circuited run, that of the armature before and after the short circuited run, and the temperatures of the windings cold should also be recorded. During both runs volts and amperes field and speed should be recorded. During the open circuit run, volts armature are recorded, and during the short circuit run amperes armature.

On some of the large induction motors, only about one-fourth of the normal voltage is impressed. The machine is then loaded until the desired current flows in the stator, the run being continued as described above.

Another method of making an equivalent load test, used especially with turbo and other large three-phase alternators, is known as the circulating open delta run. The phases of the machine are connected in delta, one side of which is left open. The fields are excited to give the load desired, this excitation being determined from the saturation and synchronous impedance curves. Due to harmonics which may exist in the legs of the delta, an alternating cross current may flow in the winding. This is measured by an a.c. ammeter (with current transformer, if necessary) inserted in the opening of the delta. The difference between the square of this current and the square of the current with which it is desired to load the machine is found, and a direct current of a value equal to the square root of this difference is circulated through the winding. The run is then continued, a careful record of volts armature, direct and alternating amperes armature, volts and amperes field being made. It will be noted that the alternating cross current in one side of the right angled triangle and the direct current in the other are combined vectorially to obtain the load current desired.

Another method of loading an a.c. generator is to give it normal excitation and run an unloaded synchronous motor from its armature circuit. The field of the motor is varied to give a leading or lagging current in the armature circuit. This is known as the phase control method. The rise in temperature on the fields during open circuit run, and on the armature during the short circuit run, is practically the same as will obtain during operation under load. The rises in temperature obtained from a circulating open delta run are also so considered.

With induction motors, it has been found that the temperatures on low voltage runs when combined with temperatures at no load and normal voltage, give very nearly the same results as an actual load test.

Except in the case of commutating pole machines, it is often necessary to shift the brushes to get good commutation while under load. The point at which the best commutation is obtained is known as the running point. Its position should be plainly marked on both the rocker arm and the frame by means of a chisel.

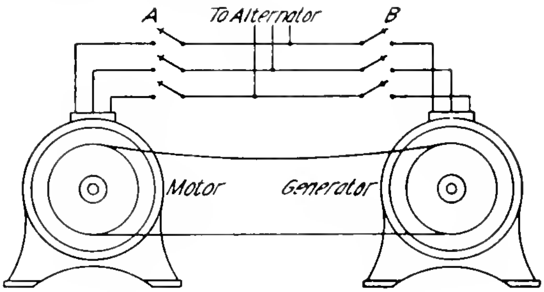


Fig. 16. Full Load Test on Induction Motors

It is the present practice to adjust all series field shunts cold, except in cases where a hot compound is expressly desired. This compounding consists in placing a shunt across the series field terminals, in order to obtain the proper voltage at no load and full load. The contacts of the shunt should be perfect. In making a no-load field setting on the machine, the voltage should be raised about 15 per cent. above normal no-load voltage, and then reduced to normal. With the rheostat left in this position, the load is thrown on, and if the compounding is high, the resistance of the german silver shunt should be reduced, a new no-load reading taken, and the operation repeated. This should be continued until the machine compounds according to specifications.

To take final temperatures after a heat run requires the greatest care. Arrangements should be made so that no delay results in placing the thermometers on the proper parts. Temperature readings should be made every few minutes until all temperatures begin to drop, when the thermometers may be removed. When final temperatures are being taken the hot resistance of the machine should be measured. After all the necessary tests are made, the wiring should be removed and the high potential tests applied while the machine is still warm.

In calculating the rise of temperature by resistance the following formula is used.

Let Rt_2 = hot resistance of copper measured at the temperature t_2

Rt_1 = cold resistance of copper measured at temperature t_1

R_0 = resistance of copper at 0° C.

$$t_2 = \left(238 + t_1\right)\frac{Rt_2}{Rt_1} - 238$$

When using this formula it is assumed that 0.0042 is the temperature coefficient of copper at 0° C. The rise obtained from this formula should be corrected by one-half of one per cent. for each degree C. that the final room temperature differs from 25° C. This correction is added if the temperature is below 25° C. and subtracted if above. The temperature of the winding itself must therefore be very carefully observed, as well as that of the room, when the hot and cold resistances are taken.

It is often necessary to make a heat run on an a.c. machine at a specified power factor. To do this, in the case of a generator, the machine is loaded on water boxes connected in parallel with a synchronous motor. The motor merely floats on the line, its field being adjusted to give the desired power factor. Instead of loading the generator on water boxes, the motor is often belt or direct connected to a d.c. generator which feeds back onto the shop circuit.

Synchronous motors are run under load at a certain power factor by being driven from an a.c. source of power and loaded on a d.c. generator. When power factor runs are made, generators should always be run with lagging and synchronous motors with leading current, unless otherwise specified.

In addition to an ammeter and voltmeter, wattmeters should always be inserted in the armature circuit of the machine tested, in order to check up the power factor of the circuit.

Equivalent load heat runs are frequently made at a given power factor. In the case of an open circuit run, the excitation given the machine is a certain percentage over that which will give the desired voltage at the desired power factor and load. This excitation is determined from saturation and synchronous impedance curves. Short circuit runs are made with a certain percentage of excitation over that required to give the desired kilovolt-ampere reading.

Circulating open delta runs are made as previously described, an allowance being made for the proper excitation and armature current at the power factor desired.

(To be Continued)

HIGH VOLTAGE POWER TRANSFORMERS

By Edwin R. Pearson

The demand for transformers of greater capacities and higher voltages for power transmission work has been constantly increasing for a number of years. Comparatively a few years ago, the construction of a transformer of 50 kw., wound for 4,000 volts primary, was considered an achievement. Later on, a text book on transformers was issued showing a transformer of small capacity which stepped up to 10,000 volts, and the author cited this as an instance of the possibility of what *could* be done.

From such beginnings advancement has steadily continued so that at the present

3,750 Kw. Transformer, 138,500 Volts

time single transformers of a capacity of from 1,000 kw. up are not at all unusual. There are installed on the lines of the Great Western Power Company, of California, a number of 3-phase transformers having a capacity of 10,000 kw. each.

The constant potential transformer is the connecting link in every transmission system, which fact made it necessary for the designing engineer to keep pace not only with transmission developments but to show his ability to produce transformers of a voltage in excess of the demand. Voltages have increased gradually, until a considerable proportion of large transmission systems use voltages from 90,000 to 110,000 The latest advance in the art is outlined by the requirements of the Stanislaus Power Company, of California, the voltage in this case being a long step ahead of anything previously used. The Stanislaus Company's requirements are for 60-cycle single-phase, water-cooled transformers of 3,750 kw. capacity, with a high tension voltage of 138,500 and a low tension voltage of 12,100.

The high tension windings of the transformers are so designed that voltages in several steps from 40,000 to 120,000 can be obtained with transformers connected in "delta"; the maximum voltage of 138,500 being obtained by "Y" connection. The low tension windings are also arranged for either 4,000 or 12,000 volts with "delta" connections. At all voltages, transformers will operate at full capacity.

In designing and building these transformers the standards set for smaller and lower voltage transformers have been fully maintained. Careful attention was paid to every feature of the design, the proper insulations, ducts and cooling surfaces being provided to insure uniform strength and cooling throughout all parts The results of the tests show that these efforts were well directed, and while there was no fear of the outcome, considerable gratification was felt that no sign of weakness was evident throughout the severe tests. An insulation test of double the maximum line voltage: *viz.*, 280,000 volts, was applied between the high tension winding and all other parts for one minute

Inasmuch as these transformers are, as above stated, considerably in advance of anything else ever attempted, some details will doubtless be of interest. Efficiencies are 98.8, 98.7, 98.3 and 96.8 for full load, three-fourths, one-half and one-quarter loads respectively. In other words, the total losses at full load are approximately 1.2 per cent. of the rating The non-inducti e regulation is approximately 1.25 per cent. at unity power factor.

An idea of the size of these transformers and the immense quantity of material required is given by the following approximate

Transformer Removed from Case

dimensions: Floor space occupied is approximately 9½ ft. by 5½ ft., with a height from the floor to the top of the leads of about 17 ft. Each unit complete with oil weighs 28 tons. The windings in each transformer require approximately four miles of copper strip, built up into the usual flat coil structure having one turn per layer. The fact that transformers of this character can be built in quantities indicates the enormous facilities and resources of the manufacturer.

All of the coils in these transformers are impregnated under vacuum with an oil-proof insulating compound, making, in connection with a good mechanical construction, a very substantial structure. The leads used in these transformers are the regular oil-filled type, of good proportions, providing a wide margin of safety.

TRANSMISSION SYSTEM OF THE SOUTHERN POWER COMPANY

By John Liston

The cotton mills of the Piedmont district take about 80 per cent. of the entire output of the Southern Power Company's generating stations, the balance being utilized in various other industries and for lighting. The scattered location of the numerous mills in North and South Carolina rendered the problem of economical transmission unusually complicated, and it was necessary to provide several main transmission lines with a number of branch circuits and taps to the mills: so that the present transmission system, as indicated in Fig. 1, involves a network of 11,000 volt, 44,000 volt and 100,000 volt, three-phase, 60 cycle circuits, which have an aggregate pole and tower length of 639 miles, with a single circuit total of 983 miles.

The present lines extend north from the Rocky Creek power station for a distance of more than 100 miles, while their range east and west is approximately 165 miles. When the new power stations and the projected lines are completed the total mileage of the transmission system will be more than double that of the existing lines.

Fig. 1. Map of Transmission System Showing Existing and Projected Lines

The main generating stations at present constructed are arranged for parallel operation and are tied together by means of a trunk line with three circuits, two circuits on twin towers and one on poles running from the Great Falls and Rocky Creek stations to

Catawba. The general transmission system is not, however, operated as a trunk line, but the various sections are interconnected through four main switching stations, and 57 local transformer sub-stations. These insure uninterrupted service in case a generating station is either overloaded or shut down. If trouble occurs on any one of the lines, the particular section affected can be readily cut out and the balance of the line fed through the switching stations at either end.

The entire system is patrolled each week, fourteen men being employed in this work. They keep the right of way clear and do all ordinary repair work; under normal conditions each man patrols a limited territory, but in case of serious trouble an effective communication system enables them to be readily assembled within a short time after the discovery of the trouble.

Fig. 2. Single and Twin Circuit Poles

At present the total transformer capacity of the local sub-stations on the 11,000 volt lines is 7000 kw., and on the 44,000 volt lines 55,350 kw. In the 17 stations on the 11,000 volt lines the secondaries of the transformers are arranged for 550 volts. On the 44,000 volt lines there are 22 stations having transformers with 2300 volt secondaries, and 8 stations having transformers with 550 volt secondaries. Nine stations are already provided for the 100,000 volt lines, and these all have transformers with 2300 volt secondaries. In addition to these, two stations on the 100,000 volt line will have transformers for stepping down to 44,000 volts, for tying in with the 44,000 volt system in case of breakdown.

At present a total of 130,000 kw. in 100,000 volt transformers has been installed. In all sub-stations on the 100,000 volt lines three single-phase transformers will be used, and in no station will the capacity of the transformers be less than 1000 kw.

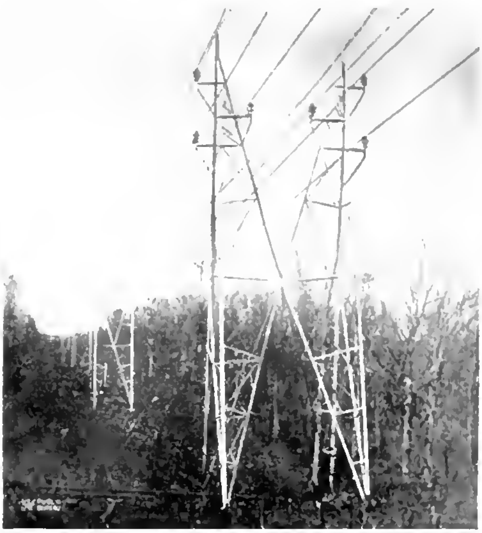


Fig. 3. Twin Circuit "Aermotor" Towers Carrying 44,000 Volt Conductors

The main switching stations referred to above have operators, but most of the local transformer sub-stations do not require the services of special attendants.

At present the transformer connections throughout the system are delta-delta, from generating station through sub-stations to the mills. When the 100,000 volt system is put in operation, the transformer connections at the generating station will be changed to delta-Y, and those at the junctions with the 44,000 volt line to Y-delta.

A reference to Fig. 1 and the following tabulation will give an idea of the extent of territory covered by the existing lines, and will indicate the problems which confronted the engineers of the Company when planning the routes to be followed, so as to obtain economical current distribution and, at the same time, secure immunity from serious interruption of the service, this latter feature being further complicated by the frequent local lightning storms which are characteristic of the region served.

For the various transmission lines five distinct types of poles and towers have been used. The two forms of wooden poles shown in Fig. 2 were used for the original Catawba transmission line—they are either cypress, juniper or chestnut (chestnut being finally selected as the most suitable available wood), and the cross arms are all of hard pine creosoted. The twin circuit pole shown on the right hand of Fig. 2 is used for 11,000 volt circuits, while the single circuit poles at the left now carry 44,000 volt conductors, and will also be used for a short 100,000 volt line.

The bulk of the 44,000 volt lines are now carried on twin circuit structural steel "Aermotor" towers similar to that shown in Fig. 3, while for the intended 100,000 volt lines a 3-arm steel twin circuit "Milliken" tower (see Fig. 4) has been provided. These towers are practically duplicates of those used in the Schaghticoke-Schenectady line of the Schenectady Power Company, which were fully described in the May, 1909, REVIEW.

For running tap lines to mills and carrying the conductors across railroad tracks and through cities, a type of pole similar to that used for the Chicago Drainage Power Transmission system (see Fig. 5) has been adopted. These are twin circuit 2-arm poles built of structural steel, and are used intermittently in the different transmission lines, their height varying from 45 to 80 feet, the 80 foot poles weighing 9000 pounds each. These poles, as well as all the "Aermotor" type, have their bases weighted with concrete.

The "Milliken" towers are mounted on metal stubs sunk 6 feet in the ground. Where the angle of the line is over 15 degrees, however, these stubs are weighted with rock and concrete, and where an angle of over 30 degrees occurs, two and sometimes three towers are used for making the turn. The weight of the standard "Milliken" tower is 3080 pounds, and its height from ground line to peak 51 feet. The towers are spaced

EXISTING TRANSMISSION LINES OF THE SOUTHERN POWER COMPANY

		Poles	Distance in Miles	No. of Circuits	Total Mileage Single Circuit
		44,000 Volt Lines in Operation			
Rocky Creek	—Gt. Falls	Aermotor	2	2	4
Great Falls	—Gastonia	"	63	2	126
Great Falls	—Gastonia	Wooden	4	2	8
Great Falls	—Catawba	"	36	1	36
Clover	—99 Islands	"	18	1	18
Gastonia	—Kings Mt	"	13	1	13
Bessemer City	—Shelby	"	20	1	20
Gastonia	—Newton	"	32	1	32
Gastonia	—Statesville	"	59	1	59
Catawba	—Charlotte	"	18	2	36
Charlotte	—Spurries	"	12	1	12
Charlotte	—Concord	"	18	2	36
Concord	—Salisbury	"	24	1	24
Taps of various mills			10	1	10
		100,000 Volt Lines now Operating at 44000 Volts			
Great Falls	—Monroe	Milliken	37	2	74
Great Falls	—Chester	"	22	2	44
Chester	—Greenville	"	74	2	148
Monroe	—Greensboro	"	105	2	210
High Point	—Winston Salem	Wooden	17	1	17
		*** 11,000 Volt Lines Total**			
		Wooden	56	1	56

* 7 Miles Double Circuit

to average 8 to a mile and a strain tower weighing 4250 pounds is used every mile. For particularly long spans a special heavy tower weighing 6000 pounds is used. The circuits are transposed every 30 miles. The magnitude of the operations carried on by the Southern Power Company will be indicated by the fact that there are 2157 of these "Milliken" towers already erected, having a total weight of almost 3700 tons.

The "Aermotor" towers vary in height from 35 to 50 feet, and the circuits are transposed every 10 miles. All steel towers were assembled on the ground and erected by means of gin poles.

Both copper and aluminum conductors have been used in the construction of the line. On the

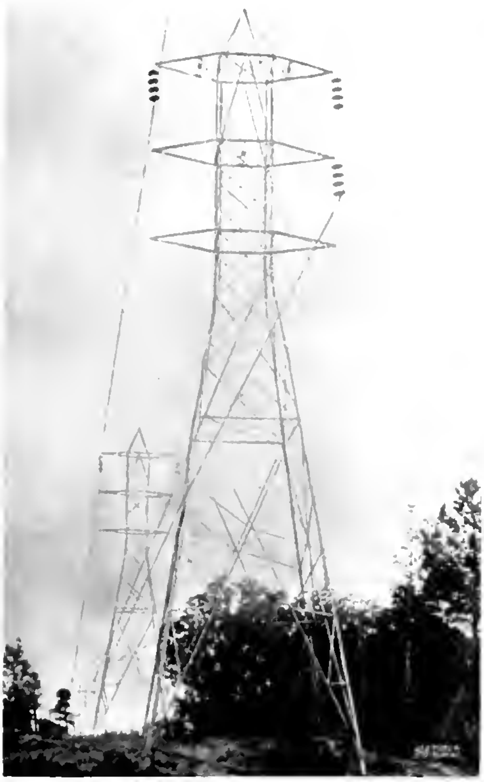


Fig. 4. 100,000 Volt "Milliken" Towers with one Circuit Strung

44,000 volt, 2-circuit trunk lines, from Great Falls to Catawba, a No. 000 6-wire stranded copper cable weighing 8 tons per mile of two circuits and provided with a hemp core, has been used.

On the 18 mile line between Catawba and Charlotte the two single circuit 44,000 volt wooden pole lines carry an aluminum cable weighing 1029 pounds per mile. This cable is 6-strand with a cross section of 208,000 cir. mils.

Fig. 5. 44,000 Volt Lines entering the Gastonia Substation

For the 140 miles of 100,000 volt line from Great Falls to Greensboro a No. 00 7-strand copper cable weighing 2144 pounds per 2-circuit mile has been used.

All conductors except those on the 100,000 volt lines are carried on triple petticoated pin insulators. The center stud provided with these insulators is of special design, and is the invention of Mr. W. S. Lee, Vice President and General Manager of the Company; it permits the rapid replacement of insulators in case of breakage.

On the 100,000 volt lines multiple disk insulators are used—four disks being used to suspend each conductor from standard towers, and ten disks to each conductor on strain towers.

The length of span required on the different lines varies with the topographical conditions; the standard distance for the wooden pole lines is 150 feet, the "Aermotor" towers being normally spaced 500 feet apart with a sag of 5 feet 8 inches. The minimum distance between towers is 300 feet, and the maximum 720 feet this latter span occurring where the line crosses Fishing Creek.

The "Milliken" towers have a standard span of 600 feet; the sag at a temperature of 50 degrees F. being 11 feet. At a point where the line crosses the Catawba river just above the Great Falls station the distance between the towers is 1300 feet. The lines are strung at an average tension of approximately 1537 pounds per conductor and a single guard wire of $\frac{3}{8}''$ stranded Siemens-Martin

Fig. 6. Bessemer City Transformer Substation Built to Accommodate Multigap Lightning Arresters

steel is carried along on the peaks of the towers. This guard wire weighs 316 pounds per mile, and has a breaking strength of 9,000 pounds. A similar guard wire of $\frac{9}{32}''$ steel is used on the wooden pole lines, and the "Aermotor" towers are provided with two.

The sub-stations have the usual equipment of transformers, oil switches, switchboards, etc., and either multi-gap or electrolytic lightning arresters. Disconnecting switches are also provided outside each station.

The interior of a typical sub-station is shown in Figs. 8 and 9, all the apparatus in view being of General Electric manufacture.

Reference has already been made to the lightning storms which are of frequent occurrence in the territory through which the transmission lines run, and every sub-station is, therefore, provided with a lightning arrester outfit. The experience of the Company in testing out various types of lightning arresters has resulted in the final adoption of the electrolytic aluminum cell type for all future installations, and there are already installed 22 sets of this type.

The illustration, Fig. 7, shows a set of General Electric electrolytic lightning arresters installed outside sub-station and the conductors entering the building through heavy plate glass windows, and also indicates one of the economies which the adoption of this type of arrester has made possible. When the multi-gap form of lightning arrester was first used, a high wall was provided on one side of the sub-station in order to provide sufficient space to suitably install them, the type of building used being shown in Fig. 6. It was later found advisable to discontinue this form of construction and erect a separate building in the form of a tower similar to that shown in the left hand of Fig. 7, in which the multi-gap arresters were installed. In view of the great number of sub-stations on the system, it is obvious that, with the adoption of the electrolytic type of lightning arrester, which can be installed out of doors, a very considerable item in the construction expense of sub-station buildings has been eliminated.

The completion of the 100,000 volt lines and the construction of the new 100,000 h.p. hydro-electric plant at Wateree on which work has already been commenced will, at an early date, add appreciably to the range and volume of the greatest transmission system in the South, which is already

Fig. 7. Highland Park Substation, Charlotte, N. C., Showing Old Lightning Arrester Tower on left, G.E. Aluminum Cell Lightning Arrester and Horn Gaps in Foreground

one of the most extensive, in respect to aggregate mileage, in the world.

While the transmission line construction work has been characterized by few departures from standard practice, a comparison of the original 11,000 volt Catawba pole line with the 100,000 volt tower system, now nearing completion, gives a graphic illustration of the general advancement which has been made in transmission line con-

Fig. 8. Interior of Kannapolis Substation Showing Conductors entering through heavy glass plates G.E. K-6 Oil Switch and T.P. Fuses

struction during the few years which have elapsed since the Southern Power Company was organized.

The success with which this Company has met the requirements of the cotton mills and other industries of North and South Carolina is indicated by the readiness with which mill operators have adopted electric drive and the very noticeable increase in the industrial activity of those sections of

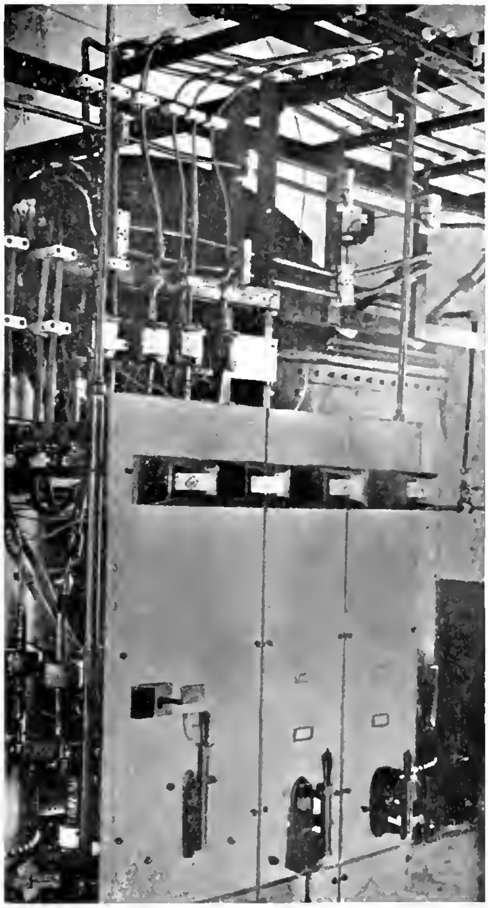


Fig. 9. Interior of Kannapolis Substation Showing G.E. Transformers, Switches, Panels, etc.

the Piedmont cotton belt where the transmission lines of the Southern Power Company have been run.

GAS-ELECTRIC MOTOR CAR—SELF CONTAINED TYPE

By A. W. Jones

The immediate and gratifying success of the larger type of gas-electric motor car manufactured by the General Electric Company for steam railroads, and the successful application of this form of drive on trucks and passenger vehicles operated on streets without rails, has naturally suggested the use of the gas-electric drive for cars of medium size for which there has already been manifested a marked demand. This demand will increase and new uses will be found for this type of equipment when its reliability and ease of operation become better known.

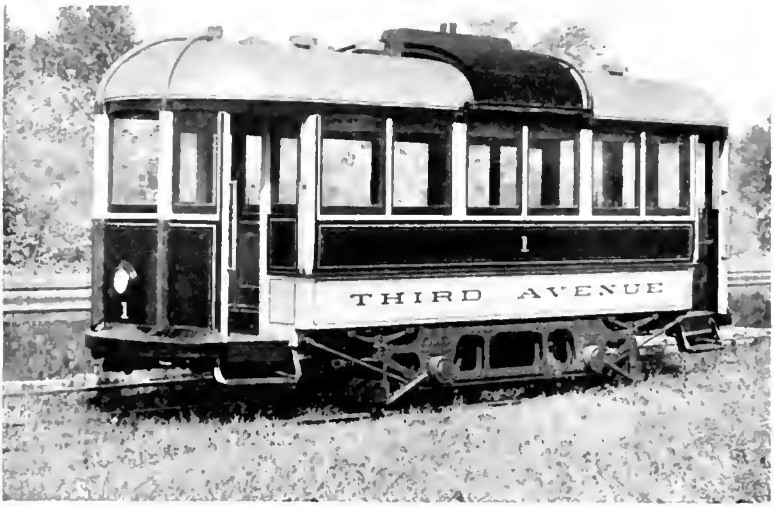


Fig. 1. Third Avenue Gas-Electric Car

The General Electric Company has just completed the first car of this type, which has been placed in commercial service with excellent results. The car is shown in Figs. 1 and 2. The car body and trucks are especially designed for strength and lightness, and the equipment, briefly described, consists of a direct coupled gas engine and generator with exciter on the same shaft, all completely enclosed and mounted between the axles of the truck and below the car floor. This arrangement permits low and convenient platforms, and leaves the interior of the car entirely unobstructed. The car is heated in cold weather by hot water pipes under the seats through which the circulating water is passed. A railway motor, of the standard type, is mounted on each axle, and the current for these motors is transmitted from the generator through a controller at either end of the car designed to vary the resistance in the shunt field of the generator and place the motors progressively in series and parallel. The car is illuminated by tungsten incandescent electric lights, deriving their current from the exciter circuit.

The operation is like that of an ordinary electric trolley car, and, due to the characteristics of the gas engine and generator, there is less liability of abusing or overloading the apparatus by improper use of the controller. The car is reversed by a reversing handle on the controller, without affecting the gas engine, and can be equally well operated in either direction, a controller being provided on each platform.

The Gas Engine

The gas engine is of the 4-cylinder, 4-cycle type, the cylinders being $5\frac{3}{4}$ in. diameter by 5 in. stroke, and cast *en bloc* (Fig. 3). The inlet and exhaust valves are of large size, located on opposite sides and actuated by separate cam shafts. The crank shaft is of high grade steel, hand forged, and oil treated. Fig. 3 shows a side view of the engine and generator. The crank shaft is supported by three babbitt lined bearings. Both the crank shaft and the bearings have been made of extra large size, and much greater strength and bearing surface are provided than would ordinarily be used on an engine of this size. The crank case is arranged so as to provide a constant level system of splash lubrication for the engine, oil being kept in circulation and the level maintained by a centrifugal pump with adjustable overflow.

The pistons are of the trunk type and made of the same material as the cylinders. They are provided with four cast iron snap rings. The wrist pins are of steel, hardened and ground and are fastened in the connecting rod in a special manner.

The connecting rod is of drop forged machinery steel, and oil treated. The cylinders are water jacketed, circulation being secured on the thermo siphon principle, the circulating water being cooled by a radiator located on the roof of the car, which can be seen in Fig. 1. This radiator has a cooling surface of approximately 900 square feet, and a capacity, including water jackets and piping, of about 65 gallons.

A centrifugal type of governor gear driven from the inlet cam shaft is furnished, which acts directly on a balanced valve controlling the quantity of the mixture admitted to the cylinders, and maintains the speed of the engine and generator with small variations

The engine exhausts into a muffler, the exhaust gases thence being carried to the roof of the car, thus avoiding all odor of burned gases and eliminating noise.

Generator and Exciters

The generator and exciter, Figs. 4 and 5, are direct coupled to the gas engine and are completely enclosed. The armatures of these two machines are assembled on the shaft so that the commutators are adjacent.

IS AMERICA ALWAYS AHEAD OF THIS COUNTRY? THE FIRST AUTO-TROLLEY CAR RUN IN NEW YORK.

This photograph of the first auto-trolley car run as an experiment in New York suggests the question whether America is always in advance of Great Britain in the matter of new inventions, especially in regard to the problem of road locomotion and quick transit in great cities.

From *Illustrated London News*. Fig. 2

at about 800 r.p.m. Ignition is provided by a gear-driven Bosch low tension magneto and magnetic plugs.

The entire engine is so designed that when it is assembled, together with the governor, magneto and spark plugs, it is completely enclosed thus being protected against dust, dirt and water. This construction is clearly shown in Fig. 3

The carburetor is of the Venturi type, with float feed, the gasolene being admitted by gravity from the gasolene tanks located under the car seats. Two of these tanks are provided, each of 35 gallons capacity.

This arrangement permits of using but one inspection cover for both machines. The generator is shunt wound, and the exciter, in addition to the shunt winding, has a series field.

Motors

Two standard GE-60 250 volt railway motors are used. Each motor will develop 22 h.p., the output being based on standard rating.

The magnet frame is made of two castings bolted together, the suspension side bolts are hinged, and the lower frame is arranged to swing down so as to permit of inspection of fields and armature. The axle and armature bearings are of bronze, lined with babbitt,

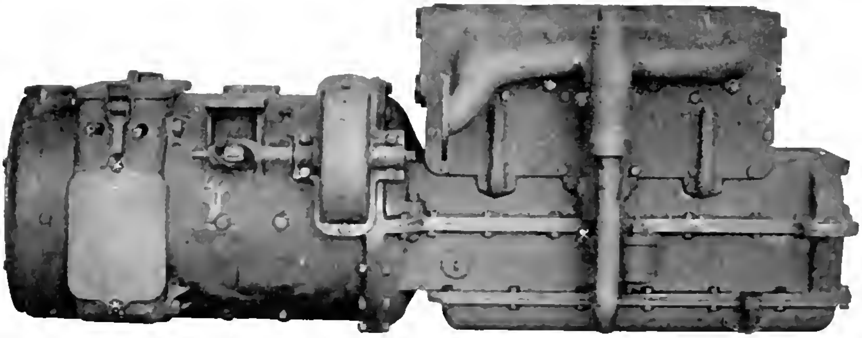


Fig. 3. 35 40 H.P. Gas Motor Direct Connected to 15 Kw. 250 Volt Generator

and are designed for use with oil and waste lubrication.

The pinions and gears are of steel, and entirely protected by a gear casing. The

Fig. 4. Generator and Exciter Armatures Mounted on Same Shaft

number of teeth in the gear and pinion, that is to say, the gear ratio, may be varied to suit different conditions of service.

Controllers

Two controllers (Type P-15-A) are furnished, one for each end of the car. These controllers are provided with the usual reversing cylinder, fingers, and connections for placing the motors progressively in series and parallel. Magnetic blow out coils for main contacts, and cut-out switches for the motor circuits are also provided. In addition there are provided fourteen steps introducing resistances in the generator shunt field for varying the voltage impressed upon the motors, thus securing a smooth and even rate of acceleration.

A separate reversing handle is provided, so designed that the controller is locked in the off position when the reverse handle is removed.

Truck

The truck is of a special light construction of riveted plate frame, and is supported on the journal boxes by helical springs.

The car body is carried on the truck by means of helical springs, in addition to four half elliptic springs which prevent excessive

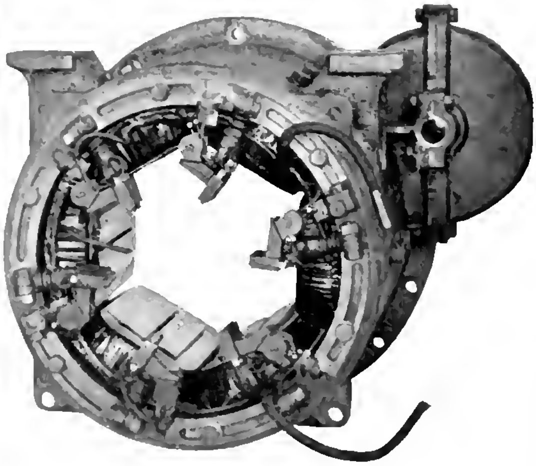


Fig. 5 Generator Field

longitudinal rocking of the car body. The truck is 7 ft. 6 in. wheel base with 31 in. wheels.

The generating unit is swung centrally in the truck and bolted directly to cross ties which are riveted to the side frames.

The motors are outside hung on the truck, with the suspension side supported on the main truck frame. An extension shaft is brought out from the engine to the end of the car for purpose of cranking.

Car Body

The car body, which is clearly shown in Fig. 1, is designed with especial reference to strength and lightness. The platforms are semi-vestibuled.

The roof has no monitor, it being dome shaped and provided with suction ventilators. The radiator is placed on the roof over the center of the car, and is connected to the water jackets of the cylinders by pipes enclosed within the center posts of the car. The seats are longitudinal, finished in rattan, and have a capacity of 26 passengers. Trap doors are provided on the bottom of the car floor, giving ready access to engine, generator and motors. The controllers, hand brakes, auxiliary switches, etc., are carried on the platforms. The accompanying table gives principal dimensions:

DIMENSIONS

Length over bumpers	28 ft. 0 in.
Length of car body (inside)	19 ft. 0 in.
Length of each platform	4 ft. 0 in.
Width over body	7 ft. 4 in.
Width over radiator	8 ft. 0 in.
Height from rail to top of roof	11 ft. 1 in.
Height from rail to top of radiator	12 ft. 4 in.

An obvious usefulness for this type of car on trolley systems lies in its adaptation to "owl" trips, thus permitting the power station to be entirely shut down, say, between midnight and morning, when otherwise one generating unit would have to be kept in operation.

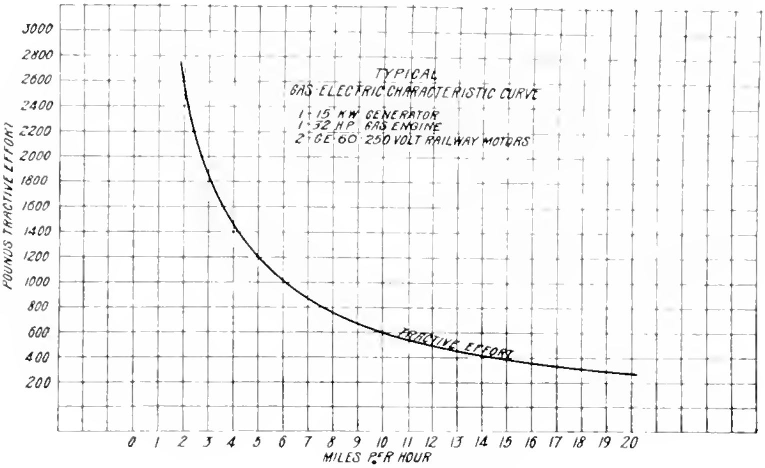


Fig. 6. Performance Curve of Gas-Electric Car

The type of car body which may be used with this equipment is, of course,

TABLE OF SCHEDULE SPEEDS IN FREQUENT STOP SERVICE AND ON GRADES

AVERAGE LENGTH OF RUNS IN MILES

Per Cent. Grade	Duration of Stops 5 Secs.							Duration of Stops 30 Secs.					Free Running Speed
	1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	2.0	4.0	
0.	6.7	9.0	10.5	11.5	12.4	11.3	11.9	12.4	12.9	13.3	15.9	17.4	25.0
.25	6.5	8.5	9.8	10.7	11.5	10.5	11.0	11.4	11.9	12.3	14.1	15.6	20.0
.50	6.3	8.1	9.2	9.9	10.6	9.7	10.1	10.5	10.9	11.3	12.9	13.9	17.0
.75	6.1	7.6	8.6	9.2	9.7	9.0	9.4	9.7	10.0	10.3	11.5	12.3	14.5
1.00	5.9	7.2	8.0	8.5	8.9	8.3	8.7	8.9	9.4	9.3	10.3	10.8	13.0
1.25	5.7	6.8	7.6	7.9	8.2	7.8	8.1	8.3	8.5	8.7	9.5	9.9	11.5
1.50	5.5	6.5	7.2	7.4	7.6	7.3	7.5	7.7	7.9	8.0	8.7	9.1	10.0
1.75	5.3	6.2	6.8	7.0	7.2	6.8	7.0	7.2	7.3	7.4	7.9	8.3	9.0
2.00	5.2	5.9	6.4	6.6	6.8	6.1	6.5	6.6	6.7	6.8	7.2	7.4	8.5

not restricted to that shown in the illustrations and described above. Many other designs suggest themselves. A baggage space can be provided. An open type of car with transverse seats will be useful in warm climates. A flat car with plain roof to support radiator, and open ends and sides will be found very convenient in construction work for carrying men and tools.

STANDARDIZATION RULES OF THE A.I.E.E.*

By Dr C. P. Steinmetz

The subject on which I desire to speak is the Standardization Rules of the American Institute of Electrical Engineers. My reason for selecting this subject is that, in my experience, these standardization rules are not as well known to many engineers as their importance makes it desirable. In my opinion, the Standardization Rules represent the most important work the American Institute of Electrical Engineers has ever undertaken, and constitute one of the most important documents in the literature of the electrical engineering industry, for I believe that the rapid and successful advance of the electrical industry of the United States is to no small extent due to their existence.

At present few of us realize the conditions which existed before these rules were drawn up and generally adopted. These rules have made it possible to build good apparatus and sell good apparatus, which procedure was not always possible before that time. The standard set by the rules is high, but not too high. It can easily be attained and yet it is sufficiently high to be safe, though no more. Since their adoption, the rating of any piece of electrical apparatus whatever means something definite, and means the same thing within the limits of the relative conscientiousness of the different manufacturers, no matter from what manufacturer it may be bought; and these limits are very narrow, because the tests are specified and may be easily made to check up the required performance, thus making it impossible to deviate much from the standard without having it noticed. Now that has not always been the case. On the contrary, in the early days, a small manufacturer would make high guarantees regarding the efficiency and performance of his apparatus, which an engineer, knowing all about the apparatus, could not make. It will be realized that it was a very severe handicap to the advance of the electrical industry that those engineers who knew as much about the apparatus as was known at that time, were not able to build as good apparatus as possible because it could not be sold in competition with inferior apparatus which was guaranteed to have higher efficiencies. For instance, in those times core loss was a quantity not generally known. Quite commonly small manufacturers guaranteed efficiencies without figuring the core loss. It can be realized that a larger manufacturing company, having engineers who understood and could calculate this, might have built apparatus with much lower core loss and much higher efficiency, and still could not guarantee as high an efficiency as the manufacturer who did not take it into consideration. They knew of losses which others did not and which others therefore did not consider. At that time the commutator losses had just begun to be found out, but often the manufacturer did not dare include them in the losses because nobody else did, although they amounted to several per cent. It was a very unfortunate condition of affairs which made it necessary for those designing engineers who knew of the losses in the apparatus to count them in, while the engineers who were ignorant of their existence were able to sell inferior apparatus under higher guarantees; for the happy custom used to count only those losses which were specified, and of course the less specified the less the losses appeared. That condition of affairs has passed, and now the higher class of producers find it desirable to have everything known; to have tests of the performance and calculation of efficiency made, and the customer to know what the efficiency is, because they can gain by it. The same advantages accrue to the customer. He was formerly helpless when in the market to buy electrical apparatus, as one manufacturer guaranteed his apparatus at 92 per cent. efficiency while another and smaller

* Lecture before Schenectady Section A I E E , Nov 2, 1909

manufacturer was willing to sell him the same kind of apparatus cheaper and guaranteed at 95 per cent. efficiency. What could the customer know and do? That condition is not possible now, for the manufacturer could not guarantee efficiencies not in existence—he would be found out. In 1892, when I wrote a paper on hysteresis losses, I remember that one engineer even claimed there was no such thing. It could not be, because the efficiency was known. There could not be such a loss, because it would have shown up in the efficiency and it would have been noticed. All that has now become generally known and understood, and this fact is to a very large extent due to the educational work done by these standardization rules.

The benefit resulting from these rules extends throughout the entire field of electrical work. In those early days, it must be realized that it was not generally accepted and recognized that the efficiency could be got by adding the losses. Commonly the engineers or customers rejected an efficiency test made in this manner. The recognition of the correctness of the method of measuring efficiency by adding the losses has from the first been brought out in those Standardization Rules. I recall an instance where some big machines were built and the question was, how to measure their efficiency. The input and output could not be measured very well on a 400 kw. machine, which, in those days, was a monstrous machine. It was agreed that the core loss was one of the losses which was to be added. The customer insisted that it be taken at no load and full load excitation. The machine was one of those early high frequency alternators, and when run light at full load excitation gave 40 or 50 per cent. higher voltage and two or three times the actual core loss obtained at full load. It took a long time to satisfy the customer that the addition of the losses gave the correct efficiency. Ultimately, however, the machines were accepted. When these machines went to England and were turned over to the customer, he would not accept them without further test; so they were coupled together, one being used as a motor and the other as a generator, and a whole series of tests were made, measuring the power input and output, and the input at all possible displacements, etc., to satisfy him that the efficiency was right. He finally accepted those tests, although I do not believe they meant anything; but he got what he wanted.

We know now what the efficiency is, what the losses are, and how the efficiency should be determined. Some consulting engineers had the habit of drawing up the most wonderful specifications, often 65 pages or more, specifying everything covering the armature, conductors and many other things. This was entirely improper, because that was no business of the customer what he looks for is the performance. Even prominent consulting engineers frequently specified things of decided disadvantage and made it impossible to get the best machines for their purpose; for, while desiring to get the best apparatus, they made the mistake of specifying things which would be a disadvantage, as they were not familiar with the state of the art at that time. The early days of the industry are full of such instances.

Even though an agreement was reached, nothing definite was understood—it meant a different thing to different people. Speaking of the regulation of a machine: what did it mean? The Westinghouse Company understood something entirely different when guaranteeing regulation from what the Stanley Company or General Electric Company did. The one understood the percentage rise of excitation from no load to full load, and the other, the percentage increase of voltage at full load excitation when full load is thrown off. Such disagreements naturally made matters very difficult for a customer desiring to get apparatus, for the regulation would be guaranteed by one manufacturer as 8 per cent. and by another as 12 per cent. Twelve per cent. might have been a better regulation than 8 per cent. because the latter might mean that if load is thrown off at full load, the voltage will not rise more than 8 per cent., and the other, if a change is made from no load to full load, a full excitation of 12 per cent. increase was necessary.

Before people could understand each other and before customers could compare intelligently the offerings of different manufacturers, it became necessary to have some definite meaning for the different terms. People might use the same term and mean very different things.

The radical advance in the industry became possible only when all these childrens' diseases —the competition of manufacturers of inferior apparatus guaranteeing superior results by reason of lack of knowledge, etc., became eliminated, and all manufacturers and customers could meet on a common footing, employing the same terms and having to come up to the same performance. So in those early days the question of standardization was really of the greatest importance to customers, operating engineers, and to the manufacturers; and it was natural that the question of establishing standard rules should be brought before the Institute. That this was done is due to Mr. S. D. Greene, who is still a member of the organization. Mr. Greene read a paper before the American Institute of Electrical Engineers, drawing attention to the necessity of deciding what represented the best standards, the best practice, and the best definitions in the field of electrical engineering, as far as the prominent engineers could agree on the subject. As a result, the motion was made and finally carried to establish such standardization rules, and a committee was appointed to draw them up. Naturally, there was considerable discussion as to whether such rules would not handicap the development of the industry; they might hinder it, because of limitations, or they might sap inventive activity by establishing standards. Experience has shown that this has not been so. The rules have been very helpful in assisting development, have made unnecessary an enormous amount of waste effort, have combated foolish ideas by educating people to understand the meaning of terms, and have cleared up mistakes of understanding and made it possible for the results of the work to be recognized. If machinery and apparatus is superior it can be shown which advantage was not always possible before. It is amusing now to remember some of those discussions. For instance, a motion was made that engineers connected with manufacturing companies should not be included in this Standardization Committee because of the fear that they might make the standard of the rules so low that it would be easy to build apparatus. As a matter of fact, most of the work on the rules as they stand has been done by Mr. C. F. Scott, of the Westinghouse Company, and by myself, both representing manufacturing companies which have always insisted on strictness and rigidity, and on making the requirements as high as could well be made, firmly resisting any attempt to reduce them. This is natural, because it can easily be seen that the manufacturer has no objection to building better machinery—it is really an advantage, because the better machinery will give a better record and not as much trouble; while if a cheap and poor machine is built the manufacturer gets the blame for it, and justly.

The standardization rules are of great advantage to the producer, to the designing engineer, and to the customer. They were started by a committee appointed by the A.I.E.E. and since then a committee for this work has been appointed every year, Every few years it becomes necessary to bring the rules up to standard and to add whatever new features have been developed in new industries that require attention.

Standardization rules have been drawn up and an attempt made to follow them in other countries, but in no country, as far as I know, have they been so generally accepted and so helpful to the industry as here in the United States. To a very large extent this is due to the close co-operation of the manufacturers, operating engineers, and theoretical men here; but in other countries the tendency is to delegate it to the theoretical men, who draw up rules from mere theoretical knowledge, which no manufacturer or customer can follow or cares to follow, and therefore such standardization rules have occasionally been handicaps.

It is natural that manufacturers' engineers should have done most of the work in drawing up the rules, because the engineer who designs the machine, and afterwards follows it in test and is held responsible by the Commercial Department for its successful operation, naturally knows the ins and outs of the machine better than can anyone else. He therefore knows better to what extent strict specifications should be made in order to get the best machine; and for him it is an advantage to see that specifications are high enough, so that he may not be held responsible for troubles that develop in his production outside.

The reason that the Standardization Rules have been so successful is that, from the beginning, the principle has been very rigidly maintained that the performance should be specified and not the design data. For instance, in an armature winding, it is proper to specify the temperature, but it would be improper to specify curren. density. Any specifications or standards of design data are a handicap to the development of the industry; but the standardization of performance has put a premium on designs which will make it possible to produce the same performance with a less amount of material and smaller apparatus, thus making the apparatus cheaper to manufacture.

Another mistake which has been carefully avoided, and which has been made especially by our European friends, is the attempt to specify size, speeds, etc. Such specifications tend to stop the advance of the art.

As I have already stated, the result has been accomplished by the co-operation of all representatives of the electrical industries in the country, and therefore the rules have not met with much difficulty in finding general acceptance.

We now come to a more specific discussion of some of the leading features of the Standardization Rules:—

Classification of Apparatus. Classifying apparatus as motors and generators was entirely unsuitable. If it is desired to classify and draw up rules for measuring efficiency and specify what performance should be expected from motors, it is evident that synchronous motors, direct current shunt motors, induction motors and railway motors cannot be put in the same group. They are entirely different types of apparatus. Neither can synchronous generators, direct current commutating generators, and induction generators be put in the same group. Again, a direct current generator and direct current motor are practically the same machine. A direct current motor can be run as a generator, and inversely, a direct current generator can be run as a motor. A synchronous motor and an alternating current generator are the same class and type of machine, and the specifications for the performance of each would be the same. There may be some quantitative differences of a minor nature, as for instance, if a synchronous machine is designed to operate only as a motor, a higher armature reactance is chosen than if the machine is designed to operate only as a generator. We also have compound motors and shunt generators, and a definite line cannot be drawn between generators and motors; but there is a distinct dividing line between commutating machines and synchronous machines and between induction motors and synchronous motors. In many cases machines are installed where it is impossible to say whether they are generators or motors. To-day they may be running as synchronous motors and tomorrow as generators. It is common in steam stations or water power plants to install synchronous motors to receive power from the transmission line and drive other apparatus, such as commutating machines for railway work, etc. During a period of low water it may not be possible to get power enough from the water and the synchronous motor has to be started as an alternating current generator. That is a very common thing. It became necessary to find a classification of electrical apparatus based on its nature, structure, and construction, and not on the particular use to which it happens to be put.

As an illustration of the confusion which existed in nomenclature of electrical apparatus before these rules were generally accepted, I mention the converter and transformer. It just happened that when the Westinghouse Company started to build alternating current transformers they called them converters. When the Thomson-Houston Company, the predecessor of the General Electric Company, started to build transformers, they called them transformers; so the same type of apparatus went by the name of converter in the Westinghouse Company and transformer in the the General Electric Company. A synchronous converter was developed by the Westinghouse Company which they called a rotary transformer, because the stationary apparatus was called a converter; and the General Electric Company, which had used the name transformer for stationary apparatus, naturally called the other a rotary converter. This is one illustration of the different definitions which were applied to the same things. The Standardization Rules adopted what appeared to be the best practice, and in this case adopted the name transformer because it had come into general use by other people. Rules were drawn up to establish as definitions those terms which appeared to the committee as representing the best practice and were most generally accepted. Then we find definitions of quantities like load factor, saturation factor, pulsation, etc., which had to be standardized so as to mean something definite.

With the advance of the art, this work has been expanded and new chapters inserted. The procedure which has been followed is never to standardize anything until best practice has already crystalized upon some definite form, and not to create definitions, but accept those definitions toward which good practice tends and which therefore can easily be accepted. It is no longer the definition of a competitive company, but a definition of the Institute, an impartial body. A company may hesitate to change the name of its apparatus and adopt the name used by a competitor, but there can be no hesitation to adopt the name given to it by the general body of the Institute; and this tends to uniformity, which is not only desirable but absolutely necessary.

Then comes the second part of the rules, covering specifications of performance of apparatus, and tests; that is, how the apparatus should perform and how this performance should be determined by test. It can be readily appreciated that one of the most important considerations is efficiency—the definition and determination of efficiency—and one of the most important features of the work done by the rules is the establishment of a method of measuring efficiency by adding the losses, making that method safe by carefully scrutinizing the losses and showing how they should be measured. These efficiency specifications and the method of making tests are well worth careful study, because they are really the general standard for testing electrical apparatus.

In the matter of insulation, which is an important one, attention is directed to the importance of high voltage tests and the relative unimportance of measuring the ohmic resistance of insulation. The ohmic resistance of the insulation is increased by baking, and in this way one could get 50 megohms or more; but this is liable to weaken the dielectric strength of the insulation. Tests of ohmic resistance are desirable as merely showing that there is no great leakage but they do not show how the insulation will perform, which performance is given by the dielectric test. A standard of one minute has been established for tests for dielectric strength. It is unsafe and objectionable to extend the time of test much longer, because of harm to the insulation. High voltage tests must be made at voltages very much higher than those to which the insulation will be normally subjected, and such high voltage puts a strain on the insulation which deteriorates it. Therefore, the test should not be continued longer than necessary to make sure that the voltage is there, and one minute is sufficiently long for this purpose. With some kinds of apparatus, however, a half hour is specified. With some apparatus half an hour is not so bad, although a minute is better. Naturally when saying a minute is better, the same test is intended to be applied. One minute at 25,000 volts is preferable to half an hour at 10,000 volts. The shorter the time the voltage is kept on, with correspondingly higher voltage used to get the same severity, the less will be the deterioration of the insulation. Apparatus must be tested with at least twice its rated voltage twice the rated voltage of the circuit to which the apparatus is to be connected—except, of course, on machines for very low voltage, on which tests are made at a voltage much higher in proportion. There would be no sense in testing a 100 volt machine at 200 volts; but when you come to 10,000 volt apparatus, the test which experience has shown is sufficiently high, but not too high, is 20,000 volts, which really means four times the normal voltage strain. The reason that this is necessary is because of the abnormal conditions of operation which may occur. On a high voltage system, if one side of the winding becomes grounded, the whole rated potential is exerted between the winding and the iron; and in normal operation, during conditions which we must expect frequently, voltages occur which last but for a small fraction of a second that are as high as the testing voltages of the apparatus. No insulating material can stand higher voltages momentarily than continuously. It would not be safe to lower the testing voltage. Once it was done. It was very difficult to test alternators at double voltages. At that time a 20,000 volt alternator could be built that could be tested at 30,000 volts, but which would not stand 40,000 volts. Since the engineers agreed that it would be desirable to have such alternators, they asked the Standardization Committee to lower the specification for high voltage apparatus to 1½ times the rated voltage. All kinds of breakdowns followed the introduction of this practice, and we came back to the double voltage, and experience has shown that the double voltage is not too high and not too severe a test.

Then going further, overload capacities is another point. Very great difficulty existed formerly in comparing our apparatus with foreign makes, and it has often been noticed how superior the continental companies are in their designs; how much smaller and cheaper their smaller motors are; but they do not follow the Institute rules, and a 5 h.p. motor may mean a very different thing with them from what it does with us. It may mean a motor which can give power at but 5 h.p., or it may mean a motor which can continuously carry power averaging 5 h.p.; sometimes going below that figure. The tendency here in America has been to rate the apparatus at the average output which it can give. Without any guidance of standardization rules, the tendency has been very often to rate apparatus at the maximum which it can perform. Naturally, where these two classes of apparatus are compared, the one appears very much larger and more expensive than the other. The uniform rating which has been established as a minimum is 25 per cent. overload for two hours, and for motors or apparatus which may go out of service by reason of excessive overload, 50 per cent overload for one minute. One minute means that it shall be able to carry 50 per cent. overload at least, without stopping, falling out of step, or doing anything to interrupt operations.

Now as to temperature rise The uniform rating of 50° C. rise by resistance and 40° C by thermometer has been established for all apparatus, with a few exceptions. Commutators and brushes are allowed 5° C. more. In looking over these specifications we must naturally realize that they do not attempt to represent best practice, but the maximum safe value. It does not mean best practice to specify 50° C.; very commonly 40° C. is called for. In drawing up general specifications, it is not safe to permit a rise of more than 50° C

I have spoken of Standardization Rules, but really, as they stand at present, they constitute a list of all electrical apparatus, and very few, if any, kinds of apparatus which is used or contemplated in any electric light or power system, are not mentioned, described and classified in those rules sufficiently for an engineer to be able to handle them and know what to do with them, and specify their performance. In this respect they are more complete than any text book of electrical engineering I know of, for during the last twelve years so many people have worked on them, studied them, and discussed them, that they have really become a very complete compendium or dictionary of electrical apparatus in the matter of its performance and test.

ROSENBERG GENERATORS*

By J. L. Hall

In supplying power for projectors some means must be provided whereby a drooping characteristic is obtained at the lamp terminals; ordinarily this is accomplished by inserting a resistance in series with the arc. Upon the steepness of the characteristic, or rate of change of potential at the lamp terminals, with reference to the current, depends the regulation of the current. With rheostatic regulation the higher the potential of the line from which the projector is operated, the steeper the characteristic and the closer the regulation, as shown by curves in Fig. 2.

In operating large projectors such as the 60-inch size, taking an amount of current relatively high, it is impossible to obtain a characteristic too steep; in fact, as near actual constant current conditions as possible is desirable. To meet this latter condition, as well as to save the energy ordinarily wasted in rheostatic regulation the Rosenberg type of generator seems to be the solution of the problem. This type of generator (the Rosenberg American patent rights having been purchased by the General Electric Company), has been described in the Review (December,

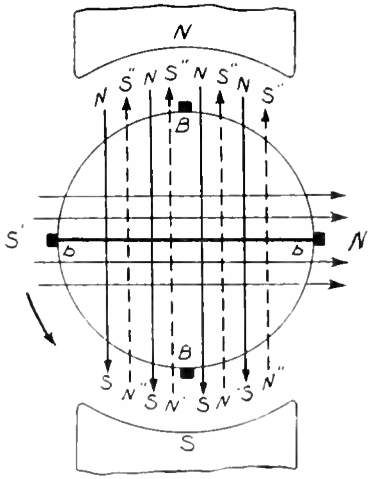


Fig. 1

1907) and various other technical magazines and little can be added to the mass of literature already published.

As constructed at the present time it resembles, to a certain extent, an ordinary bipolar generator but differs from it by having four sets of brushes. Two of the four sets of

* Reprinted from the Journal of the United States Artillery

brushes are located in the same position on the commutator as in the ordinary generator, and are connected together, or short circuited, by a heavy copper conductor, and are called the "short circuit" brushes. The remaining two sets of brushes, called the "service" brushes, are located midway of, or 90° from the short circuit brushes.

From the field excitation is derived the primary flux, which induces a current in the armature flowing through the short circuit brush circuit, as would be the case in an ordinary generator short circuited. The short circuit current sets up a secondary flux at right angles to the primary flux, the path of which is through the armature and pole shoes. This secondary flux induces a current in the service brush circuit, which in turn induces a tertiary flux at right angles to the secondary and 180° from the primary flux, and having a tendency to neutralize the latter.

The flux distribution is diagrammatically shown in Fig. 1 and the relation between service and short circuit amperes at different generator voltages is shown in Fig. 3. The curve sheet also shows the load amperes taken by the motor driving the Rosenberg generator. This generator was shunt separately excited, and it will be noted that the curve showing the current in the short circuit brush circuit would extend beyond the limits of the curve sheet if completed. The operation may perhaps be better understood by outlining the conditions at no load and the actual short circuit of the generator with shunt separate excitation.

At no load the tertiary flux is at zero, as no current is being taken from the generator, and the excitation due to the primary flux will be at the maximum. Under these conditions the current in the short circuited brush circuit will be the maximum, but the secondary flux induced by it has little effect on the primary flux.

If the generator be short circuited, which can be done with impunity, the tertiary flux is at its maximum, being induced by the service current, and its magnitude is such as to practically neutralize the primary flux, and the potential at the service brushes will be zero. As the effect of the primary flux is practically neutralized, the current in the short circuited brush circuit will fall to zero.

This type of generator may be wound either for series self excitation or for separate shunt excitation.

For series self excitation the field cores are purposely made very small in cross section in order that saturation may be reached quickly, after which the primary flux increases less rapidly than the tertiary. In Fig. 4 the shape of the characteristic of the series wound generator illustrates this feature.

At no load the potential is that due to the residual magnetism only. As the load comes on, the potential rises until saturation is reached, after which, the tertiary flux increasing more rapidly than the primary, the curve begins to droop; but as the current is still rising in the service brush circuit, and consequently the excitation, there will still be some increase of primary flux. It is for this reason that the volt-ampere curve is less steep than if the primary flux were derived from a constant excitation.

The poles are laminated and purposely made massive and are cut away at a point corresponding to the location of the service brushes to provide a weak field for good commutation.

The highest no load voltage obtainable is by the use of cast iron for the magnet frame. This, in an ordinary generator, would result in an increase in weight, but in the Rosenberg generator the cross section of the iron need be no heavier than consistent with actual mechanical strength, as the pole cores are small.

For a shunt separate excitation the cross section of the field cores is designed for the proper density of the primary flux, and the field is excited from a constant potential source. For projector use it appears that this is the better practice and a comparison of the curves shown in Fig. 4 will illustrate the point in question.

As already explained, in the series self excited generator, while the primary flux is limited to a certain extent by a reduction of the cross section of the field core, there is still a rising field and the droop in the characteristic is not as steep as it would be if the primary flux were derived from a constant excitation. The current in the short circuit brushes, however, does not reach so great a magnitude.

In the shunt separately excited generator, the droop in the characteristic is more steep and the origin of the curve much higher. The disadvantage of this form of excitation is the high current in the short circuit brushes at no load. This high short circuit current at no load causes abnormal sparking at the short circuit brushes, and would be a serious matter were it not possible to easily limit it at no load by the use of a simple automatic switch which reduces the excitation and consequently the primary flux. The main switch could are in contact, when the current flowing will keep the crater hot ready for starting at a moment's notice without actually developing a crater, as there will be no arc.

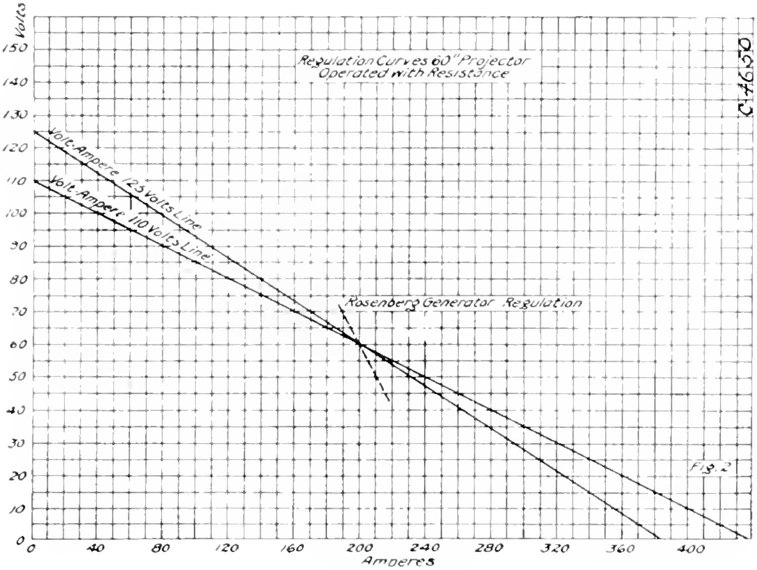


Fig. 2

also be so designed as to short circuit the generator when opening the load circuit, which would entirely take care of the sparking were it not for the period between closing the switch and the actual starting of the lamp, or the short time necessary for the carbons to feed together. A reference to the motor current curve in Fig. 3 will also show that economy is a second reason for short circuiting the generator when removing the load, as the generator requires the minimum amount of energy to drive it when actually short circuited.

This feature, the ability to short circuit the generator with safety, and without serious increase in current, makes the Rosenberg type of generator of special value in Coast Artillery service.

It is possible to occult the light by feeding the carbons together until they

Furthermore, it removes the necessity for any protective devices in the lamp circuit, as the current can increase but a small amount above the normal, and the load

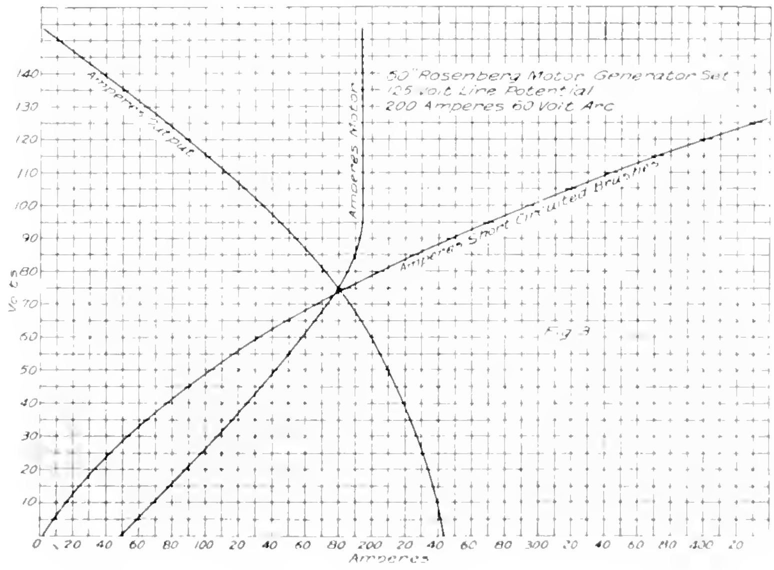


Fig. 3

on the generating plant is decreased rather than increased by a short circuit on the Rosenberg generator.

It is also on account of the small increase in current at short circuit above the normal that the shunt separately excited generator is preferable.

In order to compare the degree of regulation obtainable with the Rosenberg generator with that obtained by rheostatic regulation, a section of the Rosenberg curve taken from Fig. 3 is plotted in Fig. 2 in dotted lines.

The curves shown in Fig. 5 illustrate the performance of this type of generator with a varying speed.

The left-hand curve was taken from a 1 kw. generator series self excited, and the speed varied between 800 and 2100 r.p.m. It will be noted that the output current increases considerably, but not nearly as much as would be the case in an ordinary generator.

The right-hand curve was taken from the same machine, shunt separately excited, and here we find nearly constant current conditions with the speed varied between the same limits.

An analysis of all the curves shown indicates that for projector use the Rosenberg generator wound for separate shunt excitation provides the highest degree of regulation combined with stability.

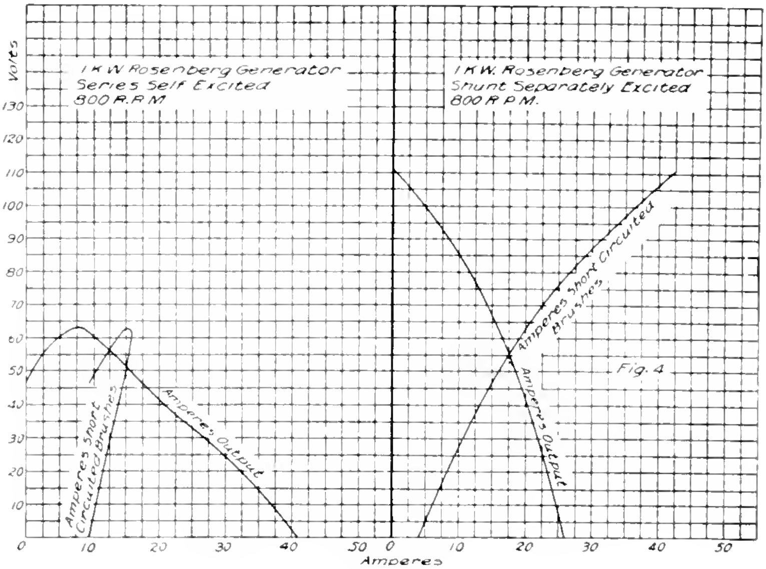


Fig. 4

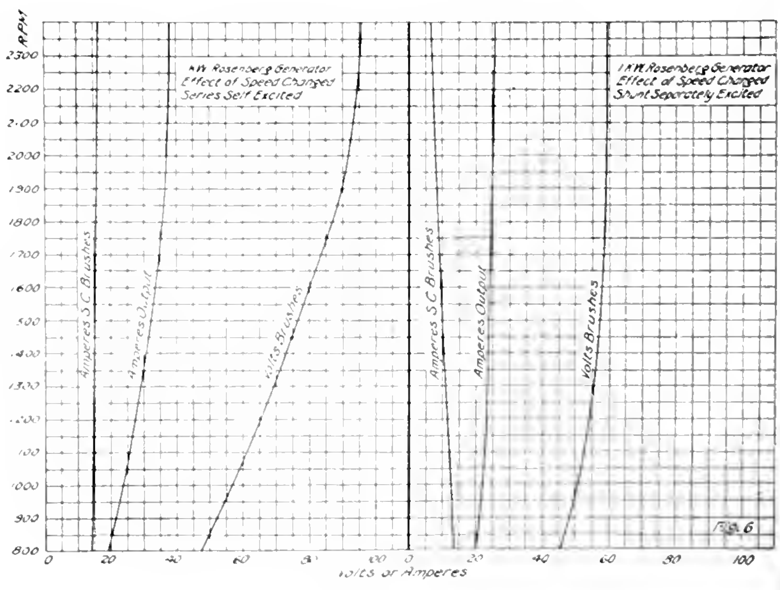


Fig. 5

TRANSMISSION LINE CALCULATIONS

PART IV

By Milton W. Franklin

LINE CAPACITY

In any given system of electrical conductors a potential difference between two of them corresponds to the presence of a quantity of electricity on each, the one being positive and the other negative. With the same charges, the P.D. may be varied by varying the geometrical arrangement and magnitudes and also by introducing various dielectrics.

The constant connecting the charge and the resulting potential is called the Capacity of the System and this may be calculated in the cases of a few sample geometric forms.

Capacity of an Isolated Thin Cylinder

Let L_2L_1 (Fig. 10) be a thin cylinder.

Let Q be the electrostatic charge per cm. of L_2L_1.

Let Qdy be the charge on element dy at p.

Let ϕ be $\tan^{-1}\frac{y}{r}$

Then the distance $Pp = r\sec\phi$, and if dF_1 be the force exerted by Qdy on unit charge at P

$$dF_1 = \frac{Qdy}{(r\sec\phi)^2} = \frac{Qdy}{r^2}\cos^2\phi \qquad (1)$$

The component of dF_1 perpendicular to L_2L_1 will be $dF_1\cos\phi = \frac{Q}{r^2}\cos^3\phi\,dy = dF$ (2)

and

$$F = \frac{Q}{r^2}\int_{L_1}^{L_2}\cos^3\phi\,dy \qquad (3)$$

but

$$\cos\phi = \frac{r}{\sqrt{r^2+y^2}}$$

whence:

$$F = Qr\int_{L_1}^{L_2}\frac{dy}{(\sqrt{r^2+y^2})^3} \qquad (4)$$

$$= Qr\left[\frac{y}{r^2\sqrt{y^2+r^2}}\right]_{L_1}^{L_2} \qquad (5)$$

In the case of a transmission line the length may be regarded as infinite, and the values of L_2 and L_1 in (4) may be represented by $+\infty$ and $-\infty$ respectively, thus:

$$F = \frac{Q}{r}\left[\frac{\pm 1}{\sqrt{\frac{r^2}{y^2}+1}}\right]_{-\infty}^{\infty} = \frac{2Q}{r} \qquad (6)$$

The potential at a point in the vicinity of a charged cylinder is defined as the work necessary to bring a unit charge to this point from a point at which the force due to the charged thin cylinder vanishes. From (6) it will be seen that $F = 0$ when $r = \infty$, *i.e.*, the force vanishes at ∞.

The potential at point P may now be defined as the work done in bringing a unit charge from infinity to P.

Work = force × distance, whence,

$$dW_r = Fdr \qquad (7)$$

from (6),

$$W_r = \int_r^{\infty}\frac{2Q}{r}dr.$$

$$= 2Q\left[\ln r\right]_r^{\infty} = 2Q(\ln\infty - \ln r)$$

$$= C - 2Q\ln r \qquad (8)$$

C is an infinitely great constant and (8) shows that the potential at P cannot be determined from the conditions given alone.

The potential at the surface of the thin cylinder, whose radius may be taken as ρ, will be given by:

$$W_\rho = C - 2Q\ln\rho \qquad (9)$$

From (8) and (9) the *difference in potential* may be calculated thus:

$$W_\rho - W_r = 2Q(\ln r - \ln\rho) = 2Q\ln\frac{r}{\rho} = V \qquad (10)$$

V is the potential difference between the surface of the conductor of radius ρ and the point P distant r from the center of the conductor, the potential at P being due solely to the charge on the conductor rad. ρ. If there exist other charges in the vicinity the potential at P will be

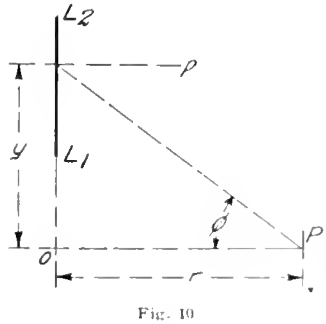


Fig. 10

$$V = \sum(2Q\ln X + C) \qquad (11)$$

where Q represents the charges

X represents the distances of P from the various charges.

C is an infinitely large constant.

The potential difference between two parallel cylinders (Fig. 11) equally and oppositely charged may be calculated as follows:

Let V_1 be the potential at P due to B_1

Let V_2 be the potential at P due to B_2

From (9)

$$V_1 = C - 2\,Q\,ln\,X$$
$$V_2 = -C + 2\,Q\,ln\,(d - X)$$

From (11)

$$V = 2\,Q\,ln\left(\frac{d-X}{X}\right) \qquad (12)$$

when P is at the surface of B_1

$$V_1 = 2Q\,ln\left(\frac{d-r}{r}\right) \qquad (13)$$

similarly at B_2

$$V_2 = 2\,Q\,ln\left(\frac{d-(d-r)}{d-r}\right) = 2\,Q\,ln\,\frac{r}{d-r} \qquad (14)$$

the potential difference between the surfaces of B_1 and B_2 is (13) − (14) thus

$$V = 2\,Q\left(ln\,\frac{d-r}{r} - ln\,\frac{r}{d-r}\right)$$
$$= 2\,Q\,ln\left(\frac{d-r}{r}\right)^2$$
$$= 4\,Q\,ln\left(\frac{d-r}{r}\right) \qquad (15)$$

Capacity is defined as the ratio $\frac{Q}{V}$ whence from (15)

$$C = \frac{Q}{4\,Q\,ln\left(\frac{d-r}{r}\right)} = \frac{1}{4\,ln\left(\frac{d-r}{r}\right)} \qquad (16)$$

where C is the capacity per unit length
d is the distance between conductor centers
r is the radius of each conductor

and Q is the charge per cm. length of two parallel conductors, in a medium whose specific inductive capacity is unity. In actual calculations an imaginary line is devised and the capacity of the wire with respect to this line is called the capacity of the wire.

The capacity of either wire with respect to an imaginary line situated in the vicinity may be found from (12)(13): *e.g.* the capacity of B_1 with respect to the line bisecting the plane of centers of B_1B_2 is calculated as follows:

From (13) $V_1 = 2\,Q\,ln\left(\frac{d-r}{r}\right)$

From (12) $Vp = 2\,Q\,ln\left(\frac{d-\frac{1}{2}d}{\frac{1}{2}d}\right) = 2\,Q\,ln\,1 = 0$ (17)

From (15) $V = 2\,Q\,ln\left(\frac{d-r}{r}\right) = P.D.$ between B_1 and P

From (16) $C = \frac{1}{2\,ln\left(\frac{d-r}{r}\right)}$ (18)

Equation (17) shows that the above imaginary line is of zero potential; for this reason the line is called the neutral line and also for this reason it is situated parallel to and midway between the line wires and is the imaginary line selected, in the case of a single-phase, two-wire line.

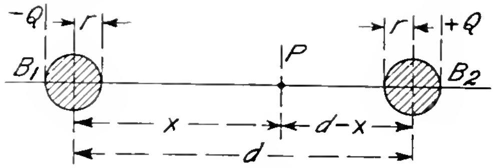


Fig. 11

Equation (18) shows that the capacity of a single wire and the central line is two times that of the two wires considered as a condenser.

The significance of this is evident from the relation

$$V = \frac{Q}{C} \qquad (19)$$

which shows that the potential difference varies inversely as the capacity, and therefore the potential difference between B_1 and the neutral line, being one half that between B_1 and B_2, the capacity between B_1 and the neutral line will be two times that between B_1 and B_2.

The values given in (16) and (18) are for absolute units, *i.e.*, capacity in farads, per centimeter for an interaxial distance given in centimeters and natural logarithms. Reducing to units of 1000 feet and to common logarithms the expressions (16) and (18) reduce respectively to

$$C = \frac{3.677 \times (10)^{-9}}{log\left(\frac{d-r}{r}\right)} \qquad (20)$$

farads per 1000 feet of 2 parallel wires, and

$$C = \frac{7.354 \times (10)^{-9}}{log\left(\frac{d-r}{r}\right)} \qquad (21)$$

farads per 1000 feet of one wire and neutral line.

A three-phase three-wire transmission line spaced at the corners of an equilateral triangle behaves as regards capacity precisely as though the neutral line were situated at the center of the triangle. This has been proven experimentally by Perrine & Baum.

For three parallel wires equally spaced, in a plane, the neutral or zero potential line moves harmonically between the positions midway between the other lines and the center line.

Tables (12) (26) give the capacities for solid and stranded conductors respectively.

(*To be Continued*)

EXHAUST FAN BLOWERS FOR RESIDENCE FURNACES

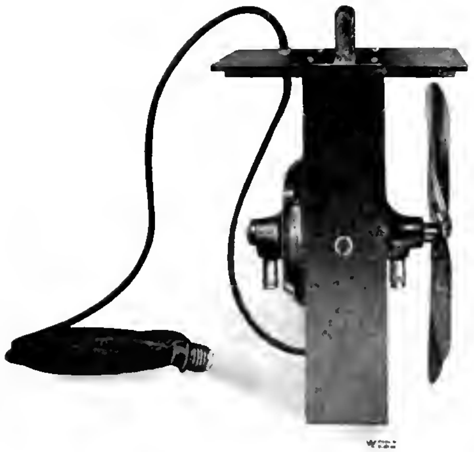
By R. E. Barker

Small Motor Department, General Electric Company

The ordinary hot-air furnace is used very widely for heating residences and usually performs an economical and satisfactory service. There are, however, cases where the natural air currents from the furnace do not properly heat all parts of the house. In nearly every installation some rooms may be found which cannot be comfortably warmed, although excessive quantities of fuel are burned. The length of feed pipes, direction and force of the wind outside, etc., all have their effect in impairing the heating afforded by the furnace. The exhaust fan blower is offered by the General Electric Company as an easy means of relieving such conditions. It often proves to be a very effective remedy.

The device is well shown in the illustration and consists of a moderate speed motor driving a six blade fan in a supporting frame. The apparatus is supplied with an attaching cord and plug, and thus connections to the ordinary lighting circuit may be made with ease. No special wiring is required, as the motor takes no more power than one sixteen candle-power incandescent lamp.

The above mechanism will undoubtedly improve the heating effect of the average



Fan Blower for Residence Furnace

hot-air furnace, and as its cost of operation is very low it will show a considerable saving in fuel consumed. Instead of piling on extra coal when the weather becomes severe, the extra heat required may be moved through the piping system by the action of the furnace blower without any appreciable increase in the fuel burned. The heat which under usual conditions remains in the cellar is taken up by the air forced through the pipes by the fan and is sent to the rooms above before the heat is lost.

These motors are furnished for the following circuits:

ALTERNATING CURRENT	SINGLE-PHASE	
Size	Cycles	Volts
12 in.	60	110
12 in.	60	220
12 in.	40	120
12 in.	40	220
DIRECT CURRENT	SERIES WOUND	
12 in.	1100	110
12 in.	1100	220

The outfit should be installed in the cold air box or duct near its junction with the furnace. To receive the motor, an opening $14\frac{3}{8}$ in. by $8\frac{3}{8}$ in. should be cut in the top of the box. This hole should be fitted with a hinged door or lid, with the hinges set back to allow the iron cover of the outfit to rest on the box when placed in the operating position. In mild weather, when the motor is not required, it may be easily removed and the opening closed by the hinged cover. The handle on the top of the motor support provides a ready means of moving the apparatus when necessary.

Among the several good features possessed by this blower, the following may be mentioned:

Simplicity of construction.
Ease of installation.
Quietness of operation.
Low cost of operation.
Saving of fuel.
No special wiring required.
Moderate first cost.

This outfit in its complete and special form is the result of a practical test of the application herein described. This statement may be somewhat reassuring to a prospective buyer to whom the theory appeals but who is doubtful of the results to be obtained in actual practice. There is nothing experimental either in the outfit itself or in the manner of its use.

TRANSMISSION LINE CONSTANTS

PART VII

TABLE XXVI

CHARGING CURRENT PER 1000 VOLTS

THREE-PHASE

25 CYCLES

Divide Values in this Table by 100

Amperes each Conductor per 1000 Volts for 1000 Feet of Line

STRANDED CONDUCTORS

Interaxial Distance, Inches	500,000	450,000	400,000	350,000	300,000	250,000	0000	000	00	0	1	2	3	4
	CIRCULAR MILS SIZE OF CONDUCTOR B&S GAUGE													
1	.4220	.3286	.2753	.2317	.1978	.1690	.1506	.1302	.1160	.1050	.0947	.0871	.0811	.0757
2	.1132	.1070	.1023	.0970	.0917	.0860	.0817	.0762	0717	.0679	.0639	.0605	.0579	.0552
3	.0833	.0806	.0777	.0748	.0717	.0684	.0669	.0622	.0594	.0568	.0541	.0518	.0497	.0477
4	.0708	0686	.0668	.0646	.0624	.0601	.0581	.0554	.0531	.0510	.0488	.0468	.0454	.0438
5	.0635	.0619	.0604	.0586	.0568	.0550	.0534	.0510	.0492	.0474	.0455	.0438	.0426	.0410
6	.0588	.0571	.0561	.0546	.0531	.0519	.0500	.0480	.0463	.0448	.0430	.0416	.0405	.0392
9	.0504	.0494	.0486	.0474	.0463	.0450	.0440	.0425	.0411	.0400	.0386	.0374	.0365	.0354
12	.0459	.0450	.0443	.0134	.0425	.0414	.0405	.0392	.0381	.0371	.0360	.0350	.0341	.0332
18	.0408	.0401	.0396	.0388	.0381	.0373	.0365	.0355	.0346	.0338	.0328	.0320	.0313	.0305
24	.0380	.0373	.0369	.0362	.0356	.0349	.0342	.0333	.0325	.0317	.0309	.0301	.0295	.0288
30	.0360	.0354	.0349	.0344	.0338	.0331	.0326	.0317	.0310	.0303	.0296	.0289	.0283	.0277
36	.0345	.0340	.0335	.0330	.0325	.0318	.0313	.0306	.0299	.0293	.0285	.0279	.0274	.0268
42	.0332	.0328	.0324	.0320	.0314	.0309	.0304	.0297	.0290	.0284	.0278	.0271	.0266	.0261
48	.0323	.0319	.0315	.0311	.0306	.0301	.0296	.0289	.0283	.0277	.0271	.0265	.0260	.0256
54	.0316	.0311	.0308	.0304	.0299	.0294	.0289	.0283	.0277	.0271	.0265	.0260	.0256	.0250
60	.0309	.0305	.0301	.0297	.0293	.0288	.0283	.0277	.0272	.0266	.0260	.0255	.0251	.0246
72	.0298	.0294	.0290	.0287	.0283	.0278	.0274	.0269	.0263	.0259	.0253	.0248	.0244	.0239
84	.0289	.0285	.0282	.0279	.0275	.0271	.0267	.0261	.0257	.0252	.0247	.0242	.0238	.0233
96	.0281	.0279	.0276	.0272	.0269	.0264	.0261	.0256	.0251	.0247	.0241	.0237	.0233	.0229
108	.0276	.0273	.0270	.0267	.0263	.0259	.0256	.0251	.0246	.0242	.0237	.0233	.0229	.0225
120	.0270	.0268	.0265	.0262	.0259	.0255	.0251	.0247	.0242	.0238	.0233	.0229	.0225	.0221
132	.0266	.0263	.0261	.0258	.0254	.0251	.0248	.0243	.0239	.0234	.0230	.0226	.0221	.0218
144	.0262	.0260	.0257	.0254	.0251	.0247	.0244	.0239	.0235	.0231	.0227	.0223	.0219	.0216
156	.0259	.0256	.0254	.0250	.0248	.0244	.0241	.0237	.0232	.0229	.0224	.0220	.0217	.0213
168	.0255	.0253	.0251	.0248	.0245	.0241	.0238	.0234	.0230	.0226	.0222	.0218	.0215	.0211
180	.0252	.0250	.0248	.0245	.0242	.0239	.0236	.0231	.0227	.0224	.0220	.0216	.0213	.0209

CHARGING CURRENT PER 1000 VOLTS

TABLE XXVII

THREE-PHASE

Amperes each Conductor per 1000 Volts for 1000 Feet of Line

60 CYCLES

STRANDED CONDUCTORS

Divide Values in this Table by 100

Interaxial Distance, Inches	CIRCULAR MILS—SIZE OF CONDUCTOR—B.&S. GAUGE													
	500,000	450,000	400,000	350,000	300,000	250,000	0000	000	00	0	1	2	3	4
1	1.0130	.7881	.6610	.5561	.4750	.4060	.3620	.3123	.2782	.2521	.2273	.2090	.1947	.1816
2	.2718	.2570	.2457	.2326	.2200	.2065	.1960	.1830	.1720	.1630	.1533	.1450	.1390	.1325
3	.2000	.1935	.1864	.1794	.1720	.1642	.1582	.1494	.1425	.1363	.1298	.1242	.1194	.1146
4	.1698	.1646	.1603	.1550	.1498	.1442	.1394	.1328	.1274	.1224	.1172	.1123	.1090	.1050
5	.1525	.1485	.1450	.1407	.1364	.1320	.1280	.1224	.1180	.1137	.1092	.1032	.1020	.0985
6	.1412	.1377	.1346	.1312	.1273	.1245	.1198	.1150	.1110	.1073	.1032	.0997	.0971	.0939
9	.1211	.1184	.1163	.1137	.1110	.1080	.1054	.1019	.0987	.0958	.0926	.0897	.0876	.0850
12	.1101	.1080	.1063	.1041	.1018	.0993	.0972	.0941	.0915	.0890	.0863	.0838	.0819	.0797
18	.0980	.0962	.0950	.0932	.0915	.0896	.0875	.0852	.0830	.0810	.0787	.0767	.0750	.0732
24	.0910	.0895	.0884	.0870	.0854	.0836	.0821	.0798	.0780	.0762	.0741	.0723	.0708	.0692
30	.0862	.0850	.0836	.0822	.0810	.0795	.0781	.0762	.0744	.0727	.0709	.0693	.0680	.0664
36	.0828	.0815	.0804	.0793	.0780	.0764	.0752	.0734	.0717	.0702	.0685	.0670	.0657	.0643
42	.0797	.0787	.0778	.0767	.0754	.0740	.0730	.0712	.0696	.0682	.0666	.0652	.0639	.0626
48	.0775	.0765	.0756	.0746	.0734	.0721	.0709	.0694	.0680	.0666	.0650	.0636	.0625	.0614
54	.0758	.0747	.0739	.0728	.0717	.0706	.0694	.0680	.0664	.0652	.0637	.0624	.0612	.0600
60	.0741	.0732	.0723	.0713	.0703	.0691	.0680	.0666	.0652	.0640	.0625	.0612	.0602	.0590
72	.0714	.0706	.0697	.0688	.0680	.0668	.0658	.0645	.0632	.0621	.0607	.0595	.0585	.0574
84	.0693	.0685	.0678	.0670	.0660	.0650	.0640	.0627	.0616	.0605	.0592	.0581	.0571	.0560
96	.0675	.0669	.0662	.0654	.0645	.0635	.0626	.0614	.0602	.0592	.0580	.0568	.0559	.0549
108	.0662	.0654	.0648	.0640	.0632	.0622	.0614	.0602	.0591	.0581	.0568	.0559	.0549	.0540
120	.0649	.0642	.0636	.0628	.0621	.0611	.0603	.0592	.0581	.0571	.0560	.0549	.0540	.0530
132	.0639	.0632	.0626	.0619	.0611	.0602	.0594	.0583	.0572	.0562	.0551	.0542	.0530	.0524
144	.0629	.0623	.0616	.0610	.0602	.0593	.0586	.0574	.0564	.0556	.0544	.0535	.0526	.0518
156	.0621	.0614	.0609	.0601	.0595	.0586	.0578	.0568	.0558	.0549	.0538	.0529	.0520	.0512
168	.0613	.0607	.0601	.0594	.0587	.0579	.0572	.0561	.0552	.0542	.0532	.0523	.0516	.0507
180	.0606	.0600	.0595	.0588	.0581	.0573	.0565	.0555	.0546	.0537	.0527	.0518	.0510	.0502

TABLE XXVIII

CHARGING CURRENT

THREE-PHASE

Divide Values in this Table by 100

100 CYCLES

STRANDED CONDUCTORS

Amperes each Conductor per 1000 Volts for 1000 Feet of Line

Interaxial Distance, Inches	CIRCULAR MILS SIZE OF CONDUCTOR B.&S. GAUGE													
	500,000	450,000	400,000	350,000	300,000	250,000	0000	000	00	0	1	2	3	4
1	1.688	1.314	1.102	.927	.792	.677	.603	.521	.464	.420	.379	.349	.325	.303
2	.453	.428	.410	.388	.367	.344	.327	.305	.287	.271	.255	.242	.232	.221
3	.333	.322	.311	.299	.287	.274	.263	.249	.237	.227	.216	.207	.199	.191
4	.283	.274	.267	.258	.250	.240	.232	.221	.212	.204	.195	.187	.181	.175
5	.254	.248	.242	.235	.227	.220	.213	.204	.197	.190	.182	.175	.170	.164
6	.235	.229	.224	.219	.212	.208	.200	.192	.185	.179	.172	.166	.162	.157
9	.202	.197	.194	.189	.185	.180	.176	.170	.164	.160	.154	.150	.146	.142
12	.184	.180	.177	.173	.170	.165	.162	.157	.152	.148	.144	.140	.137	.133
18	.163	.160	.158	.155	.152	.149	.146	.142	.138	.135	.131	.128	.125	.122
24	.152	.149	.147	.145	.142	.139	.137	.133	.130	.127	.123	.120	.118	.115
30	.144	.142	.140	.137	.135	.133	.130	.127	.124	.121	.118	.115	.113	.111
36	.138	.136	.134	.132	.130	.128	.125	.122	.120	.117	.114	.112	.109	.107
42	.133	.131	.130	.128	.126	.124	.122	.119	.116	.114	.111	.109	.106	.104
48	.129	.128	.126	.124	.122	.120	.118	.116	.113	.111	.108	.106	.104	.102
54	.126	.124	.123	.121	.120	.118	.116	.113	.111	.109	.106	.104	.102	.100
60	.123	.122	.121	.119	.117	.116	.113	.111	.109	.107	.104	.102	.100	.0984
72	.119	.118	.116	.115	.113	.111	.110	.108	.105	.103	.101	.0990	.0974	.0955
84	.115	.114	.113	.112	.110	.108	.107	.105	.102	.101	.0986	.0968	.0950	.0933
96	.113	.111	.110	.109	.107	.105	.104	.102	.100	.0986	.0966	.0947	.0931	.0914
108	.110	.109	.108	.107	.105	.104	.102	.100	.0985	.0968	.0947	.0930	.0914	.0899
120	.108	.107	.106	.105	.103	.102	.100	.0986	.0968	.0951	.0933	.0914	.0900	.0884
132	.106	.105	.104	.103	.102	.100	.0990	.0971	.0954	.0938	.0919	.0903	.0884	.0872
144	.105	.104	.103	.102	.100	.0989	.0976	.0957	.0940	.0925	.0908	.0892	.0877	.0863
156	.104	.102	.101	.100	.0991	.0976	.0963	.0946	.0930	.0915	.0896	.0881	.0868	.0853
168	.102	.101	.100	.0991	.0978	.0956	.0952	.0935	.0920	.0904	.0887	.0871	.0859	.0845
180	.101	.100	.0991	.0980	.0958	.0954	.0942	.0925	.0910	.0895	.0878	.0866	.0850	.0836

GENERAL ELECTRIC REVIEW

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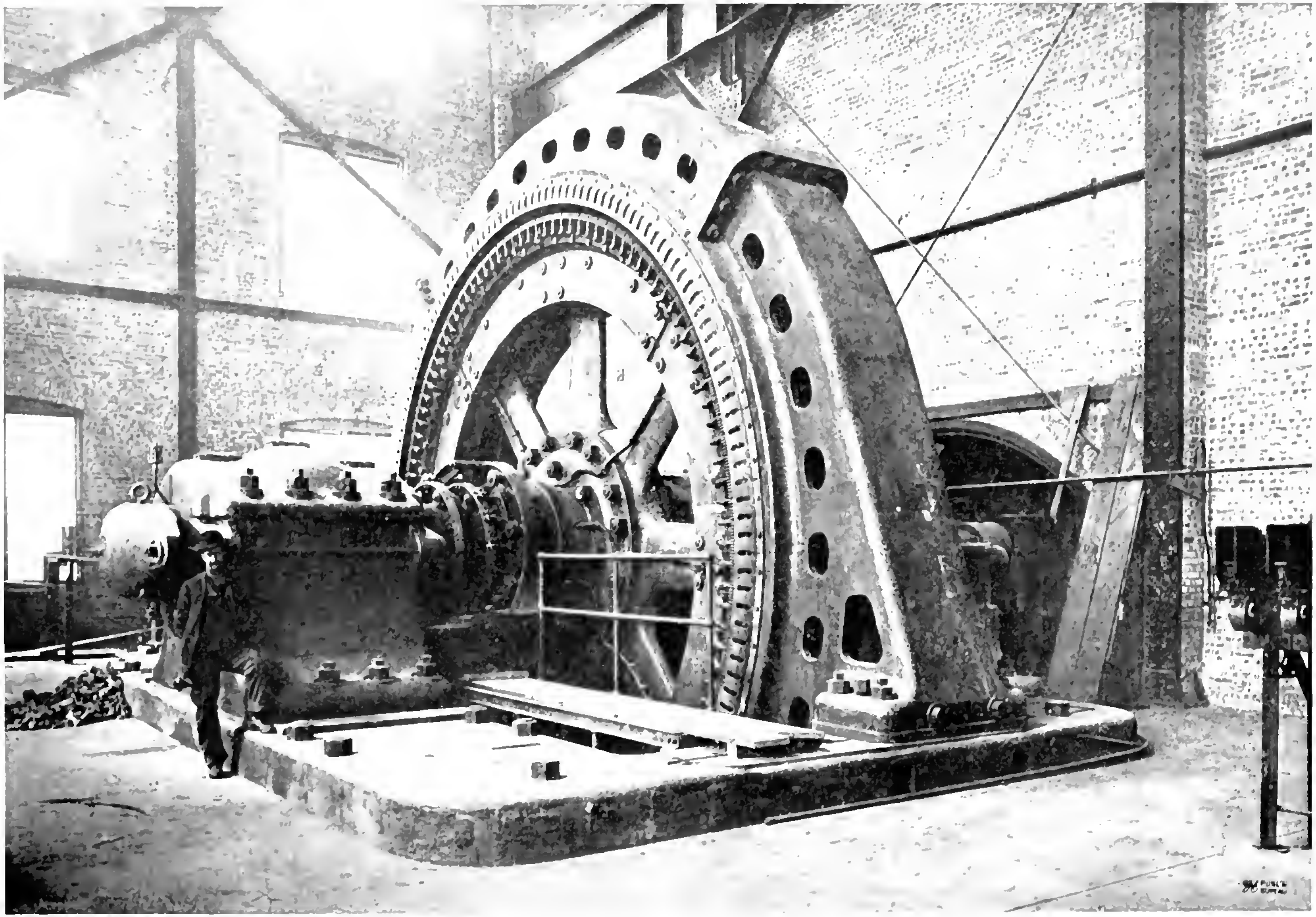

6000 H.P., 3-Phase Induction Motor Connected to Rail Mill—Indiana Steel Company, Gary, Ind.

" A Motor Operated Rail Mill "—Page 85

GENERAL ELECTRIC REVIEW

STEAM ENGINEERING DEVELOPMENT

The history of the development of the steam engine is similar to that of all man's inventions and, unlike natural evolution, has proceeded from the complex to the less complex. Nearly 150 years ago James Watt, the Scotch engineer, may be said to have inaugurated the art of steam engineering by his invention of the condenser. The rapid advance that has been made during the last century in reciprocating engine practice, and during this century in the development of the steam turbine, are indeed largely owing to his genius, while the modern high power triple and quadruple reciprocating engines are the natural offspring of the cruder and more complicated arrangements employed in steam engines in Watt's time.

During the last decade steam engineering has made a further notable advance. The steam turbine has been successfully developed, and has already superseded its one-time rival, the reciprocating engine, in many branches of the art. Possessing no reciprocating parts and with a far simpler and more compact construction, it would undoubtedly have come to the front sooner had mechanical and electrical engineering been sufficiently advanced to cope with the constructional difficulties incident to the high speeds requisite and to open a field for its services. With the advent of high speed generators, the latter difficulty was removed and mechanical engineering has been forced to solve the new engineering problems involved in the manufacture of the turbine.

The reciprocating engine, owing to its construction, is neither theoretically nor practically the best or most logical form of prime mover. Due to cylinder condensation, it wastes steam, while it is unable to utilize the greater part of the large amount of energy available in the steam at low pressures in consequence of the small limits which are practicable for expansion. It occupies considerable space per kilowatt output owing to separate cylinders being employed for each expansion and to the fact that high speeds are not possible with heavy reciprocating parts, and piston speeds are limited by various practical considerations. The piston engine is, indeed, a far more complicated machine than the steam turbine and is not so well adapted to modern power requirements. It is unable to utilize the steam energy below about 26 in. of vacuum and rejects practically all energy below this pressure. When it is realized that the steam energy available between 28 in. and 29 in. vacuum is as much as 19 per cent. of the total steam energy at 200 lbs. gauge pressure, it is evident how much the reciprocating engine is handicapped in this respect.

As pointed out in Mr. G. R. Parker's excellent article in this issue on steam turbine development, the steam turbine does not labor under this disadvantage, and it is due to the better utilization of the steam energy at low pressures that the turbine has made such rapid strides in commercial engineering. It is already installed in the greater number of large steam power plants in this country, and at the present time the total capacity of high pressure Curtis turbines of 500 kw. and over, manufactured and sold by the General Electric Company, exceeds 1,400,000 kw., representing a total of 740 units or an average capacity of about 1900 kw. for each machine.

The smaller amount of coal, fewer station attendants and boilers necessitated, and the smaller buildings required by turbine stations of a given capacity, are now realized; but it is instructive to calculate the saving that can be effected by a turbine station by applying actual costs of a Curtis turbine station and a representative modern engine station, to a power station of average capacity. Suppose a station of 20,000 kw. is considered operating at about 40 per cent. load factor:

The following results are based on figures obtained under actual operating conditions, which in nowise favored the turbine station. The quality of coal was approximately the same in both cases and the water facilities, station capacity, load factor, etc., nearly equal. The costs were also averaged over about 4 months' operation so as to obtain representative operating conditions. In the turbine station, the labor bill per kw. hour was only slightly greater than 25 per cent. of that of the reciprocating engine station, while the coal bill was only about 80 per cent., with the total cost of operation standing at less than 65 per cent. Applying these figures to a 20,000 kw. station, the following sums will be saved per annum by the turbine station; *viz.*, $40,000 for coal, $60,000 for labor, with a gross saving, including maintenance charges, of $110,000 per annum.

Besides dealing with high pressure turbines, Mr Parker describes the exhaust turbine and the latest development of this type; namely, the mixed pressure turbine. The enormous increase of capacity, without increase in coal bill, and in some cases with an actual decrease in the latter item, which can be obtained by using low or mixed pressure turbines in connection with either condensing or non-condensing reciprocating engines is clearly exemplified. The reasons for the economical operation of this turbine with high pressure steam are also given. The article finishes with a review of the field filled by the small turbine in capacities of 300 kw. and less, the conclusion being that such turbines have negligible maintenance charges owing to their very durable construction.

In reference to the exhaust and mixed pressure turbines, it is of interest to note that over 50,000 kw. have been sold to date, the average machine capacity being slightly greater than 1400 kw. So undoubted are the economies that can be derived by installing such turbines, that it is certain that no reciprocating engine stations with condensing facilities can long afford to do without them, especially as the mixed pressure turbine is exceedingly flexible in operation and will on emergency continue to deliver power, though the supply of low pressure steam from the reciprocating engine is entirely cut off.

A MOTOR OPERATED RAIL MILL

The Gary Works of the Illinois Steel Company form the nucleus of what promises to be the largest steel manufacturing center in the world. The works are ideally located both for the reception of the raw material and the disposal of the product, as their situation on the shore of Lake Michigan permits the delivery of the ore directly from the lake boats to the works' storage pile; while in addition to the readiness by which the product may be shipped by water, the proximity to the city of Chicago, with its numerous intersecting railway lines, places the exceptional transportation facilities of that great distribution point at their command.

At the present time the following mills are completed or in process of construction:

- A continuous rail mill
- A continuous billet mill
- A 60 inch universal plate mill
- An axle mill
- Four merchant mills of 10, 12, 14 and 18 inches respectively.

Each of these installations embodies many new features, both in the design of the mill and the methods of rolling the steel.

The article by Mr. Semple in this issue is the first of a series that will describe these various installations, and covers the rail mill, which was the first to be put in operation and is one of the most important as well as interesting of the several mills to be installed, as it marks a new era both in the steel and electrical industry, being the first in which rails are rolled entirely by electric motors directly from the ingot without reheating. The motors, furthermore, are not only larger but several times larger than any other motors previously built.

Few undertakings having the magnitude of these works and involving as many radically new features have experienced so little trouble in operation as this mammoth steel plant. In this connection, by no means the least conspicuous among the departures in engineering are the large rail mill motors, the operation of which has been successful from the first day they were put in commission.

ATMOSPHERIC ELECTRICITY*

By Prof. Elihu Thomson

From the remotest times the thunderstorm has been one of the most impressive of natural phenomena, inspiring terror in men and other creatures alike. The realization of its interest and grandeur is probably of comparatively modern origin. It is indeed not surprising that in pagan mythology the lightning stroke was ascribed to the anger of the greatest of the gods. It is no wonder that, in one of the greatest poems of the Bible, Job is asked, "Canst thou send lightnings that they may go and say unto thee, 'Here we are'?"

With the decay of authority and miraculous interpretation of natural phenomena and the gradual growth of rationalism and scientific study the recognition of the lightning and the thunder as a result of natural processes gradually came about. In the seventeenth century began that gradual awakening to the possibilities of the conquest of nature, the outcome of which is modern science with all its great achievements. It was the period of Bacon, Galileo, Gilbert, Descartes, Newton and others. At first the explosive action of lightning, the noise of the thunder and the subsequent strong smell of ozone, which often exists, suggested a kinship with gunpowder, or that certain nitrous and sulphurous constituents of the atmosphere supposedly had become fired. This naturalistic view even the self-constituted witchcraft exponent, Cotton Mather, willingly adopts in one of his books.

Priestly, the discoverer of oxygen gas, in his "History of Electricity," published in 1767, makes an interesting quotation from a paper of a certain Dr. Wall in the *Philosophical Transactions.* This Dr. Wall, an experimenter in electricity in the latter half of the seventeenth century, and a contemporary of Otto Guericke and later of Newton, after describing his experiments with rubbed amber and the production of light and the cracklings therefrom, says, "Now, I make no question but upon using a longer and larger piece of amber, both the cracklings and light would be much greater." Then further he says: "This light and crackling seems in some degree to represent thunder and lightening." I believe this to be the first reference to the possible relationship between electricity and lightning. The later history of Franklin's suggestion of identity, D'Alibard's experiment and that of the famous kite furnishing experimental proof, are too well known to be dwelt upon here.

The practical genius of Franklin led him at once to the suggestion of protection from lightning by means of a conducting rod of metal, well connected to the moist ground at its lower end, and projecting beyond the highest parts of the building or structure to be protected. In these later years it is not unusual to meet with statements of discredit or denial of the efficacy of this simple device. There seems to be a tendency among the uninformed to regard it as an old-fashioned and useless if not a dangerous contrivance. Often the question has been asked whether it is not an exploded notion that such rods have any value for protection. It may well be that the "lightning-rod agent" of former times is largely responsible for the distrust. He was a sort of confidence man, who supplied a sham appliance, often of marvelous makeup. A structure of twisted metal tube topped with glittering gilt points in clusters, mounted on green glass insulators, the whole as expensive as the unhappy victim could be frightened into paying for, was erected, and often left without any adequate connection to the ground. It was a tree without roots; lacking, in fact, the most essential part of its structure.

Let us add with emphasis that the Franklin rod when properly installed undoubtedly secures practical immunity from lightning damage. Its installation is an engineering undertaking demanding study of varied conditions and proper care and judgment in meeting these conditions. The one consideration originally left out was that if there were any better or more direct paths for lightning existing in the building or structure, or better ground connections than the rod possessed, these must be included in the protective system. But it is also a fact that the construction of most modern buildings, particularly in cities, involves so much metal in roofing, ventilating and other pipes, wires and the like, that it

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* Address at the formal opening of the Palmer Physical Laboratory at Princeton University, Oct. 21, 1909.

is generally unnecessary to resort to any separate means for protection.

In cities there are many lofty structures framed in steel, piping that projects above the roof, and metal stacks, generally in good connection with the underground pipe systems; all of which together tend to minimize danger from strokes of lightning. The best vindication of Franklin will, however, be found in the fact that the firmest reliance is placed by the trained electrical engineer upon the provision of an easy path for the electricity of lightning to reach the ground. Practically all his protective appliances or arresters used in electric systems are based on that principle, with modifications and additions to suit particular conditions of use. To provide such modifications and adaptations is by no means an easy task. There is still a possibility of insufficiency such that the menace of breakdowns and damage by lightning still remains a *bete noir* to the engineer. The tremendous discharge of energy possible in a lightning stroke may be sufficient to defeat our efforts. Breaking through insulation and causing short circuits, burning of wires and rupture of circuit, and damage to apparatus are still occasional experiences in spite of our safeguards. Even at a considerable distance away a stroke of lightning, by its inductive action, may set up electric waves or surgings which require to be provided against. The extremely uncertain value of the effects, the irregularity and impossibility of calculation or prediction, render the problem of protection difficult. The effects of these secondary surges are generally incomparably less violent than direct strokes, and they are seldom dangerous to life.

So long indeed as our electric lines are extended above the ground, so long must this disturbing factor be reckoned with. Fortunately it has been possible by constant effort and study to secure more and more effective appliances so that the lightning menace grows steadily less. Research and experimentation in this direction have constituted an important part of the development of electrical engineering.

Having thus at some risk of your patience vindicated our earliest worker in the study of atmospheric electricity—Franklin—let us turn from the practical issues and consider the electricity of the air from a more general standpoint.

The study of the nature and origin of electrical storms or disturbances throughout the atmosphere is of much interest; our knowledge is yet meager; there is much more yet to be learned in this fascinating field. Exploration of the electrification of the air at varying heights by captive balloons, by kites, and upon elevations of land, has generally shown an increasing electric potential upward from the earth, and usually positive in relation thereto. Sometimes this relation is reversed. It has been roughly estimated that if the differences noted can be assumed to be extended to include the total depth of the atmospheric layer, the earth's surface might be negative to the surrounding space, 150,000 volts more or less. This condition would not admit of being regarded as constant or stable, since widespread electric storms occur in both our upper and lower air levels. In the highest regions of our atmosphere they take the form of diffuse discharges as in a high vacuum and are called auroras. They either accompany or give rise to magnetic storms, which affect the direction and intensity of the earth's magnetism temporarily, and hence disturb the compass needle, sometimes through many degrees. Within a few weeks past we have experienced such a storm of a remarkable intensity; sufficient in fact to cause interruptions to telegraphic and cable transmission during several hours. Brilliant auroras were at the time seen in some places.

The frequency of auroral phenomena, and perhaps also to some extent the frequency of thunder-storms, seems to keep pace with the sunspot period, at least in our latitudes. At times of sunspot activity, the surface layers of the sun, upon the energy radiated from which so much of earthly activity depends, are stirred by great storms, or immense cyclones of hot gas or metallic vapors; storms seem as dusky spots on the sun's disc. They can attain enormous size—20,000, 30,000 or even 50,000 miles in diameter, though these dimensions are exceptional. They are visible, as is well known, not because they are non-luminous, but because they are less luminous than the surrounding solar surface. In like manner bright spots or faculæ may also be seen, because they are on the whole brighter than the sun's surface adjoining them.

There is much reason to believe that, in accordance with suggestions made many years ago, these solar storms are accompanied by exceptionally vigorous projection outward from the sun to immense distances, of streams of electrified matter. Should the earth happen to be in a position to be swept by such a stream, an aurora may be produced. During a total solar eclipse the so-called coronal streamers are seen to extend from the sun's surface to distances of upwards of two millions of miles or possibly farther than that, but doubtless they keep on outwardly, and invisibly, to relatively enormous distances. It is not unreasonable as a hypothesis to imagine that they may extend at times as far as the orbit of the earth and may, if the direction is the proper one, reach our outer air.

Further, if they consist of electric ions or particles conveying electric charges, an aurora may result. Dr. Hale, of Mt. Wilson Observatory, has indeed recently shown by the spectroscope that great solar storms are in fact attended by the motion of electric ions at enormous velocities. The phenomena of auroras present peculiar difficulties in their study, since, as in the case of the rainbow, no two obervers at a distance from each other see the same or identical appearances. Hence attempts to determine the height by triangulation at which auroras exist give most contradictory results, for it is impossible to fix upon any condensation or streamer which may not be displaced or absent to another observer some distance away. This is understood when we bear in mind that the luminous appearances are not located in one plane, but are distributed in space; condensations of light being the result of superposition in the line of observation.

I have come to the opinion that the auroral streamers often extend in a general direction outwardly from the earth, sometimes to very great distances relatively to the known extent of our atmosphere. The effects observed appear unaccountable upon any other supposition, while they are consistent with the idea of outwardly directed streams of great extent. In April, 1883, there occurred an aurora which was at its maximum a little after midnight. It was the most magnificent display of the kind, which, in spite of a continual vigilance on my part, it has been my fortune to witness. It was upon such a scale that, so to speak, the mechanism of the streamers stood revealed. At that time I could not avoid the conclusion that the auroral streamers must have extended outwardly several thousand miles. There is no space here to present the argument involved. Perhaps the most significant fact is that precisely the same general appearances were noted in Chicago as in the east, and that they occurred simultaneously. The interesting question arises, does the earth temporarily acquire streamers similar in nature to the solar coronal streamers? The answer is as yet unknown. At the time of the great display mentioned there was a sunspot near the center of the sun's disc of about 50,000 miles in diameter. During that disturbance long telegraphic lines could not be operated, owing to arcing at the keys which prevented interruption of the circuits. Apparently in subtle sympathy with its master orb, the sun, the earth's electric and magnetic equilibrium was for a time profoundly disturbed.

While it is by no means certain that auroras and magnetic storms are always dependent on solar outbursts, it is now generally recognized that the observed coincidences are too frequent to be the result of chance. It is perhaps safe to assume that although solar storms and sunspots can occur without provoking auroras or magnetic storms here, it may be doubted if these latter occur on any great scale unless solar activity is coincident therewith. And it seemingly is true that only when the projected electrified matter actually reaches the earth or comes near enough to inductively affect its electrical equilibrium are the terrestrial phenomena produced thereby.

It has even been suspected that a greater frequency and severity of thunder-storms in our lower air accompanies the active period of the sun or sunspot maximum. This is a hypothesis which would require a careful collection and comparison of data over a long period to give it status as a scientific fact or wholly to disprove it. Be that as it may, experience with lightning damage in electric installations seemingly supports the idea and, in a paper given some seven or eight years ago during the minimum period, led me to predict a severe ordeal a few years in advance. As a matter of fact the prediction was to a large extent verified with the result of extraordinary activity in devising safeguards from which the electrical engineering art now benefits. In general the harm done by thunderstorms is due directly or indirectly to the heavy spark discharges called lightning flashes or strokes of lightning.

It may be of interest to refer briefly to the conditions existing in a cloud which is the source of such destructive energy. As is well known, clouds consist of fine water particles suspended in the air. When frozen these particles are crystalline like minute snow crystals. All clouds above the snow line are likely to be of that character. At a temperature above freezing the particles of water are miscroscopic spheroids which may by gradual coalescence form drops of rain. This process of coalescence necessarily diminishes the total surface of the water existing as such in the cloud. Should, however, the original particles possess even a slight electric charge, the union of the drops, by lessening the total surface, or diminishing the electric capacity, results in a great rise of potential or electric pressure on the surface of the drops. The process of coalescence continues and the water falls out of the cloud as rain. If the cloud particles are frozen the diminution of surface and consequent increase of electric pressure can not take place. This would seem sufficient to account for the general absence of thunder-storms in winter, though perhaps other causes contribute.

A thunder-cloud has been compared to an insulated charged conductor, such as a body of metal hung upon a silk cord, but in reality the two are not at all comparable. It is a mistake to assume any close analogy to exist. The cloud being only an air body containing suspended water particles, is not a conductor, nor can it, as in the case of metal, permit the accumulation of its electric charge on its outer surface. In fact it possesses no true definite outer surface but blends with the clear air around it. The electric charge it possesses remains disseminated, so to speak, throughout, and must reside chiefly upon the surface of its constituent water drops. Accumulation in any part would require the insulating air between the drops to be overcome.

A lightning stroke from such a mass may indeed represent a discharge of hundreds of amperes at millions of volts. We must, however, be cautious not to exaggerate either the current or the potential present in a lightning flash. The current in a flash can at times be only a few amperes or may in the heavier discharge reach perhaps hundreds, or possibly in extreme cases some few thousands of amperes. It is doubtful if the potential much exceeds at any time more than a few millions of volts as it is probable that small local breakdowns start the disruptive process which then extends through miles of length. The individual water particles even when collected into drops can not be charged to such enormous potentials as millions of volts. In reality it is the combined effect of the numerous particles acting inductively that accounts for such pressures. A combined stress is set up towards the earth or towards another cloud mass of opposite charge. The lightning stroke results from a breakdown of the insulating air layer between them, and also all through the cloud itself, and for a time a partial neutralization or electric equilibrium is effected. This continues until a further redistribution of charges is required and until again the breakdown potential is reached. The continued coalescence of charged water particles which were not discharged at the first breakdown, repeats the original condition, and so on. Unlike the case of a suspended charged metal body, a single discharge does not usually equalize the electric potential of cloud and earth. Instead, many successive discharges occur. It is probably fortunate for us that the process is as gradual as it is, for the ordinary partial discharges of the cloud are each terrific enough and tax our resources sufficiently when we seek to protect ourselves and our effects from them.

Various hypotheses have been proposed to account for the presence of electric charges in cloud masses, but there is no time to discuss them here, and there is in fact little that is really known as to the origin of the electricity of clouds. We shall briefly refer to the phenomena which characterize or accompany the electric discharges. The usual form which the discharge takes is that known as disruptive spark or fork lightning, a long flash or electric spark, joining earth and cloud, or cloud and cloud, and branching within the cloud mass like a tree. Oftentimes between cloud and earth there is seen the single streak zigzag in its course, but within the cloud it ramifies or branches extensively in several directions. In this way only can any considerable part of the cloud contribute its portion to the main discharge path, for, as stated before, the cloud cannot act as a conducting body.

Some authorities treat lightning as a discharge of very high frequency like the ordinary discharge of a condenser or Leyden jar. In fact, it has not been unusual to assume that such apparatus can be substituted and inferences drawn as to the nature and character of the lightning discharge from experimentation and tests with these laboratory appliances. There is, however, abundant reason to doubt that lightning discharges are really oscillatory. If they oscillate the conditions are such as to forbid such oscillation being of a high frequency order. The cloud discharge represents what is known as a discharge of a large capacity, and the length of the path or spark may reach thousands of feet or even many miles, a long inductive path; while the heat and light given out in every part of the path indicate a high resistance to the passage of the discharge. All of these conditions are together known to be inconsistent with the idea of high frequency oscillation. But the breakdown or discharge is extremely sudden and involves an almost instant rise of the current to a large value, so that the inductive effects upon surrounding structures, such as electric lines or circuits, are very energetic and sharp like a quick blow struck; and these lines or structures become the seat of rapid vibration or high frequency oscillations. The sudden blow of the hammer on a bell in like manner brings out all the rates of the vibration, fundamental and overtones, of which the bell is capable and in which the hammer itself takes no part.

The very sudden startling character of a lightning discharge leads to an exaggeration in the popular estimate of its more evident effects. The amount of light given out is not so great as is often assumed. It does not give effects at all comparable with full sunshine. While doubtless the intrinsic brilliancy is very high the duration of the flash is small, generally only a minute fraction of a second. In photographs of lightning the landscape is generally seen only in outline or poorly lighted by the discharge. In the daytime, when the clouds are not dense enough to greatly darken the sky, the flash loses most of the blinding character it has when seen in the blackness of night. Similarly, the sound of thunder, though of terrifying quality, is not extraordinarily loud. It is a common experience when traveling in a train to note that the sound of even near-by flashes is smothered by the roar of the train so that no thunder is heard. The noise of thunder can not be due in any part, as is sometimes erroneously assumed, to collapse of the air upon itself and into a partial vacuum left by the spark. I have seen this error even recently repeated and even extended to include all the noise of thunder as due to such collapse. When, however, we consider that in a minute fraction of a second the air in the path of the discharge is so highly heated that, if it were confined, its pressure due to heat expansion alone would rise to more than ten atmospheres we can readily understand the explosive shock given to the surrounding air and the propagation therethrough of an intense air wave. In fact such waves from electric spark discharges and from dynamite explosions have been clearly recorded by photography. Moreover, that the collapse of the air after expansion can have little or no effect in the sound production, follows from the fact that the heated gas streak left in the path of the discharge takes an appreciable time to cool on account of its low radiating power. This is shown by the observation that a lightning discharge in dusty air is often succeeded by a luminosity of the streak which persists for a perceptible time and slowly fades away like the luminous trail of a meteor.

Another common misconception is that the prolonged rolling character of thunder is due to reverberations or echoes. In mountain regions with steep rock walls such reverberations possibly contribute to the effect, but it is now clearly recognized that a sufficient single explanation suffices for most cases. Owing to the great length of the lightning spark or path, we receive the sound from the nearer parts of the discharge far in advance of that from the more remote portions, and between these sounds are those from parts of the path at intermediate distances from the observer. It follows from this that no two observers at a distance from each other hear the same succession of sounds in the thunder of a discharge. Whenever portions of the discharge path are situated or extended in an approximate direction at right angles to the line from the observer, the sound from that part of the path is louder or of high amplitude owing to the sound from that part of the path reaching the observer's ear at the same instant. Whenever the path leads directly away from the observer the amplitude is less, the sound is less explosive and takes the character of an extended roll or rumble.

It will be seen from this that every twist and turn and every change of direction of the spark path with respect to the observer's position gives a varying loudness and sequence of sound. Every branch of the main discharge in like manner records its position and direction, its twistings and bendings in these sound vibrations and sequences. It would seem possible even to record on a phonograph noises from sparks invisible to the eye and map the positions of the sparks in space from records so produced. If this were done as it were stereoscopically or stereographically from two or more separated observing or recording places, the records would contain the necessary data for the reconstruction of the spark and its branches in space.

From the above considerations an attempt to determine the distance of a lightning stroke to earth by counting seconds elapsing between the flash and the first thunder and allowing five seconds to a mile approximately is seen to be futile. Should one of the cloud ramifications or branches of the great tree-like discharge extend in the cloud overhead with relation to the observer, and that part of the discharge be nearer to him than any other he will first hear a receding rumble above him, followed it may be by a heavy explosion from the main or approximately vertical spark between cloud and earth and from the parts of which his distance is nearly the same. This louder explosion will then be followed generally by a prolonged rumble of diminishing loudness which is the sound coming from the ramifications which lead farther to the distant parts of the cloud. Manifestly the counting of time should be between the flash and the heavy explosive sound due to the vertical part of the flash.

Bearing in mind that over the extent of cloud the charged water particles may be said to be waiting for a chance to discharge to earth, it is not surprising that any path which has been opened or broken down by disruption of the insulating layer of air should serve for the discharge of an extended body of cloud. The heated vapor or gas in the path of the discharge is a relatively good conductor of electricity, serving to connect the cloud mass to the earth below. The significance of this is understood when it is known that many lightning discharges are multiple. Instead of a single discharge they consist of a number rapidly following one another through the path or spark streak opened to them by the first discharge. This first discharge opens the way or overcomes the insulating barrier to the discharge of portions of the cloud mass, which, on account of remoteness or lower potential, could not themselves have caused the breakdown. These repeated or multiple flashes are exceedingly dangerous, both to life and property. The first discharge may reduce wood to splinters and the subsequent ones set it on fire. The time interval between the successive discharges in such a multiple flash is quite variable and may be long enough to be easily perceptible by the eye. The multiple character is easily disclosed by the image in a revolving mirror. If a strong wind be blowing at the time of such a multiple flash, the hot gas conducting the discharges may be displaced laterally in the direction of the wind with the result of spreading out the discharges into a ribbon more or less broad. Photographs of these ribbon flashes show their true character plainly; each separate discharge appearing as a streak of light parallel to the others and at varying distances apart. In fact parallel discharges of exactly the same contour are sometimes observed many feet apart. Here the hot gas of the first discharge has evidently been shifted by the wind over a considerable space before the second and subsequent discharges took place. Heavy rain seems to weaken the air and help to precipitate a discharge. From the fact that strokes of lightning are often followed by increased fall of rain within a few seconds it is a prevalent idea that the increased downpour is caused by the discharge. In reality the reverse is the case, for just when a gush of rain has reached from the cloud down to within a hundred feet or more from the ground, by far the major part of the air layer has been so weakened electrically by the presence of the water drops, that the discharge itself anticipates the completion of the distance of fall of the rain, and is therefore a short time in advance of the time when the descending gush of rain actually reaches the ground. As, the gusts or gushes of rain are more or less local and sweep along with the storm cloud, they are apt to mark out the places of the most frequent lightning strokes. Shelter sought at such times under tall trees is particularly dangerous.

The amount of energy which may be concerned in a lightning discharge is neither definite nor capable of estimation. It would seem that the widest variations in energy may occur and this would account largely for the observed differences in the severity of the effects. It must be remembered also that by far the larger part is expended in the long spark in the air and cloud. Even when much damage is done to objects struck it is only a small fraction of the total energy which is expended on them. Most of the damage to property comes indirectly from the electric discharge by its energy being instantaneously converted into heat. This heat evolves steam and expanded gases in the interior of such materials as wood and causes explosion, shown in the splintering or rupture.

A curious effect, often noted when a tree is struck and shattered, is that when the splinters, sometimes of large size, are thrown bodily out to distances of many feet from the shattered tree, the splinters in their movement remain parallel to the tree and in a vertical position. They are frequently found standing upright after a stroke and at distances ranging up to sixty or eighty feet away. This fact indicates that the projecting force is quite instantaneous and is exerted equally and at the same moment throughout the length of the splinter in a direction transverse to its length. Such splinters are sometimes ten or twelve feet in length and several inches thick. As will be seen, a person near a large tree which is so disrupted is in danger of being struck in a different wa , even if he escapes being included in the path of the stroke itself. Aside from this mechanical danger it is known that to take refuge under a tall tree during a heavy thunderstorm is particularly hazardous. This is so because the human body is a better conductor than the tree trunk, particularly as the trunk itself is the last part to become thoroughly wetted by the rain. The leaves and upper parts are wet and more or less conducting while the tree trunk itself may be yet dry. In such a case the body of a person forms a good path or shunt to the dry trunk and is therefore particularly apt to be traversed by any stroke which reaches the tree.

As before indicated, damage to buildings and other such structures can in all cases be prevented by the provision of an effective shunting path to earth. A most essential feature of such a structure as the Franklin conductor is its good connection with the ground, or better its connection with what we know as a good ground. In early times it was considered that it was quite important that the tip or upper end of the conducting rod should be sharply pointed, or should bristle with sharp points, so to speak. The tips were gilded and the points made of gold or platinum to prevent rusting. The points were supposed to draw off the lightning silently from the cloud and so prevent strokes of lightning. But for millions of volts at cloud distances almost all irregular objects on the surface of the earth are practically pointed. Perhaps on this erroneous assumption of the action of points as applied here little stress was laid on the direct path to earth being chosen and on the necessity of including with it or connecting to it other good paths such as gas pipes, bell wires and the like. There is no need of any special provision of points. A blunt end will do as well, for after all there is practically no silent drawing off of the charge from the cloud, for it is not an insulated conductor. The provision of a lightning conductor on a building undoubtedly increases its chances of being struck by lightning, but if properly arranged it also ensures that the structure shall suffer no harm therefrom. Viewed from our present standpoint it is a curious historical fact that in 1777, just after the war of the American revolution broke out, a miniature verbal war between the advocates of *blunts* and *points*, respectively, as applied to lightning conductors raged. In

England party politics led many to condemn *points* as revolutionary and stick to *blunts*. The Royal Society by majority vote decided for points, but those who so voted were considered friends of the rebels in America. George III. took the side of *blunts*. Franklin, who from the first had prescribed points, wrote from France: "The King's changing his pointed conductors for blunt ones is a matter of small importance to me. For it is only since he thought himself safe from the thunders of Heaven that he dared to use his own thunder in destroying his own subjects." The king is reputed to have tried to get Sir John Pringle, then president of the Royal Society to work for blunts, but received the reply: "Sire, I can not reverse the laws and operations of nature." As stated above, it matters not at all which we may use. I have, indeed, seen a number of cases in which the sharp points of lightning conductors had been melted into rounded ends by lightning.

In the foregoing we have been considering the effects of such ordinary discharges of electricity as the disruptive spark, or zigzag flash. Apparently if the testimony is reliable there are other and more rare forms of discharge. I allude to sheet lightning, so-called globular lightning and to bead lightning. But it may be asked, why call sheet lightning a rare form? It is, indeed, true that when a storm is so far distant that the spark discharges can not be seen, as when it is below the horizon, or when the spark is blanketed by a mass of mist of cloud there is to be noted a diffused light or extended illumination, which, on account of distance, may not appear to be attended by thunder. This and similar effects are often called sheet lightning. From observations during a few heavy storms, however, I am led to infer the existence at rare intervals of a noiseless discharge between cloud and earth—a silent effect attended by a diffused light, and which may be the true sheet lightning. In my experience it has accompanied an unusually heavy downpour of rain, the whole atmosphere where the rain fell most heavily being apparently momentarily lighted up by a purple glow, seemingly close at hand in the space between the rain drops. The appearance has been seen in the daytime as an intense bluish or purplish momentary glow without any accompanying sound. It could scarcely have been illusory. It is hoped that other observers will carefully note any such like effect if it occurs. It is certainly a rare phenomenon.

It is quite common that any very bright flash, the details of which from its suddenness and intensity are unobservable, be alluded to as a ball of fire. Doubtless many of the reported cases of so-called ball or globular lightning may be explained as instances of this condition of things. Nevertheless, there are so many recorded instances, apparently in substantial agreement, that it is difficult to escape the conclusion that there in reality exists this rare form of electric effect, globular lightning.

We can not properly discredit observations of phenomena which are so rare that our own chance for confirmation of them may never come. We must, in such cases, carefully scrutinize the testimony, examine the credibility of witnesses and their chances of being mistaken. It is certainly impossible at present to frame any adequate hypothesis to account for this curious and obscure electric appearance. The witnesses agree that it is an accompaniment of thunder-storms and that it resembles a ball of fire floating in the air or moving along a surface, such as the ground. It is not described as very bright or dazzling, and the size of the ball itself may be from an inch or two to a foot or more in diameter. Observers agree that it can persist for some time and that its slow movement allows it to be readily kept under observation while it lasts. When it disappears there is usually an explosion and a single explosive report like that of gun fire. Sometimes it is said to disappear silently. Usually the damage done by its explosion is only slight. This summary of characteristics is common to all accounts. Some accounts are even more detailed, mentioning that the fiery ball seemed to be agitated or with its surface in active motion. I have found two instances occurring many years apart and in widely different localities in which it is described as having a reddish nucleus, in diameter some considerable fraction of the whole. The outer fiery mass has been described as yellowish in color. In some instances it has been seen to fall out of a cloud. It is described as entering buildings and moving about therein. Personally I was for a long period in doubt as to the reality of this strange appearance, deeming it the result of some illusion, or a fanciful myth. But on hearing descriptions by eye witnesses known to me as persons not given to romancing, and finding their accounts to correspond closely with the best detailed descriptions in publications, my doubts have disappeared.

In one instance, while observing the lightning during a heavy thunderstorm, a companion, whose eyes were turned in a direction nearly opposite to my own, suddenly called to me that a ball had just dropped out of the cloud some distance away. The view of the ground was obstructed by buildings and I unfortunately just missed it. The noise of its explosion was, however, heard in the direction indicated by my fellow observer, as a single report like the firing of a gun. At the time I closely questioned him as to details of the appearance. Our ignorance of its possible nature is complete. No rational hypothesis exists to explain it. Science has in the past unraveled many obscure phenomena. The difficulty here is that it is too accidental and rare for consistent study, and we have not as yet any laboratory phenomena which resemble it closely.

Sometimes photographs taken during thunderstorms have been found to carry curiously contorted streaks in some degree resembling lightning flashes. Generally they have been found on plates upon which undoubted lightning discharges have been recorded. In some instances which have come to my notice the streaks have had the appearance of a string of dots or beads and have been taken to represent a very rare form of lightning known as bead lightning. A number of such photographs have been submitted to me for opinion as to the nature of the curious streaks. In all cases they are explained as due to the camera having been moved without capping the lens, permitting images of lights, such as arc lights, or spots of reflected light from wet or polished surfaces to traverse the plate in an irregular course. They are then only records of the inadvertence of the lightning photographer. In one instance the effect was so curious that it was several years before the true explanation was found. In that case there were two wavy contorted streaks of perfectly parallel and of similar outline, but unequal in intensity, rising each from a rail of a single track railway, and apparently terminating in the air fifteen or twenty feet above the tracks. They were finally traced to a moving camera, and a reflection from the wet and polished rail surfaces of the light of an arc lamp located outside the field of view. It required a visit to the place itself to enable this conclusion to be reached. The particular beaded streaks or lines of dots were traced to the fact that the arc lamps causing them were operated by alternating currents which naturally give light interrupted at the zero of current; one hundred and twenty times per second being the usual rate. All this emphasizes the need of care and wholesome scrutiny or even skepticism before reaching a conclusion in such cases.

Is bead lightning, which has at times been described as observed visually, a reality? If it is, it appears to be even rarer than the globular variety. Perhaps it is a string of globules; a variety of globular lightning. But we can not make assumptions. As in the case of globular lightning, there is some testimony, which can not be wholly disregarded, tending to show that a form of discharge resembling a string of beads can actually exist. An account of an instance was given me within one hour after the occurrence itself. The witness was known to me as perfectly reliable. The appearance was described as a festoon of finely colored oval beads hung as it were from one part of cloud to another, and as persisting for some seconds while gradually fading away. The opposite ends of each bead were said to be different in color. It was seen during an afternoon thunderstorm and spoken of as very beautiful, and altogether different from the usual zigzag flash.

If I have dwelt upon these exceptional appearances at some length it is because they seem to show that in electricity there is much yet to learn and abundant opportunity for future investigation. It is certainly literally true that, in the language of Shakespeare, "There are more things in Heaven and earth, Horatio, than are dreamt of in your philosophy." Such work belongs to the science of physics, now recognized as fundamental in all study of nature's processes. In electrical engineering, which is in reality an art based upon applied physics, the subject of lightning protection has always been one of considerable if not vital importance. Just as a lightning discharge from a cloud clears up a path for other discharges to follow, so in electric undertakings it opens up paths for the escape of the electricity we are sending out to do the work intended, such as for lightning, power or other use. In the past, disablement of machinery in electric stations has not been rare. The recent growth of long-distance transmission involving hundreds of miles of wire carried on poles across country, over hills and through valleys, has set new problems of protection, and called for renewed activity in providing means for rendering the lines and apparatus immune to the baneful effects of electric storms. Judging the future by the past, we may conclude that, whatever difficulties of the kind arise, in the great future extensions of such engineering work, science and invention will provide resources ample for the needs, and the rapid advance will be continued unchecked.

THE RELATION OF THE STEAM TURBINE TO MODERN CENTRAL STATION PRACTICE*

By G. R. Parker

Since the commercial introduction of the steam turbine into this country some seven years ago, so much has been said and written on the subject that it seems almost superfluous to attempt to add anything to the already large store of general information.

To a large number of readers a review of steam turbine principles will, therefore, be merely a repetition of ground covered many times. But in any branch of science an occasional brief return to basic principles is never out of place.

The objective of designers of all classes of steam prime movers has been the same; namely, the conversion of the heat of combustion into mechanical or electrical energy; and the medium employed has been water. It is true that the overall efficiency of our best steam prime movers is regretably low, due to the fact that so much heat has to be given to water before any of it can be converted into mechanical work. For example, the total heat per pound of steam at 150 lb. gauge pressure is about 1195 B.t.u. If steam be expanded to a 28 in. vacuum the total energy available in this range is only about 321 B.t.u. This 321 B.t.u. is all of the total heat we are able to use, and in practice commercial machines may convert anywhere from one-half to three-fourths of this available energy into mechanical work.

In this country we are interested chiefly in the Parsons and Curtis types of steam turbines. Briefly, the Parsons principle involves the continuous expansion of steam through alternate rows of moving and stationary blades, the former being attached to the spindle and revolving it, and the latter redirecting the steam against other revolving blades. The expansion of the steam thus occurs in both moving and stationary blades and motion is given the rotating element, both by the impact of steam on the moving blades and its reaction on leaving them. The machine is ordinarily called a reaction turbine and may in a general way be compared with a reaction water wheel.

The Curtis principle differs from the Parsons in that the expansion, instead of being continuous throughout the machine, is broken up into a series of pressure steps or stages. Each one of these contains a row of stationary nozzles which expand the steam through a certain range and direct it with large velocity against the moving buckets, through which it passes with practically no further expansion, thus moving the revolving buckets by impulse only. The expansion of steam, therefore, occurs only in the stationary element. This type of turbine is referred to as the impulse type and is somewhat analagous to the impulse water wheel. It is with the impulse turbine as invented by Curtis and perfected by Emmet that this present paper deals.

The problem confronting all turbine designers has been to reduce the speed to such an extent that the turbine itself and the generator connected with it could be made to safely withstand the centrifugal strains. Other speed limits are imposed by the commercial electric frequencies in use in this country. Evidently 1500 r.p.m. is the highest speed for a 25 cycle generator and 3600 r.p.m. for 60 cycles.

The most efficient speed for any single impulse wheel driven by a moving liquid or

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gas is one-half that of the moving element. Steam exhausting from a pressure of 150 lb. gauge through a suitable nozzle attains a velocity of about 4000 feet per second. Therefore, half this speed, or 2000 feet per second, should be the correct peripheral speed of a single impulse wheel placed in the path of the steam jet. Evidently such a peripheral velocity would necessitate an angular velocity far in excess of the highest commercial speeds. To reduce this high angular velocity and at the same time retain the efficiency of his machine, Curtis made use of two expedients. The first consisted in utilizing the velocity of a single expansion in more than one wheel, and thus dividing the initial velocity into two or more parts. This reduced the peripheral speed of each wheel in inverse proportion to the number of wheels. However, there are practical limits to the number of wheels which can be utilized in a single expansion; therefore, to still further reduce the speed, Curtis not only divided the velocity of a single expansion into two or more steps, but divided the total expansion range into two or more separate expansions.

A considerable amount of experimenting was done in the early days of manufacture to determine the correct number of stages and wheels per stage. Thus the first large turbines built contained two stages and three rows of revolving buckets per stage. Later investigations showed that for all large turbines the most economical results were obtained with not more than two rows of buckets per stage, and this is the present standard. With the exception of very large machines, four stages has been regarded as the correct number, although recent experiments indicate that possibly greater economy may be obtained with one or more additional stages.

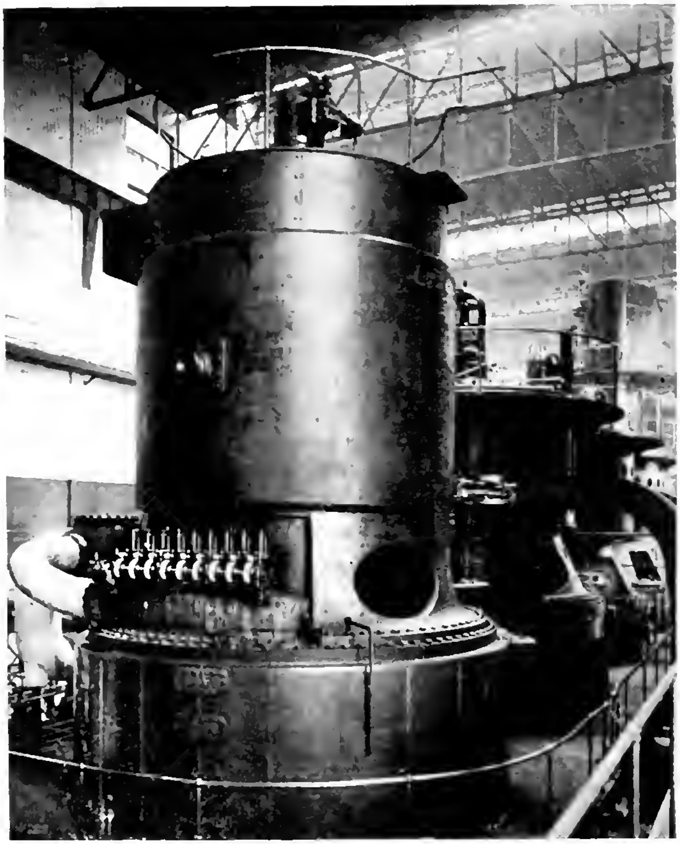
One of the principal and most justly founded claims for the steam turbine is its relatively high economy at other loads than rated load. Even in the best designed reciprocating engines the best economy is obtained at one point, and at loads greater or less than this, cut off occurs either too early or too late for the cylinder proportions, and the result is a steam consumption per horse-power relatively higher at these loads. Since very few power loads can be made to hold constant at any given point the average economy on a varying load may be considerably in excess of the best obtainable value.

On the other hand, the Curtis principle permits high economy at all loads. This is due largely to the method of governing. Most impulse wheels have partial peripheral admission of steam; *i.e.*, steam flowing through only a portion of the wheel at one time. Thus in the Curtis type the nozzles expanding the steam and admitting it to the first stage wheel extend over only a small portion of the wheel periphery. These nozzles are generally placed close together in a single continuous arc, although in the very large sizes two groups of nozzles spaced 180° apart are employed. The admission of steam to these nozzles is controlled by a corresponding series of valves which vary in number according to the size of the machine. The opening or closing of these valves evidently permits the passage of steam through a greater or less number of nozzles. The steam emerging from two or more nozzles combines to form a continuous belt or stream of steam of constant width, determined by the width of the nozzles, and of length corresponding to the number of nozzles open. Governing is thus accomplished by automatically varying the length of this steam belt by the successive opening or closing of the admission nozzles. The steam thus arrives at the point of inlet at full pressure, regardless of the load, and whether one or all the nozzles are open it is expanded with practically no throttling. The result is evident in the steam consumption curves. At fractional loads the steam consumption is relatively good, and as the load is increased the economy continues to improve, the load-water rate curve gradually becoming a nearly straight line. With such a machine it is possible to operate over at least half the range of the machine with maximum and minimum economy varying not more than five per cent. from the average. The advantages of this feature on a fluctuating load are obvious.

The question is often asked as to what are the most economical steam conditions; *i.e.*, initial pressure, vacuum and superheat. While there is much discussion on these points, the present American practice is becoming reasonably standardized. As to vacuum, there is no question that it is worth while getting the highest obtainable. Twenty-eight inches (properly speaking, 2 in. absolute) and even higher vacuum can readily be obtained with modern condensing apparatus. Steam pressures vary from 150 lb. to 250 lb. gauge. In the smaller and medium sized plants probably 150 lb. to 175 lb. is about right, while in the larger ones 175 lb. to 250 lb. should be employed.

The arguments for and against superheat are numerous, but the consensus of opinion is inclined to favor a reasonable degree of superheat, at least in the large and medium sized plants. Superheat ranging from 50° F. to 200° F. is in common use. Regarding high pressure and high superheat it should be borne in mind that the percentage increase of available energy given the steam is much greater than the percentage increase in fuel necessary to produce these conditions.

Modern steam turbine practice has advanced so rapidly in the past few years that quite startling changes have been effected in some of the original turbine stations. Improvements in details of construction, and increase in speed, have greatly reduced the size and weight per kilowatt. About six years ago the first large turbines were installed in the new Fisk Street Station of the Chicago Edison Co. The first three machines were vertical two-stage machines of 5000 kw. capacity, and the fourth, installed somewhat later, was of the same capacity but of the five-stage type. Within the last year these four machines have been removed and replaced by four vertical machines of 12,000 kw. continuous capacity each. These occupy no greater space than the original machines, and no increase in the capacity of boilers supplying them was necessary. The Fisk Street Station now contains altogether ten similar machines of 12,000 kw. each. The Quarry Street Station of this same company at present contains three vertical machines of 14,000 kw. each and three more will be installed



12,000 Kw. Curtis Turbine. This machine replaced a 5000 Kw. Curtis Turbine of older design, the original foundation and base being retained. Three of the old machines are shown in the background during the coming summer. The economies obtained in these plants are reflected in the rates which the Commonwealth Edison Company is able to make its consumers.

A somewhat similar evolution is now under way in St. Louis. In 1905 the present Union Electric Light and Power Company installed two 5000 kw., 500 r.p.m., 25 cycle, 6600 volt vertical turbines. Later, two more 5000 kw. machines were added, but with 60 cycle, 2300/4000 volt generators. The present plan, which is now well under way, is to replace all four machines with other turbines of 12,000 kw. capacity each.

The natural question is, can it possibly be a good business proposition to throw out four large turbines which have been in use only three or four years? That the answer was affirmative was due to three principal considerations.

(1) The larger machines could be installed without increase in floor space.

(2) The improvement in economy represented an annual charge which, if capitalized, would more than pay for the additional investment.

(3) Practically no new auxiliary apparatus or station piping would be required.

That these considerations were based on correct assumptions has been amply demonstrated. The first 12,000 kw. turbine has now been in commercial operation for several weeks.

In making this installation not only was it possible to utilize the original foundations, but even the base of the old turbine, which also constitutes the exhaust chamber and step bearing support, was utilized in building the larger machine. It was, therefore, not necessary to remove this base from the concrete, or break the connection to the condenser. In a general way it may be said that the old 5000 kw. turbine was lifted bodily from its exhaust base and a 12,000 kw. machine installed in its place, without disturbing the condenser piping and auxiliaries. The increase in capacity means that in this portion of the station the kilowatt per square foot of station has been more than doubled. Even the original four 5000 kw. machines were placed unusually close together, and when the remaining three are replaced by larger machines, it seems probable that the turbine portion of the Union Electric Light and Power Company station will show a greater kilowatt capacity per square foot than any other station in this country.

Aside from the increase in capacity, the improvement in steam economy is very large. Unfortunately, detailed test figures are not available at this time, but it is probable that the new turbine will show an improvement of at least 20 per cent. over the one which it replaced, besides having a flatter load curve. On this basis considerations of economy alone would have warranted the change. In addition, this enormous increase in power has been effected without any considerable change in the existing piping and auxiliary arrangements.

Any steam turbine operating condensing with the usual pressure and vacuum derives roughly half of its power from the expansion of steam from boiler pressure to atmosphere, and the other half from the remaining expansion from atmosphere to vacuum. Thus in a four-stage machine, atmospheric pressure is reached between the second and third stages. A reciprocating engine operating under similar conditions would not derive its energy from the steam in this proportion. The average engine actually develops some 15 or 20 per cent. of its power from the expansion of steam below atmosphere.

A consideration of these facts brings us to the low pressure turbine. In a general way, it may be stated that a low pressure turbine is that part of the high pressure turbine which normally operates below the atmospheric line. In general, it is possible to build a low pressure turbine for compounding with a non-condensing engine, with the expectation of approximately doubling the capacity and halving the steam consumption, while the same thing may be done with a condensing engine to a less extent. Most condensing engines can be operated at their full capacity non-condensing with a slight adjustment of the valve gear. The increase in steam consumption of the engine alone with this arrangement will be between 15 and 25 per cent.; but the low pressure turbine adds 90 to 100 per cent. capacity, so that the net economy effected is worth going after regardless of the tremendous increase in capacity. Installations of this character were first made in this country four or five years ago, although greater interest has been stimulated during the last year or two. One of the early installations was in the plant of the East St. Louis and Suburban Railway Company, where an 800 kw. and a 1000 kw. low pressure turbine were installed in connection with non-condensing engines.

The most notable installation is that recently made in the power house of the Interboro Rapid Transit Company in New York City. This station contains the highest type of reciprocating engines, operating under the best possible engine conditions and developing an economy comparable with the best engine station in the country. It has, however, been possible to install in connection with one of these engines a low pressure turbine with a nominal rating of 5000 kw. It is probable that a detailed report of this installation will be published at an early date. For the present it is sufficient to say that the improvement in steam consumption of the combined engine and turbine has effected a saving in coal consumption of over 20 per cent. and the combined capacity has been more than doubled. The turbine generator is of the induction type and runs permanently in parallel with the engine generator. With this arrangement it is unnecessary to provide any speed governor on the turbine. The engine governor takes care of both machines. It is interesting to know that in spite of the size and special character of this installation the machine was started and placed in commercial service without a hitch of any kind. A second machine of similar characteristics, but with a larger generator, is now being installed in connection with the second engine, and the present plan contemplates one turbine for each engine throughout the station. When complete, the station capacity will have been more than doubled without any increase in real estate or building investment.

What has been done in this connection can be accomplished on a smaller scale in almost any plant of 300 kw. or larger, operating reciprocating engines either condensing or non-condensing, provided proper condensing facilities are available.

A valuable feature in connection with the Curtis low pressure turbine is that, owing to the fact that even with low pressure steam the primary admission nozzles only extend a portion of the way around the wheel circumference, it is possible to equip any low pressure machine with another set of nozzles primarily designed to expand steam from boiler pressure instead of from atmospheric pressure. A machine so equipped can be operated either as a strictly low pressure machine, or should the supply of exhaust steam fail entirely due to shut down of the engine or other reason, it can operate and carry its full capacity on boiler pressure steam alone; or it can be operated on a mixture of the two, in case the load exceeds the supply of exhaust steam. It should be remembered that these high pressure nozzles do not throttle the steam to a lower pressure, but are actually designed to economically expand it to the proper internal pressure of the turbine. Such a machine operating on high pressure steam only, will show an economy fairly comparable with an engine or turbine regularly designed for high pressure operation. The operation of these high pressure nozzles is automatically controlled by the main governor, and in practice it has been found possible to instantly cut off the low pressure steam supply without a noticeable variation in the speed of the turbine. This evidently makes a most flexible machine and one that accomplishes two most desirable results at comparatively small cost, namely, increase in capacity and decrease in steam consumption.

It is also perhaps worth while mentioning the enormous field which has been opened up by the strictly small turbine, that is, from 300 kw. down. These machines for the most part are designed to operate non-condensing, and the argument in their favor is that they are extremely simple machines requiring practically no attention or adjustment. The best proof of their extremely rugged construction is found in the fact that, out of 500 small turbines of 25 and 35 kw. capacity now operating in various parts of the country, a large percentage are in use by the various railroads for electric train lighting, under which condition it is hardly necessary to say that they receive a minimum of attendance with very few opportunities for the making of repairs. The confidence which the railroad companies place in these sets is evident from the fact that many of the more modern Pullman cars are equipped with electric fixtures only, no provision being made for gas light. Machines of this size and larger are also in general use as exciters for large alternators. Numerous cases are on record where such machines have run continuously for periods of three or four months or more without at any time shutting down.

In conclusion it may be said that the Curtis turbine has been built and placed in successful operation in sizes from 5 kw. to 14,000 kw., and at the present time even larger machines are under consideration.

THE EFFECT OF ROTARY CONDENSERS ON POWER-FACTOR

By John Liston

While the relation of power-factor to the size and efficiency of prime movers, generators and conductors has long been understood by the engineering fraternity, the practical application of the synchronous motor as a rotary condenser, to raise the power factor of systems having induction motor and transformer loads, has lagged far behind other improvements in the generation and transmission of energy.

The Cleveland Electric Illuminating Company was one of the first central stations to give a practical demonstration on an extended scale of the value of rotary condensers in raising the power factor of systems carrying a heavy inductive load. Their installations exemplify the use of unloaded synchronous motors simply "floated" on the system to supply leading current to the line and of partially loaded synchronous motors for the same purpose.

Before describing the installation of rotary condensers on this system, and the very satisfactory results which have been thereby obtained, it might be well to outline briefly the theory on which these installations are based.

Induction motors and other inductive apparatus take a component of current which lags behind the line pressure, and thereby lowers the power factor of the system, while a non-inductive load, such as incandescent lamps, takes only current in phase with the voltage and operates at 100 per cent. power factor.

As transformers require magnetizing current, they may seriously affect the power

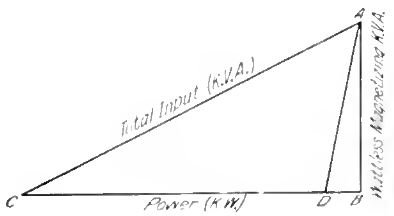


Fig. 1

factor when unloaded or partially loaded, but when operating at full loa. their effect is practically negligible.

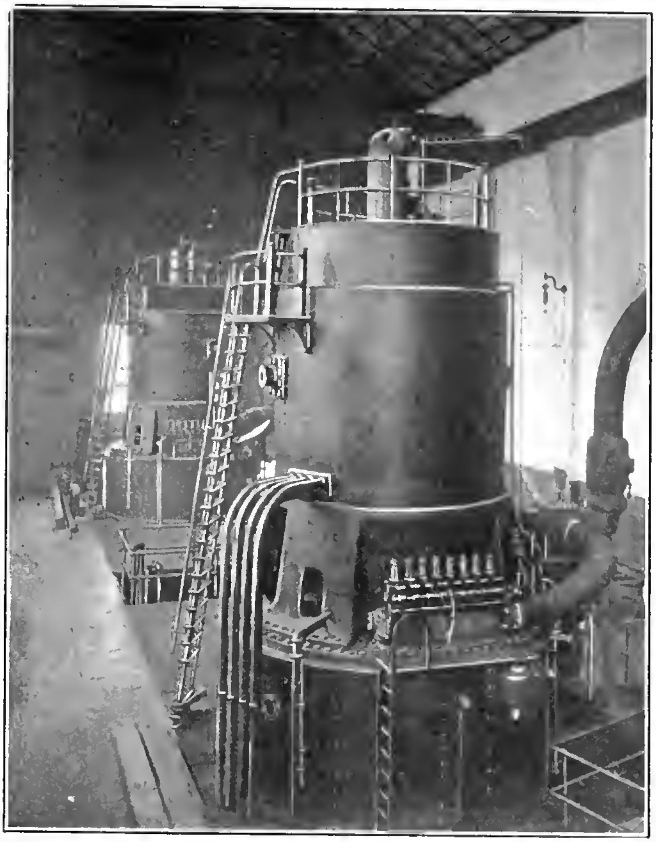


Fig. 2. Two 9000 Kw. General Electric Curtis Steam Turbine Generators in Generating Station, Cleveland Electric Illuminating Company

In order to maintain high power factor, induction motors should be run at their full rated load. Due to the complex industrial requirements of the average installation, most central stations have on their lines a group of induction motors operating at light loads, thereby lowering the power factor of the entire system. This feature of central station practice is sometimes rendered still more serious by the desire of a customer to have ample power for future extension or to take care of heavy temporary loads, so that motors of larger rating than that actually required for normal operation are frequently installed.

The relative effect of fully loaded and lightly loaded induction motors on power factor is indicated by the diagram Fig. 1.

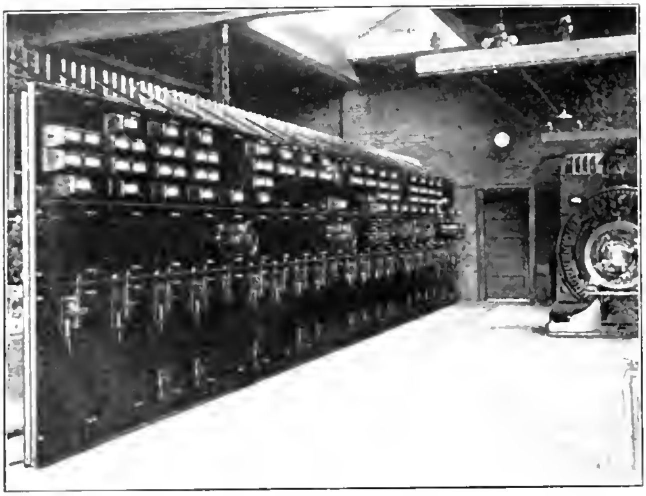


Fig. 3. 750 Kv-a. Rotary Condenser installed in a substation of the Cleveland Electric Illuminating Company

The magnetizing current is nearly constant at all loads and is wattless, lagging 90 deg. behind the impressed e.m.f., or at right angles to the current which is utilized for power.

In the figure, *AB* is the magnetizing component, which is always wattless, and *CB* the power component. The angle *ACB* gives the phase relation between voltage and current - the cosine of this angle $\frac{CB}{AC}$ is the power factor.

It is evident from the diagram that if the load is reduced, the side *CB* is shortened, and, as *AB* is practically constant, the angle of lag *ACB* is increased. It therefore follows that the cosine of this angle, or the power factor is reduced. The figure clearly shows the reason for the low power factor of induction motors on fractional loads and also shows that since the magnetizing current is practically constant in value, the induction motor can never operate at unity power factor. With no load the side *CB* (real power) is just sufficient to supply the friction and windage. If this is represented by *DB*, since *AB* remains constant, the power factor is reduced to 10 or 15 per cent. and the motor takes from the line about 30 per cent. of full load current. It therefore follows that a group of lightly loaded induction motors can take from the system a large current at exceedingly low power factor.

The synchronous motor when used as a rotary condenser has the property of altering the phase relation between e.m.f. and current, the direction and extent of the displacement being dependent on the field excitation of the condenser. It can be run at unity power factor and minimum current input, or it can be over-excited and thereby deliver leading current which compensates for the inductive load on other parts of the system. The rotary condenser, therefore, can supply magnetizing current to the load on a system while the power component is supplied by the generators.

In order to gain a comprehensive idea of the results obtained by the Cleveland Electric Illuminating Company, a brief description of the generating and transmission system is necessary.

Situated in the city of Cleveland, Ohio, which has an estimated population of 515,000, and extends, with

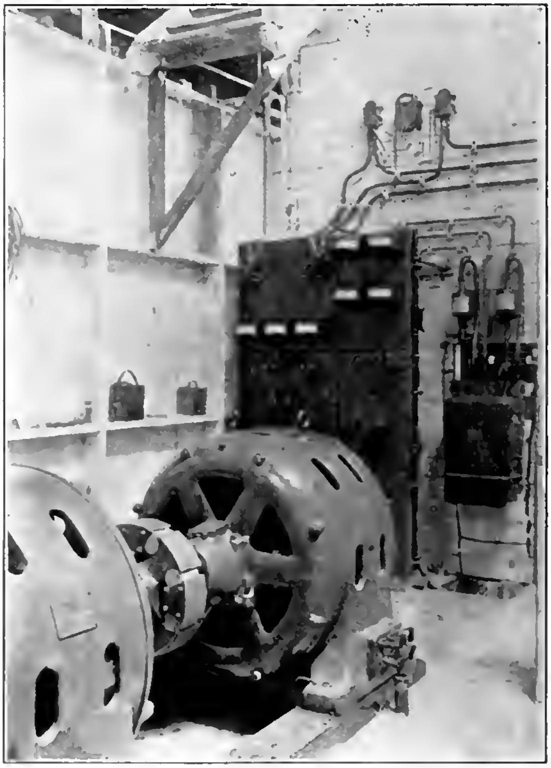


Fig. 4. 100 Kv-a., 2300/430 volt General Electric Synchronous Motor Generator Set in the Plant of the National Electric Lamp Association, Cleveland, Ohio

its suburbs, along Lake Erie for about 17 miles, the generating station, with its substations, serves a territory of approximately 50 square miles. The steam-driven generating station is located on Canal Street, near the business center of the city. The generating units now in service consist of two 9000 kw. and one 5000 kw. Curtis turbo-generator sets of General Electric manufacture, delivering energy at 11,000 volts, three-phase, 60 cycles. There are, in addition, some reciprocating engine-driven generators, delivering energy at 2300 volts, three-phase, 60 cycles. Transformers step-up the e.m.f. to 11,000 volts for the substations.

In addition to the alternating-current equipment there are three 1500 kw. motor generator sets and direct current reciprocating engine sets and a storage battery. The energy for that part of the city immediately surrounding the generating station is distributed on a direct current, three-wire Edison system. The balance is practically all alternating current, and is distributed to the substations at 11,000 volts, and re-distributed at 2300 volts, three-phase, 60 cycles.

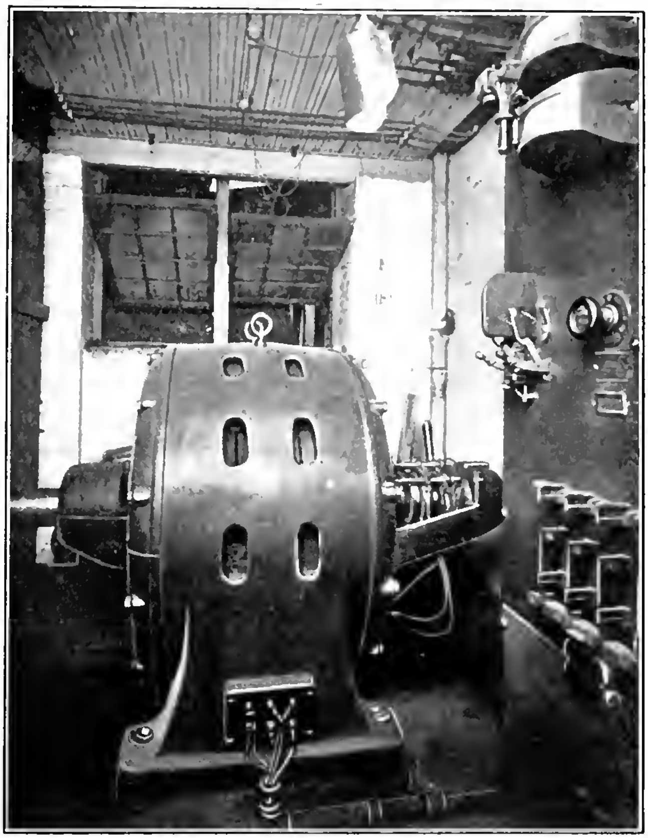


Fig. 5. 200 Kv-a. General Electric Rotary Condenser installed in factory of the National Acme Manufacturing Company, Cleveland, Ohio

There are six substations, five of them being straight transformer stations, and the sixth being provided with a motor-generator set and battery in addition to the transformer equipment; the total distance between the two end substations is about 15 miles. All of the 11,000-volt circuits are under ground, being placed in vitrified clay or fibre conduits, the latter form having been adopted as a standard for all new work. The distribution circuits from the substations at 2300 volts for motors and lamps are underground cables for a short distance from the stations, where they join to pole lines. The secondary lighting circuits are three-wire, single-phase, 115 volts to 230 volts, and motors up to 5 h.p. rating are operated from the lighting circuits. The general inductive distribution is at three-phase, 2300 volts, the e.m.f. being stepped-down to 460 volts and 230 volts at the customer's premises.

The motors are nearly all three-phase, but some two-phase motors are run from three-phase transformers by means of a T-connection. The ratio of alternating-current to direct-current load is about 2.5 to 1. The arc lighting load is nearly all carried by Brush arc generator sets.

It will be seen from the above that the operating conditions confronting the Cleveland Electric Illuminating Company are those which are ordinarily encountered by any central station located in a manufacturing city. The fact that more than 40 per cent. of the connected load consisted of induction motors, which were frequently loaded far below their rated output, had a very noticeable effect on the power factor of the system, this effect being augmented by the numerous transformers located in the substations and on the customer's premises. So serious was this that the power factor of the entire system before the rotary condensers were installed varied between 65 and 70 per cent. during the day, and at night, when the motor load was practically

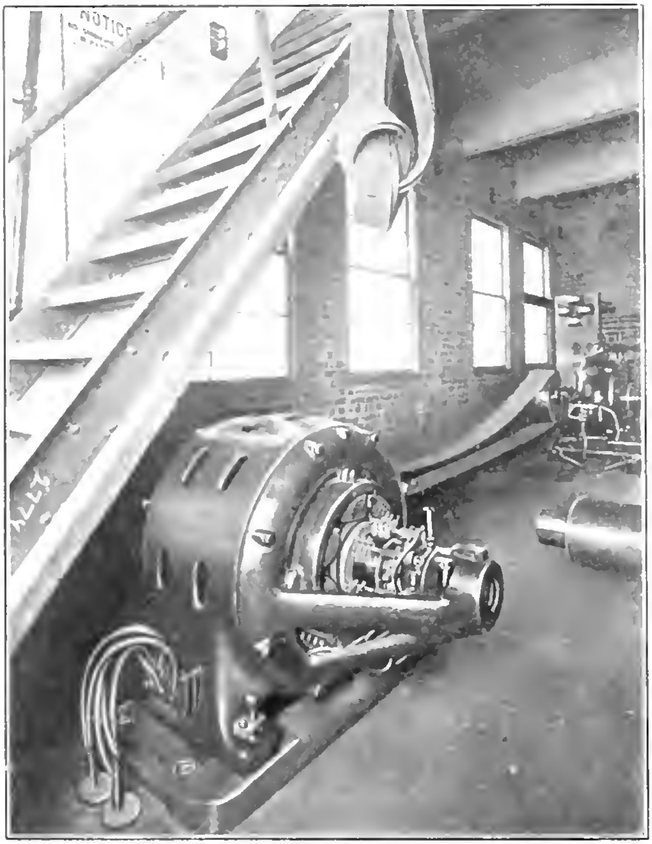


Fig. 6. 100 Kv-a. General Electric Synchronous Motor, Belt Connected to a D.C. Generator—The Ohio Ceramic Engineering Company, Cleveland, Ohio

discontinued and the lighting load substituted, it rose to between 85 and 90 per cent.

Realizing that these conditions affected both the permissible output and regulation of the entire system, it was determined to bring the power factor as close to unity as was economically possible by the installation of rotary condensers in those substations feeding induction motor installations, and also in the factories of large motor users.

Two 2300-volt rotary condensers of 750 kv-a. rating and provided with directly connected exciters were, therefore, installed in one substation, and a third unit of the same rating was provided for a second substation. In addition to these, four 200 kv-a. General Electric rotary condensers with directly connected exciters were connected to the low-tension side of the transformers on the customer's premises; the largest motor users on the various distribution lines being selected for the installation of these units. As auxiliaries to the rotary condensers, a number of synchronous motors partially loaded were installed, the kilowatt load delivered to the shaft varying from 50 to 75 per cent. of the kv-a. rating of the motor. These motors are used to drive alternating current or direct current generators for special purposes, and are the property of the customer, while the 200 kv-a. rotary condensers referred to above and installed on the customer's premises belong to the illuminating company.

The General Electric 200 kv-a. condenser has been adopted as standard for future installations in customers' plants, but will not be provided except where the power taken is in excess of 400 h.p. While this is not theoretically the best method, it was considered advisable to have a single standard condenser placed in service where conditions warranted its use, instead of working out in detail a large number of various condenser ratings.

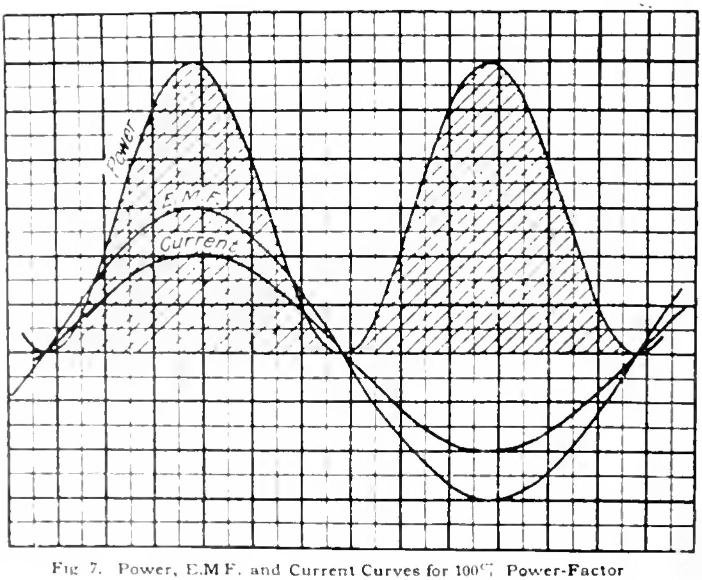


Fig. 7. Power, E.M.F. and Current Curves for 100% Power-Factor Current in phase with E.M.F.

The condensers thus installed are carefully inspected at frequent intervals by representives of the illuminating company, but are normally operated by the customers, who are glad to provide the necessary room in their plants, as they benefit from the improved regulation.

A typical installation of this nature is that in the plant of the National Acme Manufacturing Company, makers of milled screws and "Acme" screw machines (Fig. 5). The motors in this plant are 440 volt, two-phase, and have an aggregate rating of 1200 h.p. The average demand on the substation is approximately 500 to 600 kw., and prior to the installation of the 200 kv-a. condenser the power factor was about 75 per cent. on this line; at the present time it is 90 per cent.

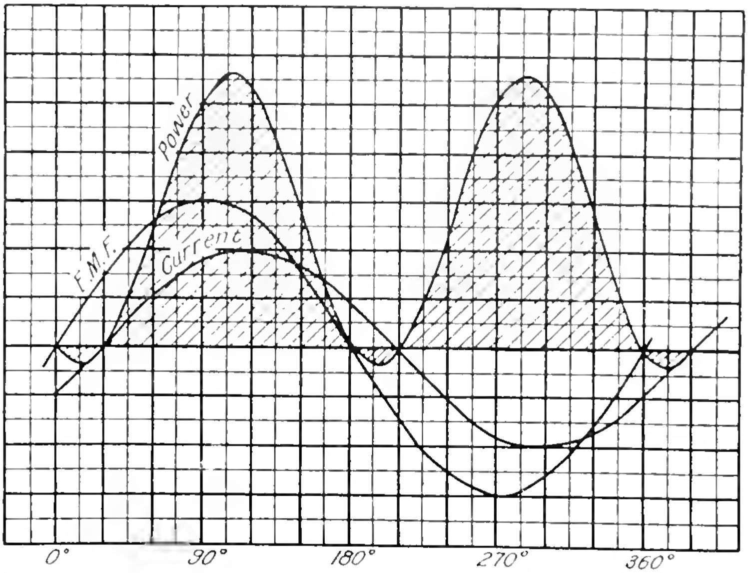


Fig. 8. Power, E.M.F. and Current Curves for 86.5% Power-Factor Current lags 30° behind E.M.F.

It will be noted that no rotary condenser has been located in the power house itself, the reason being that when a condenser is connected to the terminals of a generator it raises the power factor of the generator by supplying part, or all, of the wattless current of the load, but this wattless current has to be carried throughout the circuit external to the generator, and the condenser therefore will benefit only the generating equipment.

When the condenser is installed at the end of a line carrying an induction-motor load and provided with step-up and step-down transformers, the condenser can supply magnetizing current to the induction motors located near it, and, as a result, the generators, transformers and conductors can be of reduced size, as they do not carry the wattless current.

In order to obtain most economically the required condenser effect with synchronous motors installed in industrial plants these motors should be partially loaded so that a percentage of their operating cost can be charged to useful output. It has been found that a synchronous motor used in this way and rated at, say, 100 kw., will give the best results when delivering 71 kw. actual power and 71 wattless kv-a.

An example of a partially loaded synchronous motor is found in the plant of the National Lamp Association, which is equipped with a 100 kw., 2300 volt to 430 volt alternating current directly connected motor-generator set. (Fig. 4.)

At the works of the Ohio Ceramic Engineering Company a 100 kv-a. General Electric synchronous motor has been installed, belted to a generator which loads it to about 60 per cent. of its kv-a. rating, the balance being utilized for condenser effect; this motor operates directly from the 2300-volt, 60-cycle feeder. (Fig. 6.)

Perhaps the general effect of low power factor on the efficiency of a power system can be best illustrated by the current, volt and power curves shown in Figs. 7 and 8, which indicate clearly the relations existing between the impressed e.m.f. and current, at unity and 0.865 power factors. The product of volts and amperes at any instant gives the instantaneous value of the power. In the curves shown, the area enclosed by the power curve represents energy. It will be observed that when the power factor is unity the whole of the power curve lies above the axis and therefore all the power is available for mechanical work. With 0.865 power factor, corresponding to a lag to 30 deg. of current behind e.m.f., a small portion of the power curve lies below the axis and the total power available for work is represented by the difference between the areas enclosed by the power curve above the axis and below. This difference will equal the total area enclosed by the power curve multiplied by the power factor 0.865 equal to cos 30 deg. When the power factor is zero the current lags 90° behind the e.m.f., and the area enclosed by the power curve below the abscissa is exactly equal to the area above, from which it follows that in one complete cycle no energy is available. In this case the power factor is equal to cos 90 deg. which is zero.

If the current leads the e.m.f., similar results will follow, as any displacement of the current wave in respect to its e.m.f., whether leading or lagging, will introduce negative power loops which subtract from the area above the axis and reduce the power available. Maximum power is obtained when the power loops lie entirely above the line, as in the case of unity power factor shown in Fig. 7.

The prompt recognition of the Cleveland Electric Illuminating Company of the serious effect of its inductive load on the power factor of its system and the improved general efficiency which has been obtained by the use of rotary condensers should appeal to every practical central-station manager.

A graphic illustration of the value of rotary condensers was given recently when one of the feeder circuits on the Cleveland Electric Illuminating Company's system was put out of commission during a storm, due to a tree falling across the line. This feeder was equipped with one of the 200 kv-a. condensers already referred to, and while repairs were being made a feeder from a different sub-station which was at the time carrying a heavy load at low-power-factor, was joined to take on, temporarily, the additional load. It was found that the ammeter readings with this combined load were actually lower than they had been with a single load on the circuit not provided with a condenser. The kilowatt readings showed an increase of about 75 per cent. while the ampere readings dropped about 25 per cent.

The relative cost of condensers as compared with the investment losses in generators, conductors, etc., caused by low power factor, of course, depends on the percentage of the inductive load on a system; but the conditions which have to be met by the average central-station distribution system indicate that the heat losses, diminished effective output in generators and conductors, as well as the impaired regulation inherent in low power factor can be most economically overcome by the installation of rotary condensers.

TRANSMISSION LINE CALCULATIONS

Part V

By Milton W. Franklin

CAPACITY, REACTANCE, CHARGING CURRENT

In equation (21) part IV, the capacity of a single conductor of a transmission line was expressed as

$$C = \frac{7.354\,(10)^{-9}}{\log\left(\frac{d-r}{r}\right)} \tag{1}$$

C is the capacity per 1000 feet, in farads;
d is the interaxial distance of the conductors;
r is the radius of the conductors.

From (19) part IV the charge in a condenser of capacity C subjected to an impressed e.m.f. E is

$$Q = CE. \tag{2}$$

Current is defined by $i = \frac{dQ}{dt}$, whence the current flowing into a condenser at any instant, is

$$i = \frac{dQ}{dt} = \frac{CdE}{dt} \tag{3}$$

i is the instantaneous current.
e is the instantaneous e.m.f.

If the e.m.f. varies harmonically; *i.e.*, if $E = E_m \sin(\omega t)$; (3) becomes

$$i = \omega C E_m \cos(\omega t)$$

$$= \omega C E_m \sin\left(\frac{\pi}{2} - \omega t\right) \tag{4}$$

The effective value of i is the R.M.S. and is expressed by

$\left(\frac{1}{T}\int_o^T i^2\,dt\right)^{\frac{1}{2}}$, whence its value may be obtained from (4) as follows:

$$\left(\frac{1}{T}\int_o^T i^2\,dt\right)^{\frac{1}{2}} = \left(\frac{C^2E_m^2}{T}\int_o^T \cos^2(\omega t)\,\omega^2\,dt\right)^{\frac{1}{2}} \tag{5}$$

$$= C E_m \left(\frac{\omega}{T}\int_o^T \cos^2(\omega t)\,d(\omega t)\right)^{\frac{1}{2}}$$

$$= C E_m \left(2\pi f \left[\frac{\omega t}{2} + \frac{1}{4}\sin(2\omega t)\right]_o^T\right)^{\frac{1}{2}}$$

$$= C\,E_m\left(2\pi\ f^2\left[\frac{2\,\pi\,f}{2\,f} + \frac{1}{4}\,sin\left(\frac{2\,\pi\,f}{f}\right)\right]\right)^{\frac{1}{2}}$$

$$= C\,E_m\,(2\,\pi^2 f^2)^{\frac{1}{2}}$$

$$= C\,E_m\sqrt{2}\,\pi\,f$$

$$= C\,E_m\sqrt{\frac{\omega}{2}} \qquad (6)$$

for $2\,\pi\,f=\omega$

But

$$\frac{E_m}{\sqrt{2}} = E_{eff} \text{ whence}$$

$$I_{eff} = \omega\,C\,E_{eff} \qquad (7)$$

I_{eff} is called the charging current of the line and will flow into and out of the condenser even when the line is on open circuit. The current is wattless, but nevertheless represents an I^2R loss in the system.

In a transmission line of small length, the charging current is given with sufficient accuracy by supposing that a condenser of capacity equal to that of the line is affected by an impressed e.m.f. equal to that employed.

Tables VIII and XXII (August and November, 1909, issues of REVIEW, respectively) give the values of the charging current per 1000 volts impressed e.m.f., per 2000 feet of conductor (or 1000 feet line distance) and for a frequency of 100 cycles per second. Charging currents at other frequencies and for other lengths of line are proportional to the respective ratios of the lengths and frequencies in question to 1000 and to 100.

In a three-phase line the capacity is equal to that obtained by star connected condensers each of capacity equal to that of any single wire. The charging current per wire is thus seen to be equal (approximately) to $\frac{1}{\sqrt{3}}$ times the charging current for any pair of wires, of a single-phase line. Tables XIV and XXVIII (September and December, 1909, issues of REVIEW, respectively) give charging currents for three-phase lines. For any symmetrical arrangement of the wires, the values tabulated will not differ sensibly from the true values.

In long transmission lines, the simple calculation of charging current above used will be found to lead to error. This is due to the fact that the capacity of the line is not concentrated at a point and affected by the impressed harmonic e.m.f. but is distributed along the whole length of the line, and each infinitesimal length of line is affected by a different e.m.f. The e.m.f. is different at each point on the line because the impressed e.m.f. at the generating end of the line is lowered by the resistance and self-induction of the line up to the point at which it is impressed upon the infinitesimal condenser formed by any given infinitesimal length of line, and may also be raised by the capacity up to that point.

There is in addition to the above, a leakage or actual flow of current across the space between the line wires so that the current in the line at a point distant from the generating end is by no means equal to that at the generating end.

The general solution of the problem demands a consideration of the above mentioned conditions. The complete solution is somewhat complicated, involving imaginary as well as real roots in the resulting differential equations (Bedell & Crehore, Alternating Currents, page 177). By regarding the vector quantities I and E as complexes, the problem may be very greatly simplified.

The general problem consists in finding the e.m.f. and current at any point on the line, having given the e.m.f. and current at any other point: e.g., knowing the e.m.f. and current at the receiving end of the line, to calculate the e.m.f. and current at any point distant L from the receiving end.

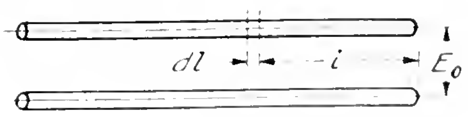


Fig. 12

Let L be the self induction in henries per unit length of line.

Let C be the capacity in farads per unit length of line.

Let R be the resistance in ohms per unit length of line.

Let g be the interlinear resistance in ohms per unit length of line.

Let E_0 be the e.m.f. at receiving end of line.

Let I_0 be the current at receiving end of line.

Let ω be $2\,\pi\,f$.

Considering the small section of the conductor whose distance from the receiving end is l and whose length is dl, the current and e.m.f. in said section are affected as follows:

The e.m.f. drop is

$$dE = IZ\cos\phi\,dl + IZ\,i\sin\phi\,dl$$
$$= IZ\,dl(\cos\phi + i\sin\phi)$$
$$\frac{dE}{dl} = IZ(\cos\phi + i\sin\phi)$$
$$= IZ\,e^{i\phi} \qquad (8)$$

where $Z = \sqrt{R^2 + (\omega L)^2}$

$$\phi = \tan^{-1}\left(\frac{\omega L}{R}\right)$$

The current flowing from line element dl across to the corresponding element of the return wire will be the current by leakage and the current across the small condenser formed by the line element dl, and is expressed by:

$$dI = EZ_1\,dl(\cos\phi_1 - i\sin\phi_1)$$
$$\frac{dI}{dl} = EZ_1(\cos\phi_1 - i\sin\phi_1)$$
$$= EZ_1\,e^{-i\phi_1}$$

where

$$Z_1 = \sqrt{\left(\frac{1}{\rho}\right)^2 + (\omega C)^2} \qquad (9)$$
$$\phi_1 = \tan^{-1}\left(\frac{\omega C}{\frac{1}{\rho}}\right)$$

$Ze^{i\phi}$ and $Z_1e^{-i\phi_1}$ are complexes of the standard form $re^{\pm i\phi}$ and in the present problem may be treated as ordinary algebraic constants.

$i = \sqrt{-1}$ and is a fictitious mathematical operator which, prefixed to a real quantity, indicates that the latter is to be added vectorially at an angle $\frac{\pm\pi}{2}$ according as the sign of i is + or −.

The typical complex quantity, $Z(\cos\phi + i\sin\phi)$, may be best understood from Fig. 13:

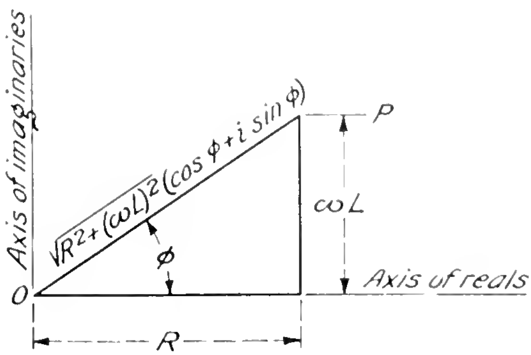


Fig. 13

$Z = \sqrt{R^2 + (\omega L)^2}$, is the modulus or numerical magnitude of the vector quantity $OP = Z(\cos\phi + i\sin\phi)$.

Putting $ZZ_1e^{i\phi}e^{-i\phi_1} = \lambda^2$

and $Ze^{i\phi}/Z_1e^{-i\phi_1} = \lambda_1^2$.

From (8)

$$\frac{d^2E}{dl^2} = \lambda\lambda_1\frac{dI}{dl}$$

and substituting from (9)

$$\frac{d^2E}{dl^2} = \lambda^2 E \qquad (10)$$

Similarly from (9) and (8),

$$\frac{d^2I}{dl^2} = \lambda^2 I \qquad (11)$$

(10) and (11) are linear differential equations of the second order and first degree and may be integrated as follows:

Taking (10)

$$\frac{d^2E}{dl^2} = \lambda^2 E$$

Multiplying by $2\frac{dE}{dl}dl$.

$$2\left(\frac{dE}{dl}\right)\left(\frac{d^2E}{dl^2}\right)dl = 2\lambda^2 E\,dE$$

integrating

$$\left(\frac{dE}{dl}\right)^2 = \lambda^2E^2 + C$$
$$= \lambda^2(E^2 + C_1^2)$$

as the constant C is purely arbitrary.

$$\frac{dE}{dl} = \lambda\sqrt{E^2 + C_1^2}$$
$$\frac{dE}{\sqrt{E^2 + C_1^2}} = \lambda\,dl$$

Integrating again

$$\log\left(E + \sqrt{E^2 + C_1^2}\right) = \lambda l + C_2$$
$$\log\left(C_1\left[\frac{E}{C_1} + \sqrt{\frac{E^2}{C_1^2} + 1}\right]\right) = \lambda l + C_2$$
$$= \log C_1 + \log\left(\frac{E}{C_1} + \sqrt{\frac{E^2}{C_1^2} + 1}\right) = \lambda l + C_2$$

and as C_1 = const. and C_2 is purely arbitrary, the last equation may be written,

$$\log\left(\frac{E}{C_1} + \sqrt{\left[\frac{E}{C_1}\right]^2 + 1}\right) = \lambda l + C_2 \qquad (12)$$

This expression may be simplified by use of the following relations.

$$sinh^2\,x + 1 = cosh^2\,x = (\tfrac{1}{2}[e^x + e^{-x}])^2 \qquad (a)$$

Put $y = sinh\,x = \frac{1}{2}(e^x - e^{-x})$ (b)

then $\sqrt{y^2+1} = \frac{1}{2}(e^x + e^{-x})$ (c)

Adding (b) and (c),

$$y + \sqrt{y^2+1} = e^x \qquad (d)$$

$$log\left(y + \sqrt{y^2+1}\right) = x = sinh^{-1}y \text{ (from [b])} \qquad (e)$$

from this development (12) may be written

$$sinh^{-1}\frac{E}{C_1} = \lambda\,l + C_2 \qquad (13)$$

$$\frac{E}{C_1} = sinh\,(\lambda\,l + C_2)$$

$$E = C_1\,sinh\,(\lambda\,l + C_2) \qquad (14)$$

but $sinh\,(\lambda l + C_2) =$

$$sinh\,\lambda\,l\,cosh\,C_2 + cosh\,\lambda l\,sinh\,C_2$$

and (14) may be written

$$E = \alpha\,cosh\,\lambda\,l + \beta\,sinh\,\lambda\,l \qquad (15)$$

Equation (11) is of precisely the same form as (10) and the solution will therefore differ from that of (10) only in the arbitrary constants of integration, α and β, thus

$$I = \alpha_1\,cosh\,\lambda\,l + \beta_1\,sinh\,\lambda\,l \qquad (16)$$

Of the four constants of integration, α, β, α_1, β_1, two may be expressed in terms of the others.

From (15)

$$\frac{dE}{dl} = \lambda(\alpha\,sinh\,\lambda\,l + \beta\,cosh\,\lambda\,l) \qquad (17)$$

From (8) and (16)

$$\frac{dE}{dl} = \lambda\lambda_1 I = \lambda\lambda_1\,(\alpha_1\,cosh\,\lambda\,l + \beta_1\,sinh\,\lambda\,l) \qquad (18)$$

equating (17) and (18)

$$\alpha\,sinh\,\lambda\,l + \beta\,cosh\,\lambda\,l = \lambda_1\alpha_1\,cosh\,\lambda\,l + \lambda_1\beta_1\,sinh\,\lambda l \qquad (19)$$

Equating coefficients

$$\beta_1 = \frac{\alpha}{\lambda_1}$$

$$\beta = \alpha_1\,\lambda_1 \qquad (20)$$

and (15) becomes

$$E = \alpha\,cosh\,\lambda\,l + \alpha_1\,\lambda_1\,sinh\,\lambda\,l \qquad (21)$$

Similarly (16) becomes

$$I = \alpha_1\,cosh\,\lambda\,l + \frac{\alpha}{\lambda_1}\,sinh\,\lambda\,l \qquad (22)$$

It remains to determine the values of the constants α and α_1. This may be accomplished as follows:

When $l = o$: *i.e.*, at the receiving end of the line, the e.m.f. and current become E_0 and I_0 respectively, and substituting these values in (21) and (22) gives:

$$E_0 = \alpha\,cosh\,o + \alpha_1\,\lambda_1\,sinh\,o$$

whence $\alpha = E_0$

Again

$$I_0 = \alpha_1\,cosh\,o + \frac{\alpha}{\lambda_1}\,sinh\,o$$

whence $\alpha_1 = I_0$ and (21) – (22) become respectively

$$E = E_0\,cosh\,\lambda\,l + I_0\,\lambda_1\,sinh\,\lambda\,l \qquad (23)$$

$$I = I_0\,cosh\,\lambda\,l + \frac{E_0}{\lambda_1}\,sinh\,\lambda\,l \qquad (24)$$

The quantity $\lambda\,l$ is an ordinary complex and the values of E and I as given in (23) – (24) may be found by evaluating $cosh\,\lambda\,l$ and $sinh\,\lambda\,l$ by the aid of any table of hyperbolic functions of a complex variable.

Various methods of calculating the charging current approximately are in use, the object in all of them being to lessen the labor involved in calculating exactly in any given case.

Ferrine & Baum have shown that in lines of moderate length the error obtained in assuming the total line capacity, as concentrated at the center, is small.

Greater accuracy is secured by assuming one-half the capacity shunted across each end of the line.

Still greater accuracy is obtained by dividing the line capacity into six equal parts and assuming that one part is shunted across each end of the line and four parts across the center. This is in accord with Simpson's Rule of approximation and gives an accuracy rarely exceeded in other calculations relating to the same line.

A still greater accuracy and one rarely justifying the additional labor involved may be obtained by dividing the line capacity into ten equal parts and spacing them equally along the line.

(To be Continued.)

COMMERCIAL ELECTRICAL TESTING

Part IV

By E. F. Collins

Superintendent of Testing

Regulation Test—Speed Voltage

Shunt regulation should be taken on shunt generators. A reading should first be taken at no-load normal voltage; then, without

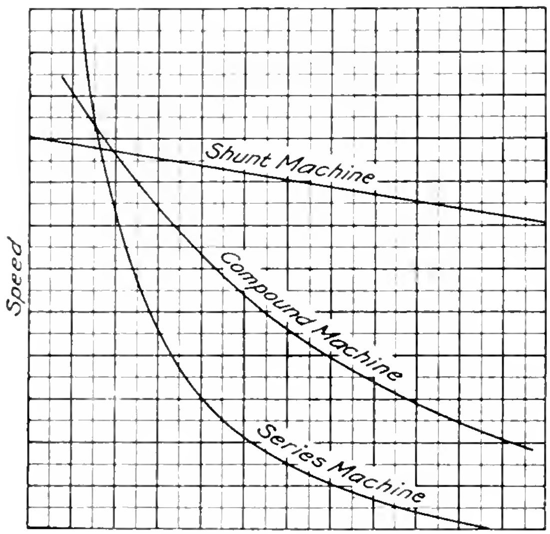


Fig. 17. Speed Curves D.C. Motors

changing the rheostat, ¼ full load should be thrown on and a reading taken of amperes armature, volts armature, amperes field and volts field. Holding ¼ full load, the voltage should be brought up to normal and the same readings taken. The load should then be increased to ½ full load, the rheostat remaining in the same position as before, and similar readings taken. This test is repeated for ¾ and full load. With full load on the machine the voltage should be brought up to normal. Without altering the position of the field rheostat, the load is then taken off the machine and the rise in voltage observed. A curve should be plotted with amperes armature as abscissæ and volts as ordinates.

If the voltage should drop to zero when ¼ load is put on the machine, the load should be applied in smaller increments. Speed should be kept constant throughout the test.

Speed regulation is important in the operation of motors, particularly in the case of direct current machines. The speed on all motors should be adjusted while the machine is hot, by shifting the brushes, but should never be corrected at the sacrifice of commutation. It should always be adjusted for full load unless instructions specifically state otherwise.

If special tests are required for a motor, a hot speed curve should be included. Starting with no load and increasing to full load, the speed should be carefully read at several intermediate points, the voltage being held constant at all loads. A curve is then plotted with speed as ordinates and amperes as abscissæ. No load and full load points of the cold speed curve should also be taken. Fig. 17 shows the general shape of the curve. Some motors with considerable armature reaction give a speed curve which rises as the load increases.

When speeding up motors with increasing load, the brushes must never be shifted far enough to produce sufficient armature reaction to weaken the field. Careless shifting of brushes under load has sometimes caused runaways; hence care should be exercised when attempting this operation.

A test of the voltage regulation of alternating current generators is sometimes made, but more frequently the regulation is calculated from the saturation and synchronous impedance curves. The method of making this calculation is more fully treated under the subject of alternating current generators. In making this test the machine is subjected to normal load at normal voltage. Holding the same field excitation, the load is suddenly thrown off and the armature voltage observed. The difference between this and normal voltage, divided by normal voltage, is the per cent. voltage regulation.

When a compound wound generator is compounded hot, a compounding curve should be taken after the german silver shunt is properly adjusted. Starting with no-load voltage, readings of volts armature, amperes armature, volts field and amperes field should be taken at ¼, ½, ¾ and full load. The load should then be reduced to zero by the same increments, and the same readings taken. A curve should be plotted with amperes line as abscissæ and volts as ordinates. The variation of this curve from a straight line will not usually exceed 5 per cent.

Input-Output Tests

It is sometimes required to measure the efficiency of a machine or set by the input-output method. The measurement of the power input to the motor and output from the generator is then required. The efficiency of the set $= \dfrac{\text{Total output of generator}}{\text{Total input to motor}}$

The efficiency of the generator =

$$\frac{\text{Total output of generator}}{(\text{Input to motor}) - (\text{motor losses})}$$

The efficiency of the motor =

$$\frac{(\text{Output of generator}) + (\text{generator losses})}{\text{Input to motor}}$$

In the case of induction motors, input-output test is sometimes taken by the string brake method, which will be discussed more fully under the heading of induction motors.

The input-output method of measuring efficiency is subject to considerable inaccuracy. It is not recommended and should not be used except under special conditions. It is much more preferable to ascertain the losses directly when reliable results are desired. By adding all the losses to the output at any load, the input for that load may be obtained, which, divided into the output, gives the per cent. efficiency.

The resulting errors from the input-output method are likely to be large, since any inaccuracy in meters or readings influences the results directly. In loss measurement tests, the same per cent. error in meters or meter readings influences the results of the efficiency calculations indirectly. Consequently the latter method is superior for accurate determinations.

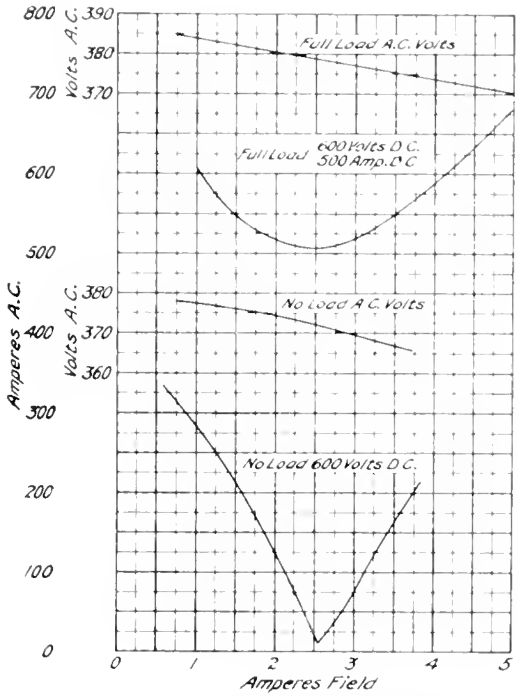


Fig. 18. No Load and Full Load Phase Characteristic on a 300 Kw., 600 Volt, 750 R.P.M., 25 Cycle, 3-Phase Rotary Converter

TABLE VI

Phase Characteristic on a 300 Kw., 600 V., 750 R.P.M., 25 Cycle, 3-Phase Rotary Converter

No Load					Full Load 500 Amps. D.C.				
Volts D.C.	Volts A.C.	Amps A.C.	Amps Field	Volts Field	Volts D.C.	Volts A.C.	Amps A.C.	Amps Field	Volts Field
600	378	315	.75	91	600	384	601	1.05	125
600	377	255	1.25	150	600	383.5	570	1.25	150
600	376	210	1.50	180	600	381	543	1.50	180
600	375	156	1.75	210	600	380	520	2.00	240
600	374	120	2.00	240	600	379	512	2.25	270
600	373	85	2.20	265	600	378	507	2.50	300
600	373	65	2.30	275	600	378	505	2.65	320
600	372	41	2.40	290	600	378	510	2.75	330
600	371	23	2.50	300	600	376	525	3.00	360
600	370	14	2.55	305	600	375	547	3.50	420
600	370	17	2.60	315	600	371	585	4.00	485
600	369	21	2.65	320	600	373	627	4.50	540
600	369	35	2.75	332	600	370	685	5.00	600
600	369	75	3.00	360					
600	368	116	3.25	395					
600	367	170	3.50	420					
600	366	205	3.75	450					

Phase Characteristic

In taking phase characteristic curves to determine the field current for minimum input at a given load on either synchronous motors or rotary converters, the machine must be operated as a motor from some source of alternating current, of correct frequency and nearly constant voltage. A reading of amperes input on all phases should be taken with zero field on the motor, when this is possible. Starting with a weak field, volts and amperes armature and volts and amperes field should be read, and the field increased by small steps until the point of minimum input armature current is found. Increasing the field current beyond this point increases the amperes armature. On a no-load phase characteristic curve, the watts input at the lowest point should check very closely with the sum of the core loss, friction and windage losses, since the power factor is unity on synchronous motors at this point. With a weak field the current is lagging and with a strong field it is leading. In taking a no-load phase characteristic the current should rise to a value of at least 50 per cent. of full load current.

A load phase characteristic should be taken, in a manner similar to that employed in obtaining the no-load characteristic. The input is held constant and the amperes load recorded in addition to the readings specified above. It is impossible to obtain a zero field point on the full load characteristic, since the current would be so large as to dangerously heat the machine and the torque not sufficient to carry full load.

All readings should be corrected for instrument factors and shunt ratios, and a curve plotted between amperes field as abscissae and amperes armature as ordinates. See Table VI and Fig. 18.

Synchronous and Static Impedance

Synchronous impedance should be taken on alternating current machines to determine the field current necessary to produce a given armature current when the machine is running short circuited. Since the regulation of the machine is calculated from the impedance and saturation curves, care should be taken that consistent results are obtained.

The armature should first be short circuited; then, with the machine running at normal speed and a weak field current, the current in each phase should be read. The field current should be increased gradually until 200 per cent. normal armature current is reached, readings being taken simultaneously of amperes armature and field, and volts field.

Although the speed in this test should be held normal, a small variation therefrom will not affect the curve, because in the formula,

$$\text{current} = \frac{\text{e.m.f.}}{\text{impedance}} = \frac{E}{\sqrt{R^2 + L^2W^2}}$$

the term R^2 is small compared with L^2W^2, and as E and W vary proportionally to the speed, the current remains practically constant.

On some of the standard machines, a stationary impedance is taken in addition to the synchronous impedance. First block the armature or field, in the case of a revolving field machine, then connect the armature leads to an alternator giving the same frequency as that of the machine being tested. Starting with about 50 per cent. normal current, the current in the armature of the machine tested is increased by steps to about 150 per cent. normal, readings of volts and amperes armature being recorded.

This method should be followed in taking stationary impedance on induction motors, except that it is only necessary to take one reading at normal current. A special stationary impedance test is sometimes taken on induction motors; this is treated under the heading of induction motors.

In the calculation of synchronous impedance all readings should be corrected for the constants of instruments and ratios, and a curve plotted on the same sheet as the saturation curve, amperes or ampere turns field being plotted as abscissae and amperes armature as ordinates. See Table VII and Fig. 19.

Wave Form Potential Curve Between Brushes

In determining the wave form of a direct current machine the following method should be used: The machine should be run at normal speed and voltage and a pair of voltmeter leads, separated a distance equal to the width of one commutator bar, placed on the commutator under the center of one pole and moved from bar to bar to the center of the next pole of like polarity, the voltage at each step being read. In this way the voltage between bars is obtained for a complete cycle of 360 electrical degrees.

The readings should be corrected for meter constants and plotted as ordinates against the number of bars as abscissae, and a sketch showing the position of the poles should be made on the same sheet with the curve obtained.

Wave form on alternators is obtained by the use of the oscillograph, which is described under the heading of electrical instruments.

D.C. GENERATORS

Preliminary Tests

Preliminary tests on direct current generators consist in drop on spool, polarity, hot and cold resistance measurements, air gap, potential curve, rheostat data, brush shift, running light and equalizing ring tests. With the exception of potential curve, rheostat data and equalizing ring, the tests have all been previously described.

On all multiple wound armatures of self-contained machines not equipped with equalizing rings, a potential curve must be taken. All the brushes except those on two adjacent studs are raised from the commutator, the voltage is raised to normal and the field current noted. This field current and the speed must be held constant for all other points on the curve. The brushes on stud No. 3 should now be lowered, those on No. 1 raised and the voltage read between studs No. 2 and No. 3. This procedure should be continued until voltage readings have been

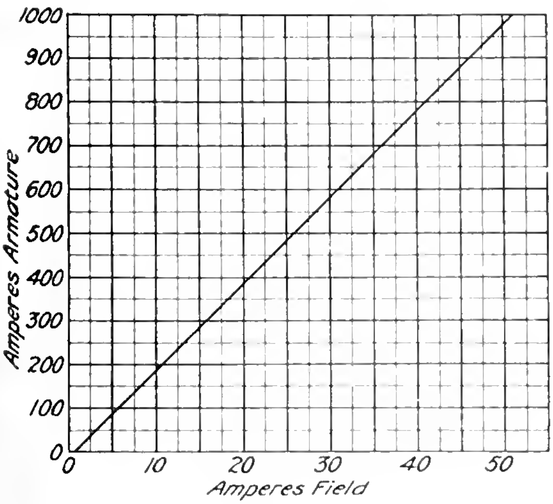


Fig. 19. Synchronous Impedance Curve on a 500 Kw., 600 Volt, 360 R.P.M., 60 Cycle, 3-Phase, A.C. Generator

taken between every pair of studs. The test should be made with the field current rising. The maximum voltage variation permissible is 4 per cent. of the average value. This test, although similar in nature, should not be confused with the bar to bar potential curve taken to determine the wave form of a direct current machine.

TABLE VII

Synchronous Impedance on a 500 Kw., 600 V., 20-Pole, 60 Cycle, 3-Phase Generator

Amps Arm	Volts Field	Amps Field	Speed R P M
224	15.0	11.9	360
260	17.8	13.7	360
300	20.6	15.8	360
352	23.8	18.3	360
398	26.9	20.7	360
474	31.5	24.5	360
480 480 480	32.2	24.8	360
518	34.8	26.7	360
557	37.5	28.2	360
704	47.0	36.1	360
796	52.8	40.6	360
896	59.5	45.7	360
1000	66.5	51.1	360

Equalizers consist of rings or cross connections tapping into equi-potential points on the winding of multiple wound armatures between each pair of poles. These rings prevent inequalities in voltage between brushes of similar potential, due to inaccurate centering of the armature. The rings allow alternating currents to flow from the stronger toward the weaker pole pieces, which slightly demagnetize the former and magnetize the latter, thus equalizing the voltage at the brushes. Not only do the rings prevent an interchange of heavy cross currents between brushes, but they also compensate for inequalities in magnetic pull at the pole pieces, tending to bend the shaft or overheat the bearings. The tester should examine these rings to see that the taps are equally spaced and all connections tight.

If a machine has been correctly connected, and there are no open circuits or reversed spools in the field, the machine should build up when the field switch is closed and all resistance cut out of the field. If it does not, the resistance of the field should be checked with that of a similar machine of the same size and voltage, as a 500 volt machine may sometimes be assembled with a 250 volt field.

When difficulty is had in building up the voltage of a machine, it will usually be found that the current does not flow through the field in the right direction to build up the residual magnetism. If, with the field switch open, the residual flux gives a few volts on the armature and upon closing the switch the voltage drops to nearly zero, the field terminals are connected to the wrong brushes. To remedy, either reverse the field or shift the brushes over one pole.

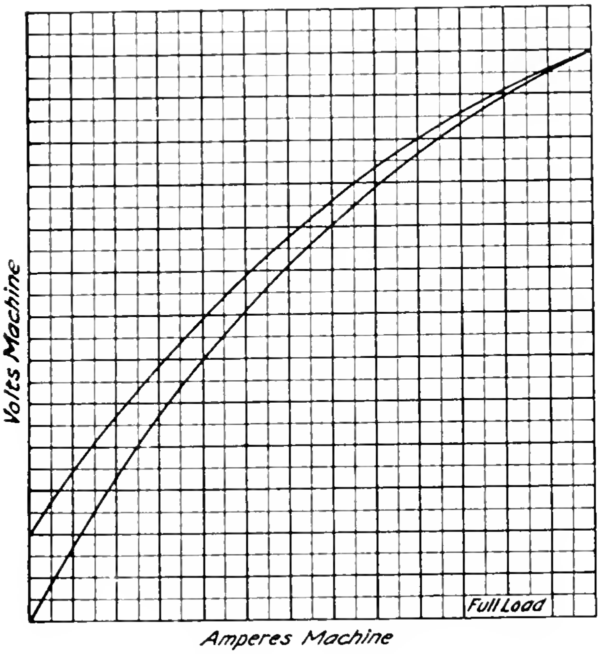


Fig. 20. Series Characteristic

In locating the no-load electrical neutral on commutating pole machines, the fibre brush method is used. A fibre brush, provided with two contacts and terminals separated from one another by a distance equal to the thickness of one bar, is placed in a brush-holder on one stud. The brush is then shifted until zero voltage is read between the two terminals. The position of the rocker arm is marked at this point. The fibre brush is then placed on the next stud and the brushes shifted again until zero voltage is obtained, this position of the rocker arm being also marked. This operation is repeated for each of the studs, the rocker arm being finally set on the mean of the positions previously marked. This setting locates the electrical neutral at no load, which should have the same position at full load.

The shunt in the commutating pole field is then adjusted to give the best commutation at full load, the amount of current shunted through the commutating pole field being measured. The amount of this shunted current should always be recorded.

The open circuit tests, already described, are sometimes taken on commutating pole generators.

The building up of a series generator is a more complicated operation. The load increases with the voltage and, therefore, great care should be taken in obtaining the correct external resistance to prevent the load from increasing rapidly. As it is practically impossible to decrease the external resistance enough (*i.e.*, put the blade of the water box in far enough) to allow the generator to pick up, the usual method is to put the water box blades in and short circuit one of the boxes with a fuse wire and then close the circuit breaker and switches. If the machine then starts to pick up, and the voltage decreases as soon as the fuse wire burns away, there is too much resistance in the water boxes. They should therefore be salted (to decrease the resistance) and the operation repeated. Should the resistance in the boxes be too small the load will increase very rapidly and the breakers may have to be opened to prevent the machine arcing over between brushes.

After the brushes are set the german silver shunt should be adjusted to give the required voltage.

A series characteristic is taken on all series wound generators. This is done by increasing the load by small steps until full load is obtained, amperes line and volts machine being recorded at each step. The load is then reduced by small steps to no load, the same readings being taken. A curve is then plotted between amperes as abscissae and volts machine as ordinates (Fig. 20.)

In the case of series machines which form part of booster sets, the guarantee sometimes does not allow this curve to deviate by more than a certain percentage from a straight line. The curve should be taken in all cases with the german silver shunt in place, if the latter is necessary.

Some direct current generators are provided with collector rings for three-wire operation. If there are two series fields, one should be connected in each side of the line. All other tests are made as on any direct current generator. If unbalanced readings are required the compensator should be wired according to diagram. (Fig. 21.)

A reading should be taken at no load, normal voltage. With no change in the field, and holding constant speed, ¼ load should be thrown on one side of the line and the voltage read from the neutral to each side of the line; volts and amperes line, volts and amperes field should also be read. One-quarter load is then put on the other side of the line, giving a balanced load, readings being taken as before. The load is then increased to ½ load on one side, this procedure being continued until 125 per cent. balanced load is obtained, readings being taken at each step. Instructions sometimes call for 50 per cent. unbalancing, in which case the load is increased 50 per cent. at each step instead of 25 per cent.

Standard Efficiency Test

The method of calculating efficiency by the method of losses is as follows:

Consider a compound commutating pole generator.

Let V_L = Volts line.

C_L = Amperes line = $C_8 + C_9 = C_{10} + C_{11}$

C_6 = Amperes, shunt field

C_4 = Amperes, armature = $C_L + C_6$

C_8 = Amperes, series field = $C_L \frac{R_9}{(R_8 + R_9)}$

C_9 = Amperes, german silver shunt = $C_L - C_8$

C_{10} = Amperes, commutating pole field = $C_L \frac{R_{11}}{(R_9 + R_{10})}$

C_{11} = Amperes, commutating pole german silver shunt = $C_L - C_{10}$

R_5 = Brush contact resistance

R_6 = Hot resistance of shunt field

R_4 = Hot resistance of armature

R_8 = Hot resistance of series field

R_9 = Hot resistance of series field german silver shunt

R_{10} = Hot resistance of commutating pole field

R_{11} = Hot resistance of commutating pole field german silver shunt

Then total CR drop = $C_4R_4 + C_4R_6 + C_8R_8 + C_9R_9 + C_{10}R_{10} + C_{11}R_{11}$

W_1 = Core loss watts, taken from the core loss curve corresponding to $V_L + CR$ for each load

W_2 = Watts brush friction from core loss test.

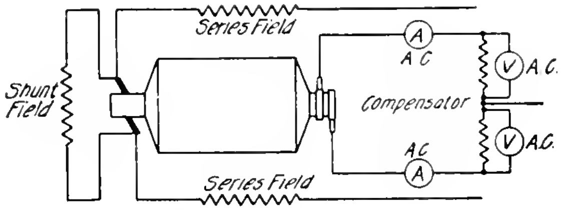


Fig. 21. Three-Wire Generator

If the value taken from test appears inconsistent, calculate W_2 by the formula:

$$W_2 = \frac{F \times N \times B \times L \times \mu \times 746}{33000} \text{ where}$$

F = Circumference of commutator in feet

N = R.p.m.

B = Number of brushes

L = Lbs. pressure per brush

μ = Coefficient of brush friction for the particular type of brush used.

In the case of engine-driven machines or those which are furnished without base, shaft or bearings, the bearing friction is omitted from the total losses, and is charged against the prime mover.

In nearly every case it is preferable to use the calculated brush friction instead of that obtained from test. During a short test, the commutator and brush contact surfaces cannot get into such good condition as that which obtains after a long period of commercial operation. Consequently, the brush friction test does not represent the conditions that will exist after the machine has been in operation for some time. The coefficient of friction determines the value of brush friction, which in turn is determined by the condition of the commutator and brush contact surface. This coefficient varies considerably at first and only reaches a constant value after a considerable period of operation. The coefficient used in the above formula for the calculation of brush friction has been obtained by means of exhaustive tests on brushes of different types with various pressures and commutators. These tests extended over a long period to obtain constant and satis-

TABLE VIII

Efficiency and Losses of a 100 Kw., 525 575 V., Comp. Wound, 6-Pole, 275 R.P.M., D.C. Generator

% Load	0	25	50	75	100	125	150
Volts Line	525	537.5	550	562.5	575	575	
Amps. Line	0	43.5	87.0	130.5	174 ·	217.5	
Amps. Shunt Field	3.10	3.18	3.25	3.32	3.40	3.4	
Amps. Armature	3 1	46.7	90.3	133.8	177.4	220.9	
Amps. Series Field	0	29.2	58 4	87.6	116.8	146	
Amps. Series G.S.S	0	14 3	28.6	42 9	57.2	71.5	
CR Drop	.417	.628	12.15	18.0	23.9	29.7	
E+CR	525.4	543.8	562.2	580.5	598.9	604.7	
Core Loss	1042	1121	1205	1295	1395	1425	
Brush Friction	314	314	314	314	314	314	
Bearing Friction	—	—	—	—	—	—	—
C^2R Armature	—	213	797	1750	3080	4770	
C^2R Brushes	—	36	135	222	331	430	
C^2R Shunt Field / C^2R Rheostat	1630	1710	1790	1870	1950	1950	
C^2R Series Field	0	33	131	296	523	820	
C^2R G.S.S	0	16	64	144	257	403	
Total Losses	2986	3.446	4436	5891	7850	10112	
Kw. Output	0	23.4	47.8	73.4	100	125	
Kw. Input	2.99	26.85	52.24	79.29	107.85	135.1	
% Efficiency	—	87.2	91.5	92.6	92.7	92.6	
Brush Density		8.3	16.05	23.8	31.6	39.3	
Brush Contact Res.		.01665	.0144	.91244	.01055	.0091	

Resistance of Armature 25° C. .0893 Ohms, Warm .098 at 51° C.
Resistance of Shunt Field 25° C. 97.4 Ohms, Warm 105.3 Ohms at 47° C.
Resistance of Series Field 25° C. 0358 Ohms, Warm 0386 Ohms at 46° C.
Resistance of Series G S.S .079 Ohms.
Dimensions of Brushes 1¼″×¾″. No. of Studs 6. No per Stud 4. Coeff. of Friction = .2.
Brush Contact Area, One Side 5.625 Sq In. Brush Pressure 1¼ Lbs. per Brush.

TABLE IX

Efficiency and Losses of a 70 H.P., 500 V., 6-Pole, 850 R.P.M., D.C. Motor

Volts Line	500	500	500	500	500
Amperes Line	29	58	87	116	145
Amperes Field	2.43	2.43	2.43	2.43	2.43
Amperes Arm	26.5	55.5	84.5	113.5	142.5
CR	3	6	9	12	15
E CR	497	494	491	488	485
Speed					
Core Loss	2500	2475	2450	2400	2350
Brush Friction	460	460	460	460	460
Bearing Friction	530	530	530	530	530
C^2R Armature	63	275	638	1150	1820
C^2R Brush	8	36	85	153	240
CE Field	1215	1215	1215	1215	1215
Total Losses	4775	4990	5380	5908	6615
Kw. Input	14.5	29	43 5	58	72.5
Kw. Output	9 7	24	38.1	52.1	65.9
H.P. Output	12 8	32.1	51	70	88.5
% Efficiency	67 0	82.8	87.6	89.8	90.8
Brush Density	5.15	10.3	15 5	20.6	25.8
Brush Contact Resis	.0178	.016	.0146	.0132	.0119

Resistance of Armature 25° C .0846 Ohms, Warm 0895 Ohms at 50° C.
Resistance of Field 25° C 169 Ohms, Warm 191.5 Ohms at 60° C
Dimensions of Brushes 1¼″ × ½″. No. of Studs 6 No. per Stud 3. 1½ lbs. per Brush.
Brush Contact Area, One Side 5.62 Sq In

factory conditions for both brush and commutator surface. The resulting values of brush friction can, therefore, be relied on to give accurate and final results.

W_3 = Bearing friction from core loss test
Wb = Watts output = $C_L \times V_L$

The brush contact resistance, R_5, is that taken from a curve made for different types of brushes, and corresponds to the brush current density per square inch at any given load.

Brush current density per square inch =

$$\frac{C_1}{\frac{1}{2}\text{ total brush area}}$$

One-half the total brush area = $\frac{l \times w \times s \times t}{2}$

where l = Length of brush parallel to the shaft
w = Width of brush
s = Number of studs
t = Number of brushes per stud.

For reasons similar to those just given, extensive tests have been made to determine the contact resistance of different types of brushes, from which curves have been plotted with brush current densities as abscissae and either brush contact resistance per square inch or CR drop in brush contact as ordinates. In order to measure the contact resistance directly the commutator would have to be short circuited and the voltage drop measured from the commutator to the surface of each brush. This would be a long operation entailing considerable expense. The results also could not be reliable owing to the newness of commutator and brushes. It is therefore preferable to use the brush contact resistance obtained from the curves mentioned.

If W_3 = bearing friction from core loss test, then total loss in watts $= \Sigma W = W_1 + W_2 + W_3 + C_4{}^2R_4 + C^2{}_4Rs_5 + C_6{}^2R_6 + (C_8V_L - C_6{}^2R_6) + C^2{}_8R_8 = C_9{}^2R_9 + C_{10}{}^2R_{10} + C_{11}{}^2R_{11}$

The quantity $C_8V_L - C_8{}^2R_6 = C^2R$ loss in the shunt field rheostats.

The watts input W_a will then be

$W_a = W_b + \Sigma W$, where W_b = watts output $= C_LV_L$

The efficiency $E = \frac{W_b}{W_a}$

In case a core loss test is not made, the running light is substituted in the formula for the quantity $(W_1 + W_2 + W_3)$. If the segregation of the losses in the series and commutating pole fields and their respective german silver shunts is not required, the resistances R_8 and R_9 may be combined to equal Rs_F, likewise R_{10} and R_{11} to equal Rc_F.

The total losses will then be

$$\Sigma W = \text{Running light} + C_1{}^2R_1 + C_1{}^2R_5 + C_6V_L + C_L{}^2Rs_F + C_L{}^2Rc_F.$$

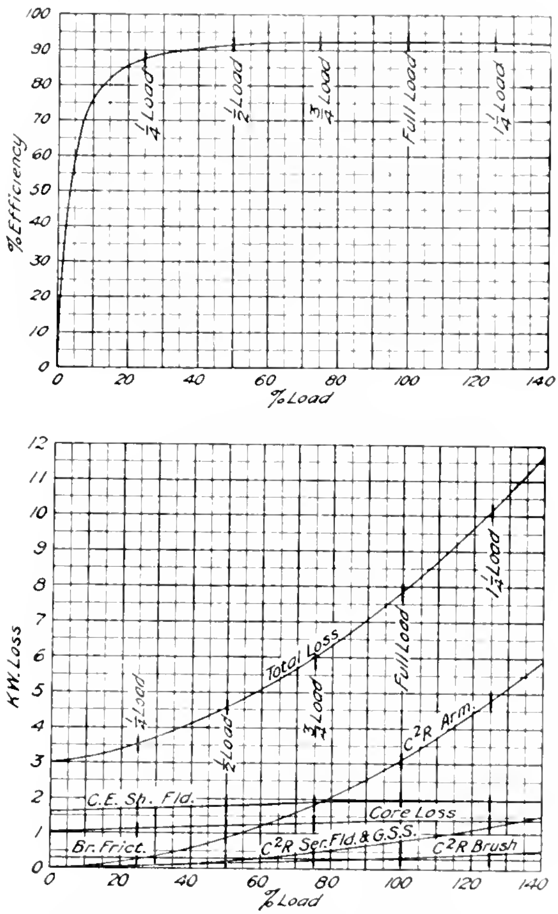


Fig. 22. Efficiency and Losses on a 100 Kw., 6 Pole, 275 R.P.M 5:5 575 Volts, Compound Wound D.C. Generator

To calculate resistances hot when calculating efficiencies, the temperature should be obtained from the formula:

$$T = (K \times \text{rise by thermometer}) + 25° \text{ C.}$$

K is the ratio between the rise in temperature by thermometer and that determined by resistance measurement. Resistance measurements of temperature have been determined by actual tests on a large number of different armatures and fields. For all armatures, or field spools of revolving field machines, $K = 1.25$. For stationary ventilated field spools $K = 1.7$. See Tables VIII and IX, and Fig. 22 for form used in calculating and plotting efficiency.

A FINANCIAL STATEMENT OF THE CAUVERY HYDRO-ELECTRIC DEVELOPMENT

In the January issue of the REVIEW, we printed a description of the Cauvery Hydro-electric development in India the first enterprise of the kind of any importance to be undertaken in that country, and as such, it testifies to the force of character and progressiveness of His Majesty, The Maharajah, and his able administrators.

Dewan L. Ananda Dao

Since the publication of this article, additional information has been received which adds materially to the interest of the subject. As stated in the former article, the development was undertaken for the purpose of supplying current to the Kolar gold mines, the London agents of which are Messrs. John Taylor & Sons, to whose foresight and co-operation the enterprise largely owes its success.

Current is also transmitted to the cities of Bangalore and Mysore, for lighting, etc.

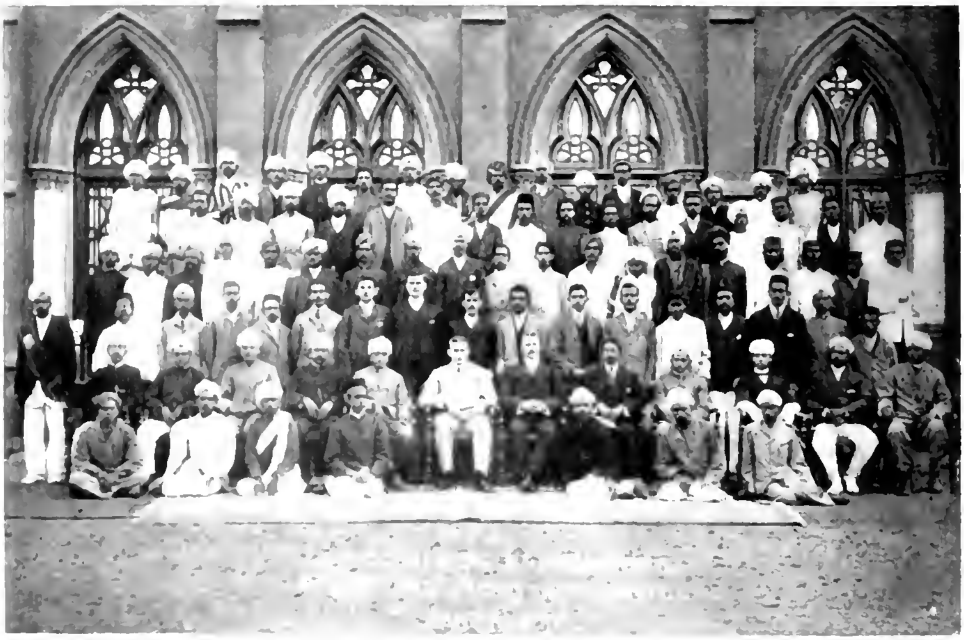
The original development generated 6000 h.p.; to this was added two extensions of 5000 and 2000 h.p. respectively, making in all 13,000 h.p. By the original arrangement, the mining companies agreed to pay for power a flat rate based on the normal full load consumption of the motors, the agreement covering a period of ten years, and the amount per horse-power varying according to the following sliding scale:

1st year	£29 per h.p. yr.
2nd, 3rd and 4th years	£18 per h.p. yr.
5th year up to	£24 per h.p. yr.
5 years following	£10 per h.p. yr.

John Taylor, Head of the Firm of John Taylor & Sons, London

During the first year the actual payment for the power was £18 as in the 3 years following, the £11 being added for the purpose of reimbursing the Government for the cost of the distribution plant. When the second installation was made, the mines installed their own distribution plant and paid £18 per h.p. year for power; with the third installation, the rate became £10.

The total capital expended by the Government in the development has been $2,500,000. The gross revenue received over a period of $6\frac{3}{4}$ years has been $3,743,000. The expense of operation and maintenance has been $703,000. The net revenue, against capital of $2,500,000, is therefore $3,040,000.



A MOTOR OPERATED RAIL MILL

By B. E. Semple

Chicago Office, General Electric Company

The rail mill at the new works of the Indiana Steel Co. at Gary, Indiana, has a capacity for rolling 166 tons of finished rails per hour, and is the largest and most modern mill of this description in the world.

This mill not only has the distinction of containing the largest induction motors ever built, but of being the only rail mill in existence entirely motor operated in which finished rails are rolled direct from the ingot without reheating.

Some 30,000 rated horse-power in alternating and direct current motors are required for the operation of the mill; about 25,000 horse-power being furnished by alternating current machines and the remainder by direct current. The main rolls are driven by six induction motors rated as follows:

Two I–14 pole, 2000 h.p., 214 r.p.m., 6600 volts, 3-phase, 25 cycles, Form M.

One I–40 pole, 6000 h.p., 75 r.p.m., 6600 volts, 3-phase, 25 cycles, Form M.

One I–36 pole, 6000 h.p., 83 r.p.m., 6600 volts, 3-phase, 25 cycles, Form M.

One I–44 pole, 2000 h.p., 68 r.p.m., 6600 volts, 3-phase, 25 cycles, Form M.

One I–34 pole, 6000 h.p., 88 r.p.m., 6600 volts, 3-phase, 25 cycles, Form M.

All of these motors are direct connected to the roll machinery through couplings of the flange type, which are constructed of steel. The motors are located in a room adjacent to the mill proper and cannot be seen by the operators manipulating the steel being rolled.

Fig. 1 is a view of the two 14 pole, 2000 h.p., 214 r.p.m. motors, each of which operates a two-high blooming mill, these motors being installed in a room on the opposite side of the mill from the other four motors.

These two motors are of the slip ring type and are rated at 2000 h.p. each, at 40° C. rise; 25 per cent. overload continuously at 50° C. rise, and 50 per cent. overload one hour at 60° C. rise. They have an equivalent break down torque of 6800 h.p. The bearings are water jacketted and are made of cast iron with babbitt lining, each being 24 in. diameter, 60 in. long.

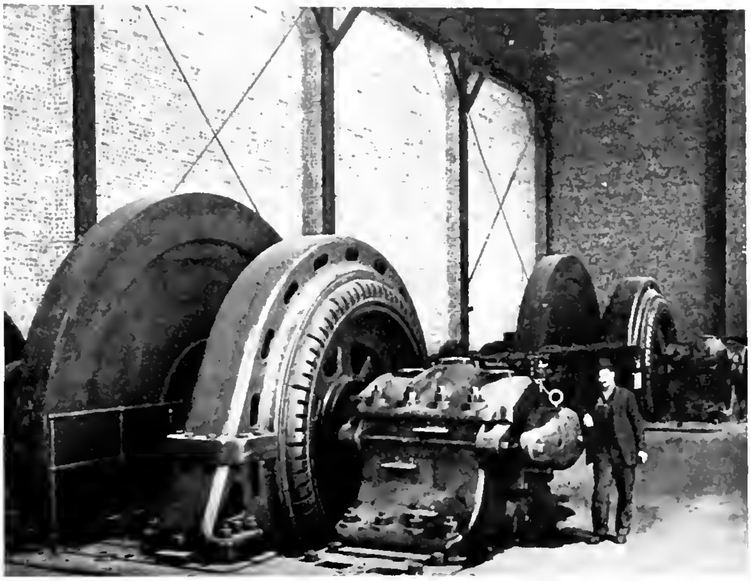


Fig. 1. 2000 H.P., Three-Phase Induction Motor Geared to Two-high Blooming Mills

The revolving element, including the flywheel, has a WR^2 value of 4,720,000 pounds at one foot radius. The flywheel is made up of steel sections, or laminations; it is 17 feet in diameter and weighs 50 tons. Each motor complete weighs 198 tons.

Both of these motors were assembled and tested at the works of the General Electric Company before shipment, only the flywheels being assembled at the point of installation. These wheels are 17 feet in diameter and have a peripheral speed at synchronous motor speed of 11429.14 feet per minute, which fact readily explains the necessity for constructing them of steel laminations. The laminations are firmly held together by very heavy rivets passing through the wheel at right angle to its diameter, and are attached to a steel hub which is double keyed to the shaft.

Each motor is provided with a thrust bearing or mechanical fuse, mounted on the front pedestal and held in place by two breakable rods which can be seen in the illustration. The purpose of this thrust bearing is to care only for ordinary thrusts in amounts less than 150 tons. This point may be exceeded at times, however, by the breaking of a roll or a roll spindle, and in such emergencies the thrust is sufficient to break the rods holding the collar in place, gear arranged to give six revolutions per minute on the first two passes and ten revolutions per minute on the next two.

A short shaft mounting a pinion is coupled to the motor shaft. This pinion engages with a large gear mounted on the intermediate shaft, which also carries a double faced pinion, each face engaging the large gears on the roll shafts.

This gearing is of special interest when the speed ratios and the power transmitted

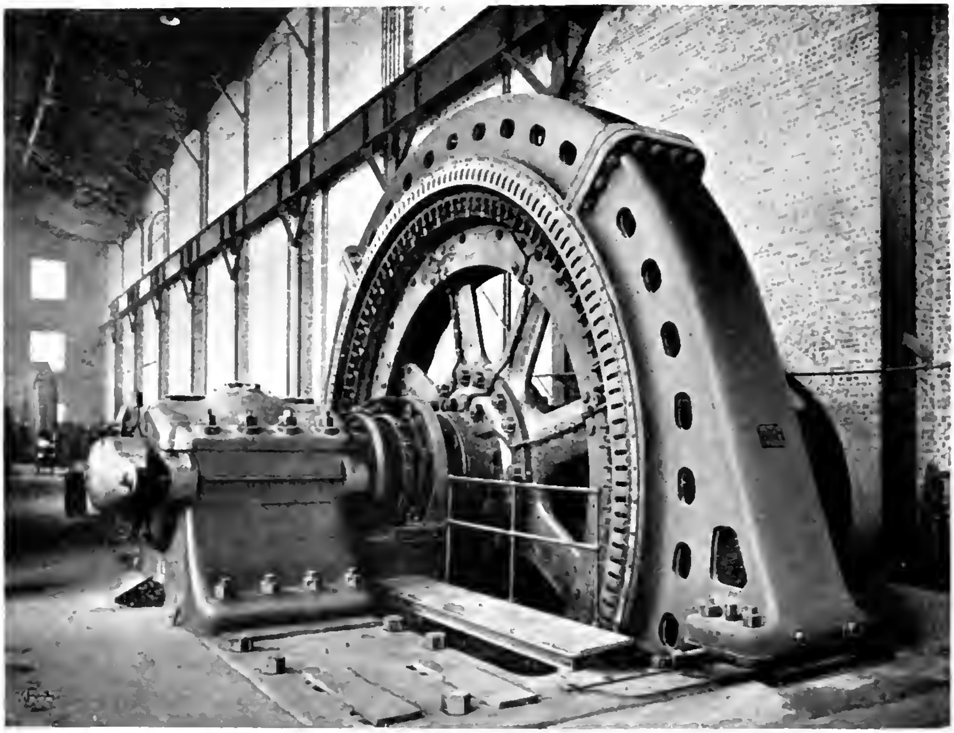


Fig. 2. 6000 H.P., Three-Phase Induction Motor. This motor drives three stands of rolls, one of which takes three passes, and the other two one pass each

thus allowing the rotating element to move longitudinally away from the rolls, thereby relieving the thrust and preventing further damage to the roll machinery or to the motor itself. The brush rigging is arranged in such a manner that it can move longitudinally with the rotating element, thus allowing the brushes to remain on the collector rings regardless of the position of the rotor.

These two motors operate the first four "passes," each motor driving two stands of 42 in. blooming rolls. They are connected to the rolls through a double reduction are considered. In one case the motor driving pinion has a 21 in. face, 23 teeth, and a pitch diameter of $26\frac{8}{32}$ in; the large gear engaging this pinion has a 21 in. face, 135 teeth, and a pitch diameter of 12 feet, $10\frac{8}{32}$ in.; and the intermediate pinion has a 27 in. face, 20 teeth and a pitch diameter of 3 feet $2\frac{1}{4}$ in. The gears on the roll shafts are each of 18 feet $5\frac{3}{4}$ in. pitch diameter, 27 in. face, and contain 116 teeth.

The ingot which weighs about 8000 pounds and measures about 65 in. long, 24 in. wide and 20 in. thick, is received from the reheating furnaces at the first pass on a motor-operated roller table and, after passing through the four passes operated by these two motors, is reduced to a piece 183.6 in. long, 14.5 in. wide, and 11.5 in. thick. As previously stated, the other four large motors are located in a room on the opposite side of the rail mill proper, being separated from it by a brick wall as in the case of the two 2000 h.p. motors.

The rolling operation is now taken up by the 40 pole, 6000 h.p., 75 r.p.m. motor, which is direct connected to a 40 in. three-high mill through which five passes are made.

This motor has the same overload ratings as those previously described and an equivalent breakdown torque of 16,500 horse-power.

It was found that this motor was too large to be shipped even partially assembled, and as a result it was entirely assembled at the point of installation, the stator punchings and windings and the rotor punchings and windings all being put into place during the construction process, expert core builders and winders being sent from the works to carry on the work.

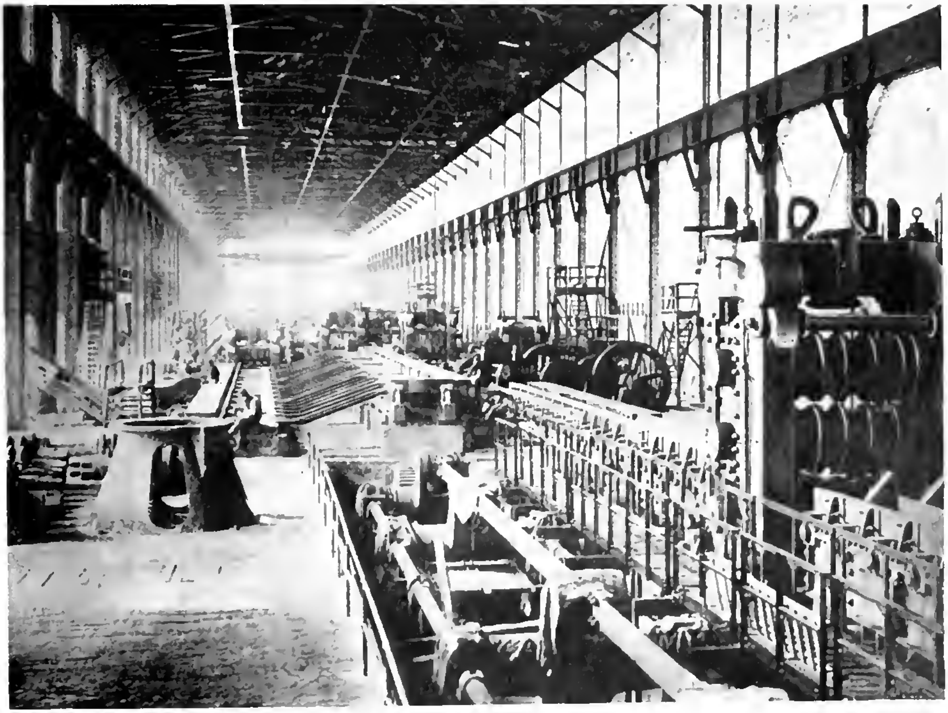


Fig. 3. Finishing End of Rail Mill

This motor differs somewhat in construction from those just described, and in addition to being larger in horse-power and slower in speed, obtains its flywheel effect of 13,100,00 lbs. at one foot radius by having its flywheel mounted directly on the spokes of the rotor as shown in illustration on page 59

The bearings for this motor are 30 in. diameter and 70 in. long, water jacketted and babbitt lined. The stator frame is 28 feet in diameter outside and arranged in four sections; the rotating element being 21 feet in diameter and the weight of the motor complete 392 tons.

On November 29th, 1908, the switches controlling the lines to this motor were closed, and the motor was started and operated at full speed for the first time; since that date it has been in regular operation.

Two trials were made in starting the motor; on the first trial the motor was only brought to about half speed when, due to a large volume of smoke issuing from the resistances, the switches had to be opened and investigation revealed a piece of arc lamp carbon lodged among the grids in such a way that one section of resistance was overheated. This trouble being removed, a second trial at starting was successful

In starting one of the other motors, two trials were also necessary, the first being unsuccessful due to a broken resistance grid.

The steel makes five passes through the stand of rolls driven by this motor, three of them being in the same direction and on the same level as that corresponding to the fourth pass, and two in the reverse direction; the mill being three-high, thus allowing the motor to operate in the same direction continuously.

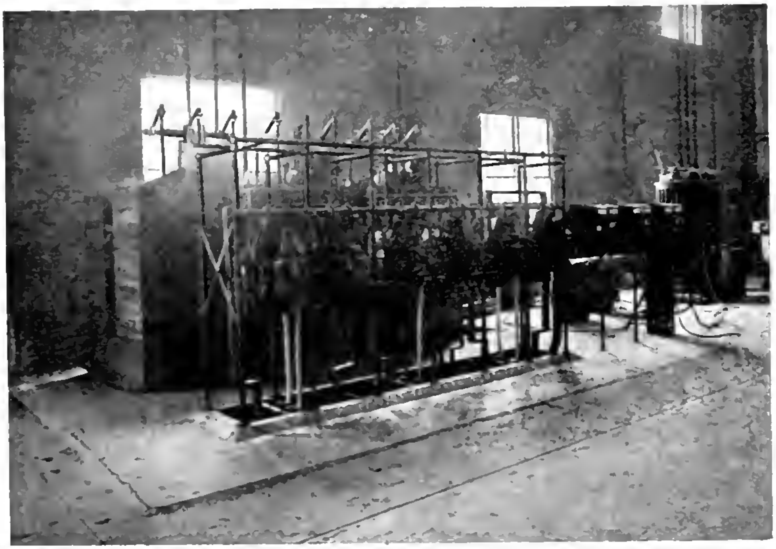


Fig. 4. Primary Control for Three 6000 H.P. Induction Motors

The fourth motor in the cycle of operation is a 36 pole, 6000 h.p., 83 r.p.m. machine, which is also direct connected to its work and differs only slightly from the 6000 h.p., 75 r.p.m. motor just described. This motor is shown in Fig. 2. It has a total weight of 374 tons, with a flywheel effect of 10,330,000 lbs. at one foot radius, the equivalent break down torque being 18700 horsepower. It was also shipped disassembled, its proportions being such as not to admit of even a partial assembly at the works.

The steel makes five passes through three stands of rolls driven by this motor, the stand next the motor coupling being three high and taking three of the passes, the two additional stands each taking one pass.

The fifth motor in the chain is a 44 pole, 2000 h.p., 68 r.p.m., machine. This is the slowest speed motor in the mill and has practically the same overall dimensions as the 6000 h.p. motors. It has a total weight of 289 tons, a flywheel effect of 7,500,000 pounds at one foot radius, and an equivalent break down torque of 5050 horsepower.

This motor drives one stand of rolls through which the thirteenth pass is made, the stand being only two-high.

The sixth and last large motor in the chain is a 34 pole, 6000 h.p., 88 r.p.m. machine having the same overall dimensions as the other two 6000 motors. Its total weight is 374 tons, its flywheel effect 10,330,000 pounds at one foot radius, and its equivalent break down torque 20600 h.p.

Three stands of rolls are driven by this motor through which the 14th, 15th and 18th passes are made, all three stands being two high.

The conversion from ingot to finished rail is accomplished in 18 passes by these six large motors, the complete cycle for one ingot requiring a trifle more than 357 seconds.

This does not mean, however, that the six motors in the chain are loaded for only a short portion of the time extending over 357 seconds, as ingots are being started on their journey almost as fast as they can be brought up to the first pass from the reheating furnaces. In rolling 166 tons per hour an ingot is started through the mill every 90 seconds.

After the steel has completed the 18th pass, and is cut into lengths by the hot saws, it passes through the cambering machine, which is driven by a 4 pole, 40 h.p., 750 r.p.m., 440 volt induction motor of the squirrel cage type, and on to the finishing department to be straightened and drilled; this work taking place after the rails have entirely cooled off.

The straightening presses, of which there are eighteen, are each driven by a 4 pole, 10 h.p., 750 r.p.m., squirrel cage type motor equipped with a high resistance rotor, the object of this high resistance being to increase the slip at full load, thus allowing the flywheel with which each press is equipped to become effective and to assist the motor in its work.

After the rails are straightened they are drilled by motor operated drills of which there are eighteen, each drill being driven by a 4 pole, 10 h.p., 750 r.p.m., 440 volt squirrel cage type motor which is a duplicate of those on the straightening presses, except that they are provided with standard low resistance rotors.

Fig. 3 is a general view in the finishing department, the rail drills being on the left and the straighteners on the right.

The apparatus for starting, stopping and controlling the six large motors is of special interest, inasmuch as it contains certain new features which were necessary in the operation of motor driven rolls to obtain the best results.

reversing switches, making it impossible to operate the latter while the main switch is closed. The reversing switches are also interlocked as regards each other, to prevent both being closed at the same time.

The main line oil switch is automatically opened in cases of overloads or short circuits.

The secondary control consists of iron grid starting resistances with contactor panels and notching up and down relays, the latter being shown directly at the left of the contactor panel in Fig. 5. The starting resistances are mounted in frames on the floor behind the contactor panel.

The regulating device mounted on the relay panel controls the opening and closing

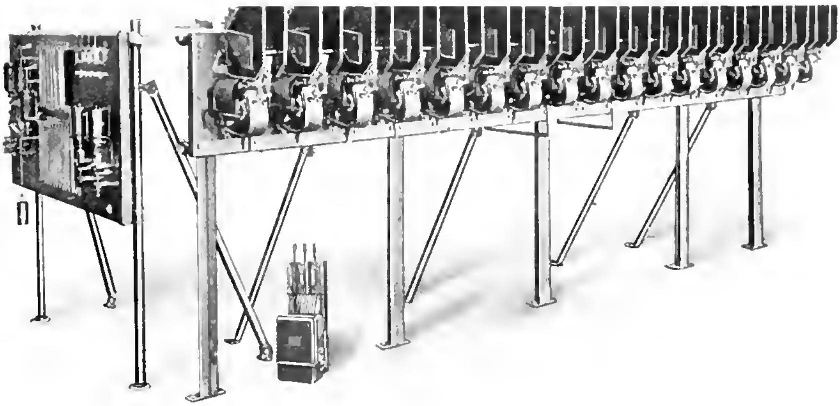


Fig. 5. Secondary Control for 6000 H.P. Induction Motor

Fig. 5 is a general view of the secondary control apparatus for one of the 6000 h.p. motors, and Fig. 4 shows the primary control for three motors.

Each motor is controlled by a master controller located in the operating pulpits in the rolling mill, the remainder of the apparatus being placed in the motor room near the motors. Provision is also made for operating the motors from the secondary control board in the motor room, if found necessary.

The primary control equipment for each motor consists of one motor-operated three-pole line oil switch, two solenoid operated reversing switches, the necessary relays, and indicating and recording instruments. The main oil switch is interlocked with the

of the contactors, and in addition to performing the function of energizing the contactor magnets during the starting operation, also opens the contactor circuits at the proper time to control the slip.

The controlling device once properly adjusted is entirely automatic. When the load increases, proportional resistance is automatically connected into the secondary circuit, increasing the slip and allowing the flywheel to share the load with the motor. As the load decreases, the slip is reduced and the motor restores energy to the flywheel in preparation for the next peak load.

The net result of this method of control is to greatly smooth out the peaks which would otherwise occur in the load curve at every pass.

The control equipment is operated by direct current at 250 volts, and in the event of failure of either the direct or the alternating current supply the apparatus is automatically protected.

The rotors continue to revolve for a long period after power is shut off, on account of the large flywheels. When, due to accident or other causes, it is necessary to stop the motors quickly, direct current is admitted to the stator windings through external resistance the rotor windings meanwhile being short circuited. Suitable oil switches interlocked with the main line switches are provided to connect the direct current power circuits to the stator windings. On one occasion one of the 2000 h.p., 214 r.p.m. motors continued to revolve for a period of two hours after the main line switch was opened; the 6000 h.p., 83 r.p.m. motor operated for one hour and thirty-seven minutes under the same conditions; while with direct current applied to one phase immediately after opening the line switches, the rotors ceased to revolve in less than three minutes.

Two 10,000 kw., 6600 volt circuits from the power station supply the six large motors, one circuit feeding the two 2000 h.p., 214 r.p.m. motors and the 6000 h.p., 75 r.p.m. motor, the other circuit feeding the remaining motors. One additional circuit enters the mill and supplies power through motor-generator sets to the direct current system for the various direct current motors used for cranes and tables.

All three of these circuits are protected against lightning and surges by aluminum cell arresters, which are shown in Fig. 6.

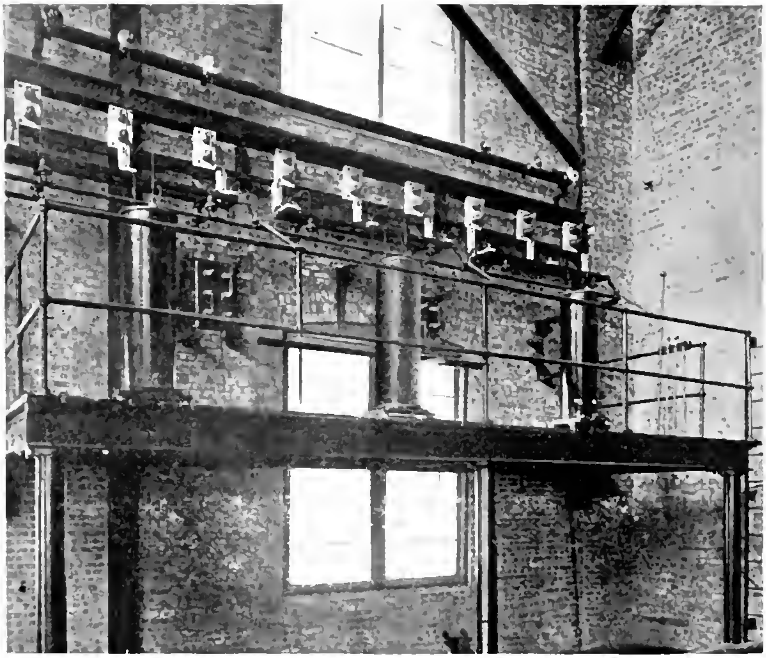


Fig. 6. Aluminum Cell Lightning Arresters

SOME POINTS OF MODERN PRACTICE IN INDUCTION MOTOR CONSTRUCTION

By E. L. Farrar

Modern practice in induction motor construction is toward the elimination, so far as is consistent with good engineering, of inactive material; this inactive material being largely confined to the stator casting, bearing brackets, and the base or rails.

Inasmuch as the designers are rather limited in the matter of distribution of metal in the bearing brackets, but little elimination of weight can be made there except at the expense of rigidity. Two rails may be substituted for a base, and a saving made there if thought advisable; but the stator frame affords the best opportunity for the elimination of weight without a sacrifice of rigidity, at the same time providing for the most efficient heat radiation.

This idea in induction motor design has been worked out very carefully in the riveted frame construction of the smaller and the skeleton frame in the larger sizes of G.E. induction motors.

The use of straight versus overhung slots in the stator punchings has been open to a great deal of discussion. While given values of efficiency and power factor may usually be obtained with the use of less active material (*i.e.*, laminations and copper) if overhung slots are employed, the difficulties in adequately insulating the windings with this construction and of making repairs render the use of straight slots desirable in all except the small sizes, even at the expense of increasing the amount of active material for a given size of motor.

In the small sizes, if the lesser insulation inherent in overhung slot construction is not sufficient, as might be the case, for instance, where strong acid fumes are prevalent, it is often preferable to use a totally enclosed motor with overhung slots, it being so much easier to maintain good characteristics in these sizes with this construction than with straight slots.

With the increase in the general use of electric drive, a greater variety of conditions under which motors have to operate must be met. This has led to the gradual improvement in the character of insulation. Often in small motors where overhung slots are usually used, the whole stator is dipped many times in heavy insulating compound and baked several hours in a high temperature. This compound thoroughly impregnates the entire winding, cementing the wires together and making the machine moisture proof.

Where straight slots are used, the stator coils can, of course, be thoroughly insulated before being placed in the slots. Except where small wire is used, it is considered better practice to wind the coils on forms which give them the exact shape and dimensions required, rather than wind them on a straight form and then pull them in shape. The coils are pressed in hot moulds to remove any high spots that might be subject to undue pressure when inserted in the slot. This moulding also melts and fills the coil with cement, binding the layers together. After being moulded, the coils are thoroughly insulated all over, the slot portion having an extra heavy re-inforcing. The coil is completed by being dipped many times in heavy insulating compound and baked several hours at a high temperature.

There is still some diversity of opinion among manufacturers as to the proper construction of squirrel cage type motors, but experience shows that for the smaller sizes a better electrical joint can be obtained by the use of soldered end rings, while for the larger sizes, a bolted construction, using spring washers to compensate for unequal expansion of the bars and bolts, is the most suitable.

The air gap of any induction motor is of necessity relatively small, and experience shows that for all except the smaller sizes it is important to have a means of centering the rotor in the stator when the wear on the bearings becomes pronounced. In order that the rotor may be centered accurately, it is of course necessary that a gauge be furnished with each motor by the manufacturer.

Exhaustive experiments have been conducted to determine the best friction metal to use for induction motor bearing linings. Based on the results of these experiments and years of experience in building induction motors, there seems to be little question but that cast iron shells lined with hard or so-called tin babbitt are the best for all except the smaller motors. For these an alloy is used that has the same desirable quality inherent in babbitt; *viz.*, that of not scoring the shaft in case the bearing freezes through lack of proper lubrication. All bearing housings should be made dust-proof.

Although some manufacturers still furnish rails instead of a sliding base, the majority of engineers agree that a universal base, which can be used for floor, wall or ceiling mounting, is superior to either rails or separate bases for floor and ceiling suspension. In order that the belt may run true on the pulley, the base should be designed to prevent the belt tension from pulling the motor out of line. Also, there are a great many advantages in having a universal belt tightening screw that moves the motor both ways on its base: the base being interchangeable end for end, thus permitting the tightening screw always to be located on the front side of the machine away from the belt.

The above is a brief outline of modern practice in induction motor construction. Improvements are continually being made, but they usually relate to details that have not been mentioned. The fundamental ideas in the construction of these motors have been so carefully worked out that they have proved highly satisfactory in operation.

SEWING MACHINE MOTORS—DRAWN SHELL TYPE

By R. E. Barker
Small Motor Department

In 1845, Howe produced the first satisfactory sewing machine, and since that time vast numbers have been made and marketed for many varied purposes. This invention has perhaps done more to lighten the labors of the housewife than any other, and the greatest number of machines sold have been those designed for household use.

However, with the advantages of convenient, uniform, and rapid sewing by machine, there comes the unpleasant and sometimes dangerous fatigue engendered by the long continued pumping action of the feet upon the sewing machine treadle. Many are the auxiliary devices proposed to avoid this laborious operation of foot power supply, but among all of these the modern electric motor of small size, comparatively easy application, and reasonable cost, is undoubtedly the most favored in all dwellings where electric power is available.

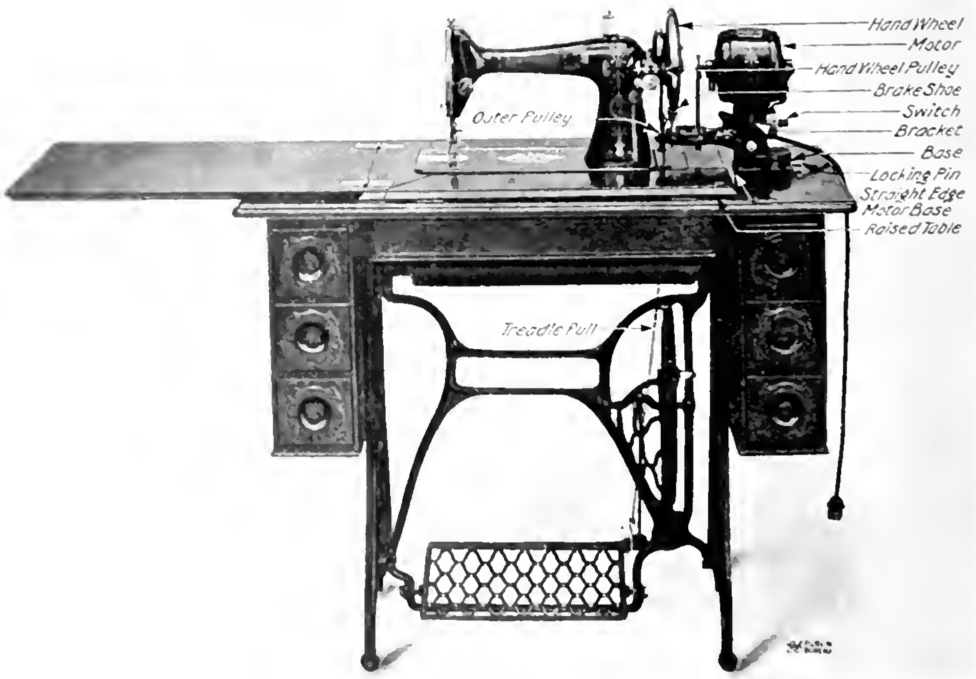


Fig. 1. Form H Motor Attached to High Arm, Drop Head Machine

To meet the demand for a motor for this

service, the General Electric Company has recently perfected a new design, in which the drawn shell type of construction is employed.

These sewing machine motors are adaptable to all standard sewing machines of either stationary or drop head style having the hand-wheel in the usual position. It is unnecessary to disturb any part of the sewing machine to attach the motor; hence in case of failure of electric current, or removal to a locality where electricity is not available, the belt can be attached immediately and the machine operated by foot power.

A noticeable feature of the equipment is the ease with which the motors can be attached to or removed from the sewing machine by persons possessing but slight mechanical skill.

This motor marks a long step in advance of the sewing machine motor formerly sold by the Company. Its design is such that by using only two forms it may be applied to substantially all types of stationary and drop head machines; thereby obviating the necessity for special attachments for each make of sewing machine, as heretofore.

The belt tightener and other accessories used with the superseded line of motors have been entirely eliminated, and the motors now offered are self-contained in every particular, the outfit including snap switch, connecting cord, etc., etc.

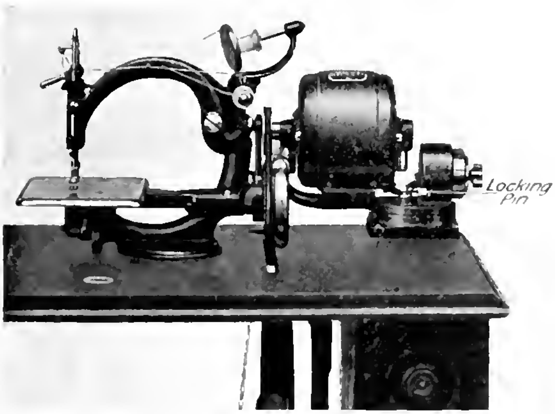


Fig. 2. Form K Motor Attached to Low Arm Machine

Fig. 1 shows an alternating current motor assembled upon a high arm drop head sewing machine; Figs. 2 and 3 show a low arm sewing machine fitted with a 1/30 h.p. new type of motor.

The Form K outfit is designed for the low arm or automatic types of sewing machines, and for the high arm machines where the Form H motor cannot be used owing to peculiarity in head design.

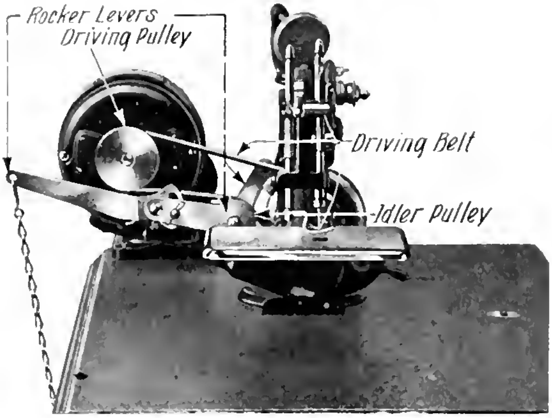


Fig. 3. End View of Form K Motor Attached to Low Arm Machine

Complete outfits are comprised of the following parts:

Form HC or H. One motor complete with bracket and base; one bobbin winder; one treadle pull; one leather and one rubber belt; one ornamental cover; one screw-driver; and four wood screws (Fig. 4).

Form KC or K. One motor complete with bracket, levers and base; one treadle pull; one leather driving belt; one rubber belt; one ornamental cover; one screw-driver; and four wood screws (Fig. 5).

Family size sewing machine motors are built in the following sizes, for the frequencies and voltages listed:

ALTERNATING CURRENT 60, 40 and 25 Cycles

Type	H P	Speed (Sync.)	Cycles	Volts	Approx. Wt. in Lbs. Net Form HC	Net Form KC	Shipping Form HC	Shipping Form KC
DSS	1/30	1800	60	110	19	18	30	29
DSS	1/30	1800	60	220	19	18	30	29
DSS	1/30	2400	40	110	19	18	30	29
DSS	1/30	2400	40	120	19	18	30	29
DSS	1/30	2400	40	220	19	18	30	29
DSS	1/40	1500	25	110	19	18	30	29
DSS	1/40	1500	25	220	19	18	30	29

CONTINUOUS CURRENT Shunt Wound

Type	H P	Approx. Speed	Volts	Approx. Wt. in Lbs. Net Form H	Net Form K	Shipping Form H	Shipping Form K
DSD	1/30	1700	110	19	18	30	29
DSD	1/30	1700	220	19	18	30	29

Full and clear instructions for assembling are shipped with each outfit. When the outfit has been installed in accordance with the directions and the motor connected to the

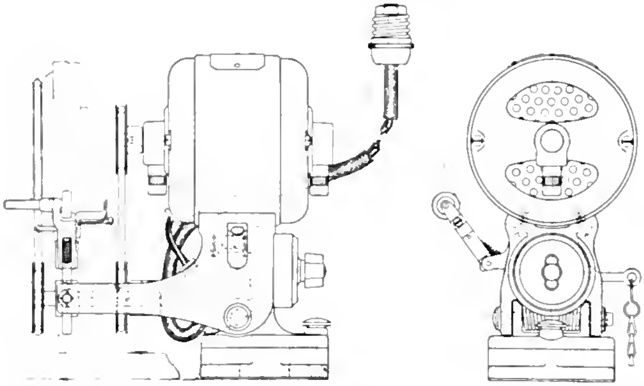


Fig. 4. Form H Motor

source of electric supply by means of the flexible cord and plug, the operator can start the machine by turning the snap switch and thereafter govern the speed to a nicety by gently increasing or diminishing the pressure of the foot on the treadle.

Pressure of the foot releases the brake and tightens the belt by means of the driving pulley, thus starting the machine or increasing the speed. Reduction of pressure on treadle loosens the belt and decreases the speed. To stop machine quickly, remove all pressure

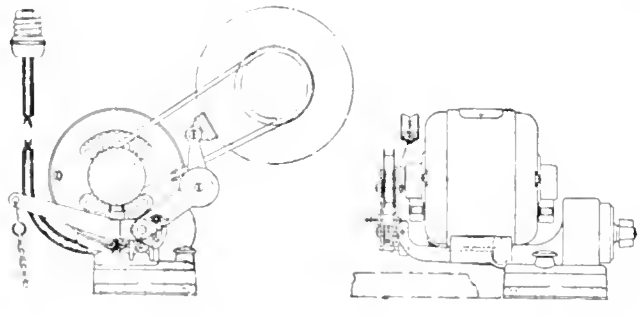


Fig. 5. Form K Motor

from the treadle and the brake will be automatically set against the handwheel, bringing the needle to rest immediately. This method of control is simple and satisfactory; the speed of the sewing machine may be regulated quickly to suit the varying requirements of different classes of work.

When it is desired to lower the drop head or place the box cover on a stationary head sewing machine, the motor may be turned on its swiveling base plate or may be removed entirely from the machine. Thus the motor, when not in use, may be protected from dust, etc. Fig. 6 shows the appearance of the same sewing machine as that illustrated in Fig. 1, when the motor is removed and the drop head closed.

Sewing machine motor drive is one of the most attractive applications of fractional horse-power motors ever made by the General Electric Company. Large numbers of the earlier type with separate belt tightener have been sold, and now that a more improved, complete, self

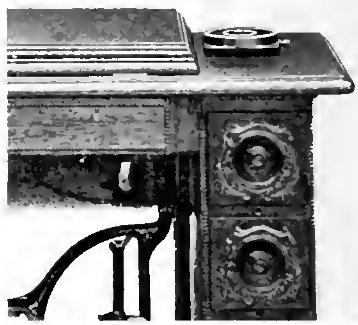


Fig. 6. Drop Head Machine Showing Motor Removed

contained, lighter and more efficient motor is offered, it is confidently expected that the demand will greatly increase when its several good features become known to the purchasing public. The new motor is much cheaper to operate than the old, actual tests showing a saving of 50 per cent. in the current bill. The power used is about equal to that taken by one sixteen candle-power incandescent lamp. This fact should make the new outfit especially attractive.

For strength, reliability, simplicity of application and facility and economy of operation, these outfits leave nothing to be desired, and persons having once tried this method of drive find it absolutely indispensable.

OIL AND TRANSFORMER DRYING OUTFITS

By E. F. Gehrkens

Experience has shown that it is practically impossible to prevent moisture from being deposited in transformers during transportation or storage, condensation taking place on the surface of the oil as well as on the metallic surfaces whenever these are cooler than the surrounding air. It is therefore important, especially with high voltage transformers, that considerable attention be given to the matter of drying out the transformer itself, as well as the oil to be used. A portable oil and transformer drying outfit suitable for this purpose has therefore been developed, which will be briefly described in the following paragraphs.

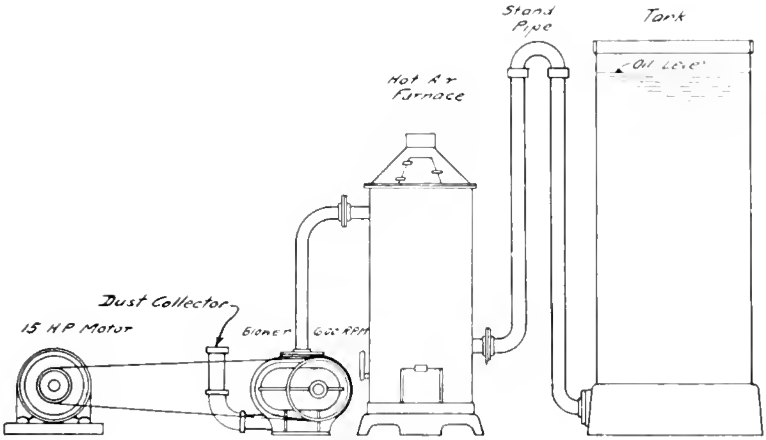


Fig. 1

The outfit consists of the following parts:

Hot air furnace,

Positive pressure blower,

Dust collector,

Driving motor,

Necessary piping, pulleys and belt.

The outfit is shown diagrammatically in Fig. 1.

Hot Air Furnace

This furnace contains a 3 in. wrought iron coil suitably mounted inside a sheet iron casing, the latter being fastened to a cast iron base. The furnace is designed in a manner similar to a self-feeding stove. Two doors are provided, one at the top of the furnace for the admission of fuel, and one at the bottom for removing the ashes and also for regulating the draft. Wood and charcoal have been found from experience to give good results as fuel. Hard coal may also be used, in which case it may be necessary to use forced draft, which can easily be obtained by tapping the pipe between the blower and the furnace.

Standard 3 in. wrought iron piping, which is procured almost anywhere, is used throughout the outfit; the connection between the blower and the furnace is, however, sent with the outfit. If the connections between the furnace and the transformer tank are of appreciable length it is advisable to have them covered with suitable heat-insulating material. Common stove pipe may be used for leading the smoke from the furnace to the open air.

Positive Pressure Blower

The blower is of the ordinary positive pressure type and should be rotated in such a direction that the air will be pulled in through the dust collector. It has a normal capacity of 300 cubic feet of free air per minute, delivered at a pressure of 6 lb. per square inch, and is designed for a speed of 600 r.p.m., requiring 15 h.p. when delivering normal output.

In case the outfit is used for drying transformers only, smaller pressure is required and a 5 h.p. motor will be sufficient.

Dust Collector

The dust collector, or air filter, is of very simple construction and is attached to the inlet of the blower. It consists of a pipe $4\frac{1}{2}$ in. in diameter, made from perforated sheet metal and connected to the blower with a suitable elbow. Cheese cloth should be tied around this pipe so that when the outfit is in operation the air must pass through the cloth, thereby being effectually filtered. The cloth must, of course, be changed from time to time.

Driving Motor

Any available driving power, be it from a steam engine, gas motor, electric motor, etc., may be used for driving the blower. The pulleys of the blower and motor should be of such a ratio as to drive the blower at the required speed of 600 r.p.m.

Piping, Etc.

In making up the pipings between the furnace and the oil tank, it is necessary to extend this pipe above the oil level, so as to prevent the furnace from being flooded with oil in case the motor is stopped and the valve at the base of the tank is not closed.

Weights

The net weights are as follows:

Hot air furnace	1250 lbs.
Blower	800 lbs.
Dust collector and piping	150 lbs.
Total	2200 lbs.

OBITUARY

John Trumbull Marshall, assistant engineer of the Lamp Works of the General Electric Company, at Harrison, N. J., died in Bermuda on January 1st, aged 50 years.

He was a direct descendant of Jonathan Trumbull, the American Patriot, friend and adviser of Washington, and Colonial Governor of Connecticut.

Marshall was graduated from the Scientific Course of Rutgers College in 1881, and went to work at the Edison Lamp Works, then at Menlo Park, in October of that year.

In 1883 or 1884 he invented the comparison method of photometering lamps, by which the voltage of a lamp at normal candle-power is determined without the use of electrical instruments. The lamp to be photometered is placed in multiple with a lamp of known candle-power and voltage and their relative candle-powers observed. A constant voltage line is not required for this work, as the relative candle-powers of two lamps is the same through a wide variation of voltage. Practically all carbon lamps manufactured by the Company are to this day measured for voltage by this method, which is very simple and enables an unskilled operator to test a large number of lamps per day.

During the last few months Mr. Marshall completed and put in operation a very remarkable development of the comparison method of lamp measuring, known as the watts-per-candle photometer. This photometer, as its name implies, gives the volts, amperes, and candle-power of a tungsten lamp at the desired watts per candle-power; the only electrical instrument required being a zero galvanometer. With this method, also, a constant voltage line is not necessary. Each photometer requires but one operator; his daily output, as well as the accuracy of his work, showing a marked increase over the older method, which entailed the use of a voltmeter, an ammeter, a constant voltage line, and a slide rule calculation for each lamp.

Besides specializing in photometry, Mr. Marshall paid much attention to the manufacture of carbon filaments, especially as regarded carbonization, and the practical methods of metalizing filaments at present in use are largely his. Mr. Marshall was a good mathematician and had a very large capacity for work, which he used to the limit.

Personally, Mr. Marshall was universally loved and respected. A man of strong character and convictions, in him truthfulness and straightforwardness were so developed that he was incapable of the least degree of deception. He signed a total abstinence pledge when a boy, and never broke it. He lived a very simple life and found his recreation and enjoyment in his garden, the woods and the fields. He knew the trees, plants and flowers growing in his neighborhood, and had many of them transplanted about his home. He was unmarried and devoted his life to his parents and sisters.

GENERAL ELECTRIC REVIEW

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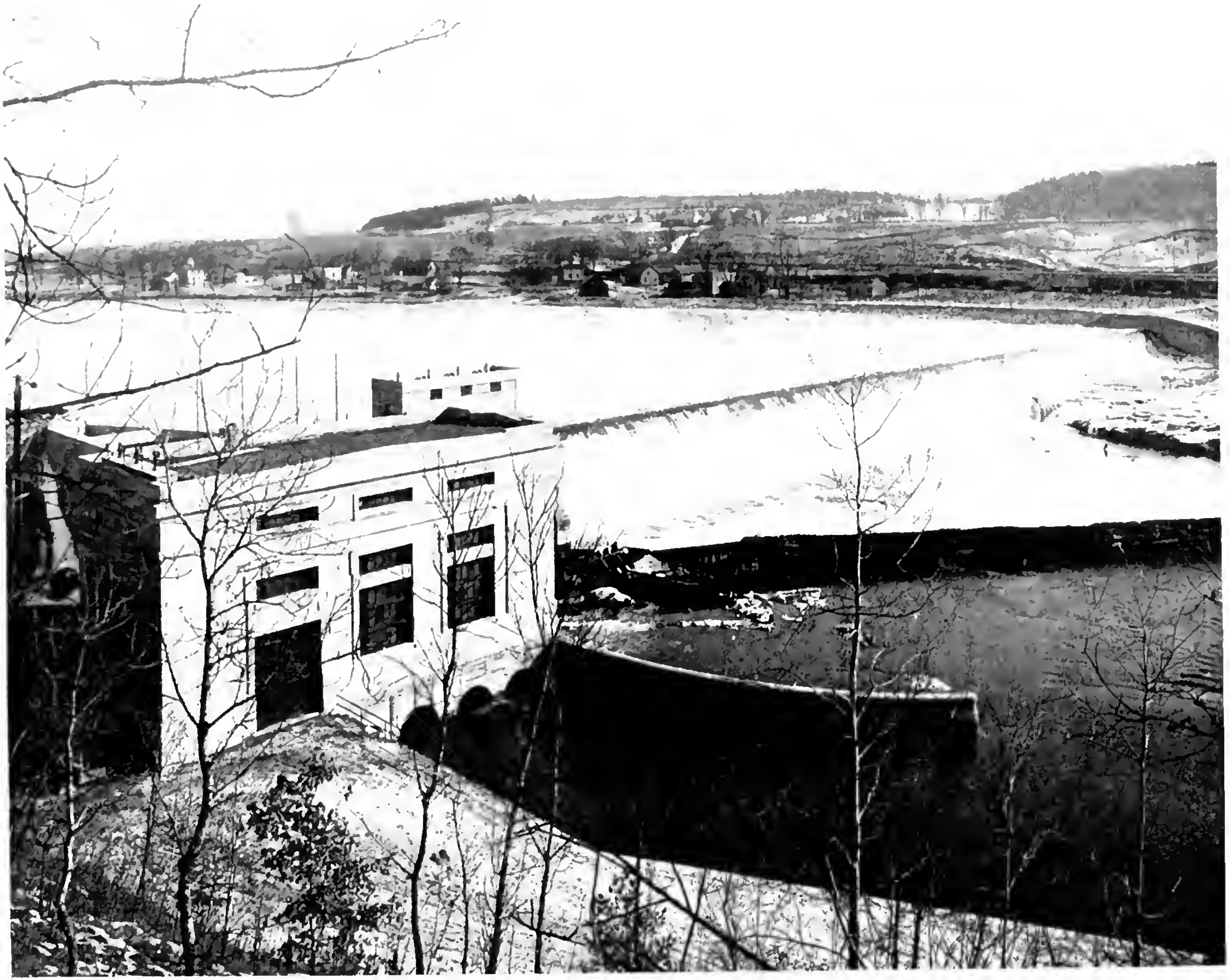


Power House and Dam at Johnsonville—Schenectady Power Company (see Page 118)

GENERAL ELECTRIC REVIEW

SOME CHEMISTRY OF LIGHT

All electrical industries deal with a transmission and a transformation of energy. Considering a typical case: mechanical energy from a steam engine or water wheel is transformed into electrical energy by the generator, transmitted some distance and re-transformed into mechanical energy by the motor. The transformations instead of being between electrical and mechanical energy may be between electrical and other forms; such as chemical energy, heat energy, or radiant energy. Of these transformations some are commercially of far greater importance than others. One of the first in importance is the conversion of electrical energy into radiant energy, or more specifically into radiant energy suitable for the production of light.

All of these transformations involve losses, the lost energy usually appearing in the form of heat. Even in the case of a heating device, the efficiency is not perfect on account of the impossibility of applying or confining all of the heat at the desired point. Unfortunately, of all the energy radiated from a heated body only a small proportion, even under the best conditions, is of the proper frequency to affect our eyes and to be recognized as "light." In fact, there is no physical difference between radiant energy with a vibrational frequency too slow to give through our eyes the sensation of red, or too rapid to give the sensation of violet, and radiant energy which gives the sensation of light—the limitations of color are physiological, that is, inherent in ourselves, and are not physically inherent in light producing bodies or in light itself. It follows, therefore, that since light is heat, it cannot be produced without heat, and the best artificial illuminant that could ever be found would be that in which all the heat waves of the wrong frequency for light effects had been eliminated.

In this number of the Review we print the recent presidential address of Dr. Whitney before the American Chemical Society, and while this paper was prepared for an audience of chemists, the outline of the research for artificial illuminants, gradually increasing in efficiency from crude oils and greases up to the modern incandescent tungsten and flaming arc lamps, can be appreciated by others than those of chemical training.

The present limitations in the number of candles per watt that can be obtained from incandescent lamps are in no way affected by the nature of the transformation from electrical to radiant energy, but solely by the ability of the filament to survive continued operation at high temperature without vaporizing sufficiently to blacken the bulb or become disrupted. That the limitations lie in the nature of the materials and not in the process of light production is decidedly encouraging.

The modern tungsten lamp consumes, roughly, half as many watts per candle as the carbon incandescent lamp in its most highly developed form; this carbon lamp in turn consuming about half as many watts as the early incandescent lamps. Dr. Whitney's statement that the tungsten lamp can for a short time produce four or five times as many candles per watt as we now obtain from it in commercial service seems almost equivalent to saying that discoveries will soon be made permitting lamps to operate commercially at better efficiency than has even yet been realized. There is no need to enlarge on the economic value of such improvements, and mention need only be made of the tremendous saving in coal that would at once be effected by the reduction of only a fraction of a watt per candle.

Incidentally, the paper may lead some to consider where the field of chemistry ends and physics begins. The dividing barriers, which were never definitely drawn, seem during recent years to be broken down at several points and a little reading between the lines of Dr. Whitney's paper shows that the investigator must study his materials from the points of view of both the physicist and the chemist.

John B. Taylor

THE FLOW METER

At the present time much thought and energy are being expended in an effort to lessen the inroads that are being made upon our diminishing coal supply; on this account, the subject of the development and utilization of the water power available has assumed grave importance. For the same reason, anything that makes for economy in coal, whether it be by the substitution of water power or by the use of more economical steam boilers, more efficient engines, motors, lamps or what not, is of increasing importance precisely in proportion to the amount of coal it saves.

In 1907 the stupendous total of over 474 million tons of coal, having a value of over $657,000,000, was mined in this country; to be used in the main for the generation of steam. Of this enormous annual output, a very considerable amount is absolutely wasted for lack of intelligent management in the generation, transmission and utilization of the steam; a lack that is due very largely, if not mainly, to the absence of simple and adequate means for measuring this product. In the steam flow meters, described on another page of this issue, these means are provided, and for the first time the steam engineer is enabled to keep track of the generation, distribution and consumption of his steam in a thoroughly practical and effective manner, and consequently to manage his plant economically.

The utility of the meters may be judged from the following list of some of the uses to which the recording type may be put:

For recording the total amount of steam generated by a battery of boilers.

For recording the amount of steam delivered to any department of a manufacturing plant.

For recording the amount of steam sold for power, heating or manufacturing purposes.

For equalizing a load on individual boilers of a battery.

For discovering losses originating from leaks between boilers and points of consumption which could not otherwise be detected; *e.g.*, from defective traps, gaskets or valves.

For discovering internal leaks in boilers as shown by the difference in the water input and the steam output.

For determining the deterioration of efficiency of a boiler due to the formation of scale, etc.

For determining the efficiency in the method of stoking, etc., etc.

The value of these meters in determining distribution losses is indicated in the case of a certain underground main, of about 2000 feet in length, which received 13,000 pounds of steam per hour and delivered but 3000 pounds of this at the distribution points; 10,000 of the 13,000 pounds being lost in transmission!

This condition being discovered by the use of the meters, the main was unearthed, when it was seen that the covering had disintegrated and some of the gaskets blown out. Repaired and re-covered, the main supplied four times its former load, with no increase in coal consumption. The saving in this case amounted to approximately $1800 a month.

Again, in some plants the steam used for heating is a large, though frequently unconsidered, item. In one manufacturing plant it was found by a meter that in November, this, together with the loss by radiation, amounted to over one-quarter of the total daily steam consumption, and thus on Sundays, when no work was being performed, the boilers were still carrying one-quarter of the regular weekday load.

The chart of the recording meter, showing as it does the steam consumption from hour to hour, is, in effect, a work record, and like the peak load chart of a central station, shows the hours of greatest manufacturing output. It has been noted that in the morning the rate at which work is being done gradually increases until about eleven o'clock, after which it declines until noon; though through the morning the rate of production is pretty well maintained. Again, immediately after the midday rest and meal, the rate of work goes up, but gradually sags as the afternoon advances until toward the end of the day the falling off is rapid.

SOME CHEMISTRY OF LIGHT*

By W. R. Whitney, Ph. D.

Director of Research Laboratory of Schenectady Works

From the dawn of history, chemistry has had much to do with the production of artificial light, and I wish now to recall to your minds a few illustrations. I will not burden you with a long story on physics or mechanics of light, but intend treating the subject of artificial light so as to show you that it has always been largely a subject for chemical investigation. I want to impress upon your minds that it is still a most green and fertile field for the chemist. It should be borne in mind that I am trying to interest an audience of chemists from widely different fields, rather than to present a chronological record of recent experimental research.

I can not tell just when chemistry was first scientifically applied to a study of artificial light. Most cardinal discoveries are made by accident and observation. The first artificial light was not made by design, nor was the first improvement the result of chemical analysis. It is supposed that the first lamps were made from the skulls of animals, in which oil was burned. Herodotus, describing events about three centuries before Christ, says of the Egyptians:

"At the times when they gather together at the city of Sais for their sacrifices, on a certain night they all kindle lamps many in number in the open air round about the houses: now the lamps are saucers full of salt and oil mixed and the wick floats of itself on the surface and this burns during the whole night."

This night was observed all over Egypt by the general lighting of lamps, and these lamps were probably the forerunners of the well-known Greek and Roman lamps of clay and of metal which are so common in our museums.

The candle and lamp were probably invented very much earlier. We know that both lamps and candles were used by the priests of the Jewish temple as early as 900 B.C. The light of those candles and lamps was due, as you know, to particles of carbon heated in a burning gas.

It is not fair to the chemists of our early candle-light to skip the fact that great chemical advances were made while candles were the source of light, and so I touch for a moment upon one of the early applications of chemical knowledge. The fats and waxes first used were greasy and the light was smoky and dull. They were capable of improvement and so the following chemical processes were developed and applied to the fats. They were first treated with lime, to separate the glycerol and produce a calcium soap. This was then treated with sulphuric acid, and the free stearic and palmitic acids separated. These acids were then made into candles and gave a much whiter light than those containing the glycerol ester previously used. Similar applications of chemical principles are probably known to you all in the refining of petroleum. The crude distillate from the rock oil is agitated with sulphuric acid and then washed with a solution of sodium hydroxide. This fact accounts, in considerable degree, for the advance of a number of other chemical processes. An oil refinery usually required the presence of a sulphuric acid plant in the immediate vicinity, and this often became a source of supply for other new chemical industries.

Very great advances have been made in the use of fats and oils for lighting purposes, but there is so much of greater interest in later discoveries that we will not consider many of them. The distillation of gas from coal or wood in 1739 was a chemical triumph, and a visit to a gas plant still forms one of the main attractions to the young chemist in an elementary course of applied chemistry. The first municipal gas plant was established in London, just about one hundred years ago. The general plan, so apparently simple to us to-day, was at its inception judged impracticable by engineers.

In spite of other methods of illumination, the improvements in the making, purification and application of illumination gas have caused a steady increase in its use. Gas owes its illuminating power to the fact that a part of the carbon in it is heated to incandescence during the combustion of the gas. It must contain, therefore, such carbon compounds as yield a fair excess of carbon, and this knowledge has led to the schemes for the

* Presidential address delivered before the American Chemical Society, December 29, 1909.

enrichment of gas and for the use of non-luminous water-gas as a base for illuminating gas.

Various schemes were devised in the early part of the nineteenth century for using gas to heat to incandescence, rods or surfaces of lime, zirconia and platinum. This was not at first very successful, owing to imperfect combustion of the gas. The discovery of the Bunsen-burner principle was made a little later. By thus giving a much higher temperature to the gas flame and insuring complete combustion, new impetus was given to this branch, and the development of suitably supported oxide mantles continued for half a century.

Most prominent in this field is the work of Auer von Welsbach. It was a wonderful series of experiments which put the group of rare earth oxides into practical use and started a line of investigation which is still going on. The Welsbach mantle practically substitutes for the carbon of the simple gas flame, another solid in a finely divided shape capable of giving more efficient light. This allows all of the carbon of the gas to contribute to the production of a hotter flame. But more interesting than the mechanical success, to my mind, is the unforeseen or scientifically unexpected discovery of the effect of chemical composition. By experiment it was discovered that the intensity and color at incandescence of the various mixtures of difficultly fusible oxides varied over a wide range. Thus a broad field for unforeseen investigation was opened, and much advanced chemical work has been applied to this industry. The color and intensity of the light varies in an unexplained manner with slight differences in composition of the mantle. The following are the composition and candle-powers of some sample mantles:

CANDLE-POWER OF MANTLES, RANGING FROM PURE THORIA TO 10 PER CENT. CERIA

No.	Per Cent. Thoria	Per Cent Ceria	Candle-Power
367	100.00	0.00	7
378	99.75	0.25	56
369	99.50	0.50	77
370	99.25	0.75	85
371	99.00	1.00	88
372	98.50	1.50	79
373	98.00	2.00	75
374	97.00	3.00	65
375	95.00	5.00	44
376	90.00	10.00	20
69	La, Zr, Ce	Oxides	30

The methods of making the present mantles were also a part of Dr. Auer's contribution to the art. Suitably woven fabrics are dipped into solutions of the rare earth salts; these are dried and the organic matter burned out, leaving a structure of the metal oxides.

The pure thoria gives a relatively poor light. The addition of the ceria, up to a certain amount, increases the light. This added component is called the "excitant," and as the cause for this beneficial action of the excitant is not known, it is possible that further discoveries along this line will yet be made.

There is hardly a prettier field for chemical speculation than is disclosed by the data on these light efficiencies. For some unknown reason, the change in composition by as little as one per cent. varies the luminosity over ten-fold, and yet more than one per cent. of the excitant (ceria) reduces the light. Besides the temptation to speculation, such disclosures of nature encourage us to put greater trust in the value of new experiments, even when accumulated knowledge does not yield a blazed trail for the pioneer. By giving a discovery a name and attaching to it a mind-quieting theory, we are apt to close avenues of advance. Calling this small amount of ceria an "excitant" and guessing how it operates, is directly harmful unless our guess suggests trial of other substances.

One of the explanations proposed to cover the action of the ceria ought to be mentioned, because it involves catalysis. This is a term without which no chemical lecture is complete. Some think that the special mantle mixture causes a more rapid and localized combustion and therefore higher temperature, by condensation of gas in its material. Others think that this particular mixture permits of especially easy and rapid oxidation and reduction of its metal oxides themselves in the burning gas mixture. The power which catalyzers have of existing in two or more states of oxidation seems to apply also to the ceria of the Welsbach mantle.

Whatever the truth may be, it has been shown by Swinton * that when similar oxide mantles are heated to incandescence in vacuo by cathode rays, the presence of one per cent. ceria produces only a very small increase in the luminosity of thoria. It is interesting

*Proc. Roy Soc., 66, 115.

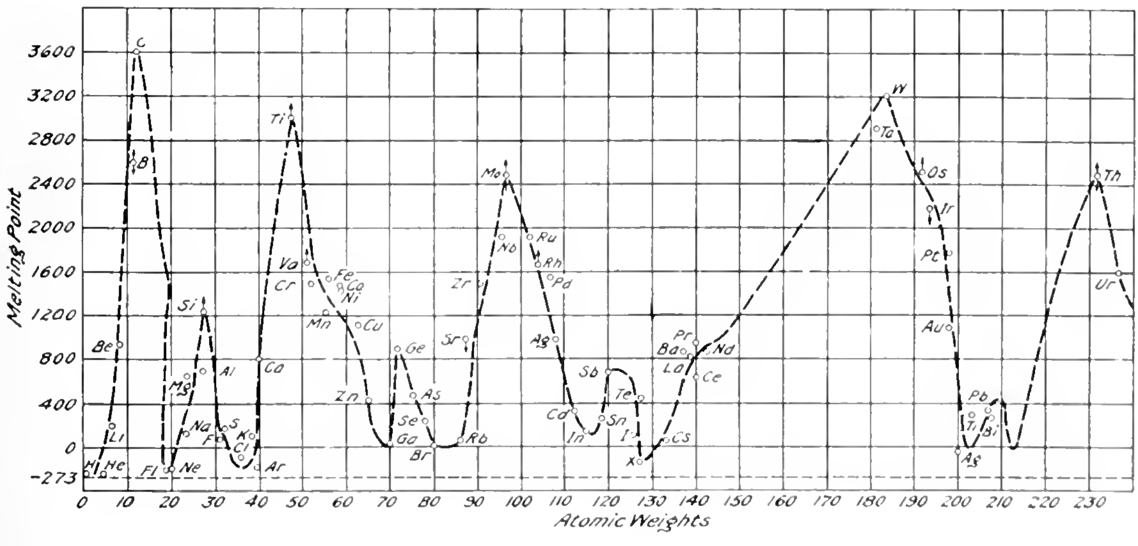
to note that in the gas flame *pure ceria* gives about the same light as *pure thoria*, while in the cathode rays of the Crookes tube,with conditions under which ceria gave almost no light, pure thoria gave an intense white light. These facts, which are still unexplained, illustrate how little is understood in this field.

I will merely refer to the fact that vapors of gasoline, kerosene, alcohol, etc., are now also used in conjunction with the Welsbach mantles. The field of acetylene I must also omit with a mere reference to the fact that the manufacture of calcium carbide was a chemical discovery; and the action of water upon it, producing the brilliantly-burning acetylene gas was another.

Turning now to electrical methods of generating light, we find the chemist early at work. Sir Humphrey Davy and others, at the dawn of the nineteenth century, showed the possibilities which since that time have been developed into our various types of incandescent and arc lamps. We naturally attach Mr. Edison's name to the development of the carbon incandescent lamp, because it was through his indefatigable efforts that a practicable lamp and illuminating system were both developed.

It had long been known that platinum, heated by the current, gave a fair light, but it melted too easily. A truly enormous amount of work was done in attempts to raise the melting-point of the platinum, and the effect of occluded gases, of annealing, of crystalline condition, etc., were most carefully studied, but the results were unsatisfactory. He was therefore led to the element carbon as the next most promising conductor of high melting-point. Edison's persistent and finally successful attempts to get a dense, strong, practical filament of pure carbon for his lamps, is one of the most encouraging lessons to the chemist of to-day.

This history needs to be read in the light of the knowledge of carbon at that time and the severe requirements of a commercially useful carbon filament. It illustrates the value of continued effort when it is based on knowledge or sound reasoning. The search was not the groping in the dark that some of us have imagined, but was a resourceful search for the most satisfactory, among a multitude of possible materials. From our point of view, all subsequent changes in choice of material for incandescent lamp filaments have been dictated by the knowledge that high melting-point and low vapor



tension were the first requirements. If you will consult the curve (Fig. 1) of the *melting-points* of all the *elements*, as plotted against their *atomic weights*, you will see at once that the desired property of high melting-point is a periodic function of the atomic weight. And it is this fact, which was independently disclosed as a general law by Meyer and Mendeljeff, in 1869, that has aided in the selection of all the new materials for this use. You will notice that the peaks of the curves are occupied by such elements as carbon, tantalum, tungsten, osmium, etc., which are all lamp materials.

A study of the laws of *radiation* also soon played a part in incandescent lamp work. The early rough and black filament of bamboo was first replaced by a polished black carbon filament, and later by one which had a bright, silver-gray coat of graphite. A black body at any temperature radiates the maximum possible energy in all wave-lengths. Heated to incandescence, it will *radiate more invisible and useless infra-red rays than any other* opaque material at the same temperature; a polished metal is therefore a more efficient light source than the same metal with a black, or even rough surface. This fact is derived from Kirchoff's law of radiation and absorption, which was early established.

It may seem like penetrating too far into details to consider for a moment the changes in structure and surface which the carbon filament of our incandescent lamps has undergone, but the development of such an apparently closed problem is instructive, because it has yielded to such simple methods of attack. The core, or body, of the carbon filament of to-day is made by some one of the processes based on dissolving and reprecipitating cellulose, such as are used in artificial silk manufacture. The cellulose solution is squirted through a die into a liquid which hardens it into dense fibers. These cellulose fibers are then carbonized by being heated, out of contact with the air, at as high a temperature as possible with gas furnaces. All of this is also merely the application of chemistry which was first worked out in some of the German chemical laboratories.

This plain carbon filament (the result of this simple process), which might have been satisfactory in the early days, would nowadays be useless in a lamp, as its practical life is only about 100 hours at 3 watts per candle. In a subsequent process of manufacture it is therefore covered with a steel gray coating of graphite, which greatly improves the light emitting power. This coat is produced by heating the filament in an atmosphere of benzene or similar hydrocarbons. The electric current which heats the filament is of such an intensity that the decomposition of the hydrocarbon produces a smooth, dense deposit of graphite.

With this graphite-coat the filament now burns about 500 hours. But the simple graphite coat is improved by being subjected, for a few moments, to a temperature of about 3,500° in the electric furnace; the life then becomes about 1,500 hours under the same operating conditions as before. The product of this treatment is known as the metallized filament, because by this last step its temperature coefficient of resistance is made similar to that of the metals; *i.e.*, 0.0037.

With an incandescent lamp containing a platinum wire filament, the intensity of its light is not very great, even when the current is sufficient to melt the wire. A much greater luminosity is produced by a plain carbon filament, and a still greater by the graphite-coated and metallized carbon before they are destroyed. In the case of carbon, the useful life of the lamp depends much more on the vaporization of the material than on its melting-point, and these lamps will operate for a short time at very much greater efficiencies or higher temperatures than is possible when a practical length of life is considered. Thus, besides the physical effect of surface quality, we have evidence of differences in the vapor pressure of different kinds of carbon. It looks as though carbonized organic matter yielded a carbon of much greater vapor pressure for given temperature than graphite, and that even graphite and metallized graphite are of quite distinctly different vapor pressures at high temperatures. It may be interesting to note here that if the carbon filament could withstand for 500 hours the maximum temperature which it withstands for a few moments, the cost of operating incandescent lamps could be reduced to nearly a fifth of the present cost.

It was discovered by Auer von Welsbach that the metal osmium could be made into a filament, though it could not be drawn as a wire. The osmium lamp was the first of the recent trio of metallic filament incandescent lamps. The tantalum lamp, in which another high melting-point metal replaces the superior but more expensive osmium, has been in use six or eight years. This surpasses the carbon in its action, and on running up to its melting-point it shows still brighter light than carbon.

More recently the tungsten filament lamp has started to displace both of the others. At present this is the element which withstands the highest temperature without melting or vaporizing, and on being forced to its highest efficiency in a lamp it reaches higher luminosity; it is similar to carbon and tantalum in that an enormously greater efficiency may be produced for a very short time than can be utilized for a suitable length of life. The inherent changes at these temperatures, distillation or whatever they are, quickly destroy the lamp. The lamp will burn an appreciable time at an efficiency fifteen times as great as that of the common operating carbon incandescent lamp (at 3 watts per candle). In other words, light may be produced for a short time at an energy-cost one fifteenth of common practice, so that there is still a great field for further investigation directed towards merely making stationary those changing conditions which exist in the burning lamp.

While it is generally true that the light given by a heated body increases very rapidly with rise of temperature above 600°, the regularity of the phenomenon is commonly over-estimated. A certain simple law covering the relation between the temperature and the light emitted, has been found to apply to what we call a black body. This so-called Stefan-Boltzmann law states that "the total intensity of emission of a black body is proportional to the fourth power of the absolute temperature." There are, however, very few really black bodies in the sense of the law. The total emission from a hole in the wall of a heated sphere has been shown experimentally to follow the law rigidly, but most actual forms and sources of illumination do not. Most practical sources of artificial light are more efficient light producers than the simple law requires. This may be said to be due to the fact that these substances have characteristic powers of emitting relatively more useful energy as light than energy of longer wave-length (or heat rays). Most substances show a power of selective emission and we might say that an untried substance, heated to a temperature where it should be luminous, could exhibit almost any conceivable light effect. A simple illustration will serve to make this clear: If a piece of glass be heated to 600°, it does not emit light; if some powder such as clay be sprinkled upon it, light is emitted, and the proportion of light at the same temperature will depend upon the composition of the powder. Coblentz has shown, both for the Auer mantle and for the Nernst glower, that the emission spectra are really series emission bands in that portion of the energy curve which represents the larger part of the emitted energy. This is in the invisible infra-red part, and so the laws which govern the emission at a given temperature depend upon the *chemical composition* of the radiant source. Silicates, oxides, etc., show characteristic emission bands.

One of the most attractive fields of artificial light production has long been that of luminous gases or vapors. It has seemed as though this ought to be a most satisfactory method. The so-called Geissler tubes in which light is produced by the electrical discharge through gases at low pressure are familiar to all. The distribution of the energy emitted from gases is still further removed than that of solids from the laws of a black body, and a large proportion of the total electrical energy supplied to a rarefied gas may be emitted as lines and bands which are within the range of the visible spectrum. These lines, under definite conditions of pressure, etc., are characteristic of the different elements and compounds. The best known attempts to utilize this principle are the Moore system of lighting (in which long tubes of luminous gas are employed), and the mercury lamps, which, while more flexible on account of size, are still objectionable because of the color of the light.

It is rather interesting that the efficiencies of all of these various sources of electric light are not nearly so widely different as one would expect from a consideration of the widely divergent methods of light production employed.

From the light of a vapor or gas to that of an open arc is not a wide step, but the conditions in the arc are apparently quite complex and there is a great deal of room for interesting speculation in the phenomena of an arc. Briefly, there are two kinds of arcs to be considered in lighting. One has been in use for a century, the other for a few years only. The first is the successor to Sir Humphrey Davy's historical arc between charcoal points. In this kind of arc the current path itself is hardly luminous, and the light of the lamp is that given by the heated electrodes. In case of direct current it is the anode, or positive electrode, which gets the hotter and gives far the greater part of the light. In this carbon arc, it can readily be seen that the light is emitted by the heated solid carbon of one electrode; this gives a steady source of light, but is not so efficient as an arc in which material in the arc stream itself is the source of light. The arc may be made to play upon rare earth oxides, and these, being heated to incandescence, increase the luminosity, but this has not proved useful. The more common way is to introduce into the carbon electrode certain salts which volatilize into the arc and give a luminous effect. Here cerium fluoride, calcium fluoride, etc., are used, and the color of the arc, just as in the case of gas mantles, may be varied by varying the composition of the electrodes. This is seen in the arc from the carbon electrodes containing such salts.

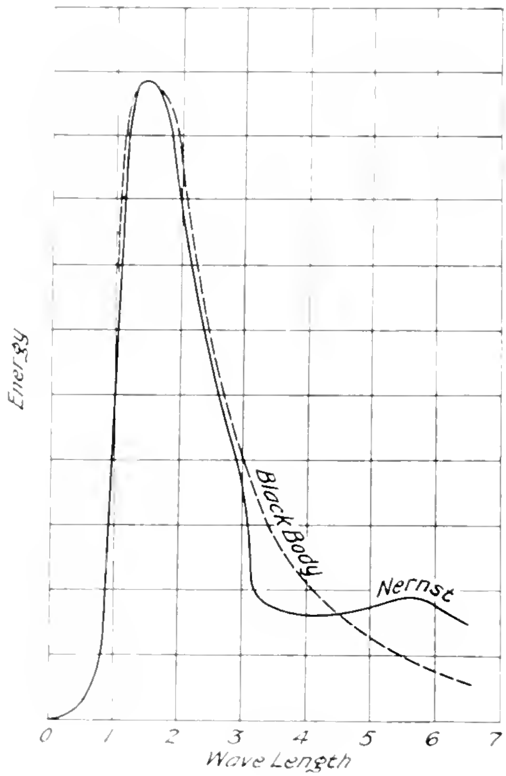


Fig. 2

In the case of the flaming arc, the greater part of the light is due to the incandescent metallic vapors in the space between the electrodes. Substitution of one chemical for another in such flaming arc electrodes has covered quite a wide range of chemical investigation. Salts are chosen which give the greatest luminosity without causing the formation of too much ash or slag. Some compounds of calcium, for example, are practicable, while others are not, though all of these would, under suitable conditions, yield the calcium spectrum. If such salts as calcium fluoride were conductors at ordinary temperature, useful electrodes for flame arcs would probably be made from them. Such conducting materials as iron oxide, carbides, etc., have been used for flame arc electrodes, and a great many of the so-called magnetite arcs are now in use. The electrodes

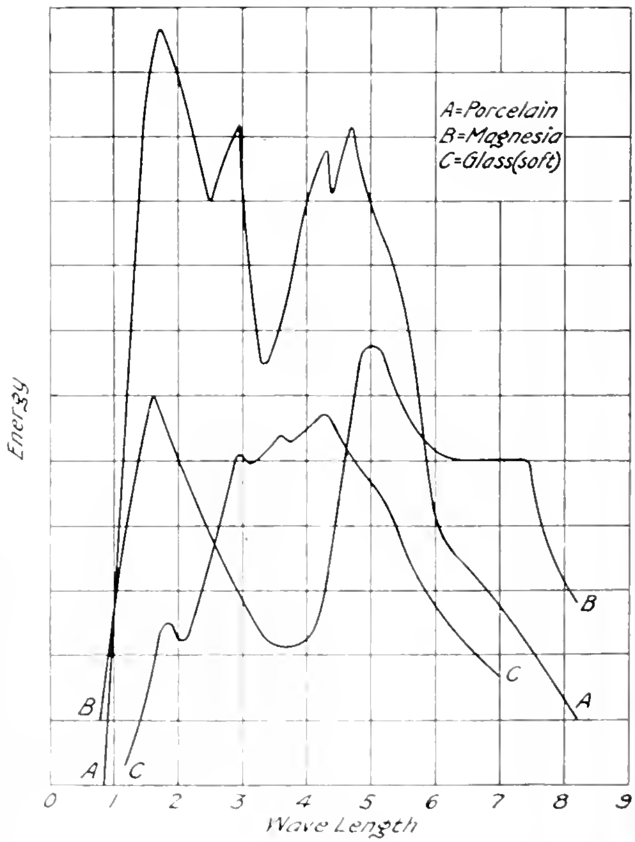


Fig. 3

in this case are largely magnetic oxide of iron, with such other ingredients as titanium and chromium oxides, to increase the intensity of light, to raise the melting-point of the mixture, etc.

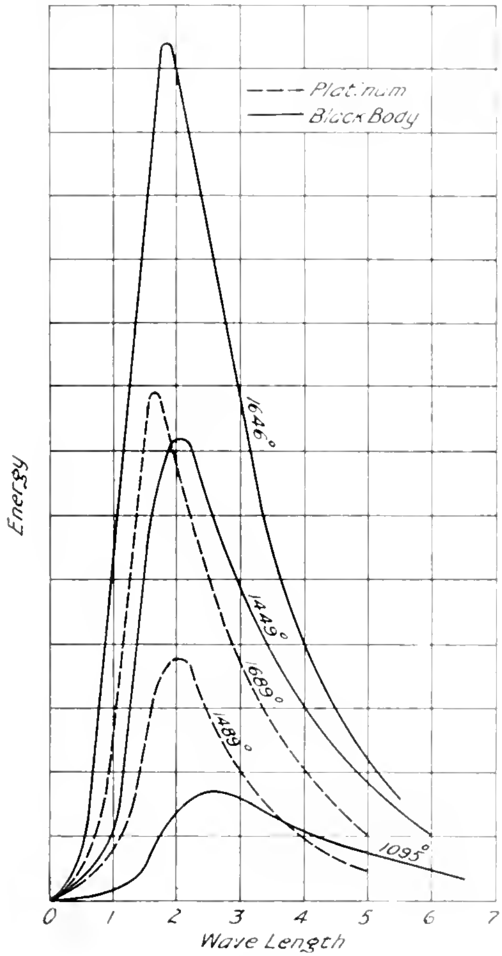


Fig. 4

As will be seen from observing this arc, the light is very white and intense and is generated by the heated vapors of the arc proper. A great many modifications of this arc principle are possible. Titanium carbide and similar substances give characteristic arcs, and some of them are very intense and efficient.

The Nernst Lamp

A distinct species of electric incandescent lamp is that invented about ten years ago by the well-known physical chemist, Professor Nernst. This employs for filaments a class of bodies which are not electrical conductors at all at ordinary temperatures, and which, at their burning temperatures, do not conduct the current as metals and carbon, but as a solution does. This kind of conductivity, the electrolytic, involves electrochemical decomposition at the electrodes, and in the case of the Nernst filaments these otherwise destructive reactions are rendered harmless by the continual oxidizing action of the air. For this reason this type of lamp will not burn in vacuo.

For its most perfect utility the principle of the Nernst lamp seems to require a mixture of oxides, because a single one is not so good a conductor nor so luminous. It uses oxides because these are the most stable compounds known, and it uses the rare earth oxides because they have higher melting-point than other oxides. As the efficiency rises very rapidly with temperature, there is a great advantage in using the most infusible base possible. For that reason, zirconia, thoria, etc., are usually employed.

In this lamp a rod or filament of an oxide mixture, much like those used in Welsbach mantles, is heated by the current, externally applied, until it reaches a temperature at which it becomes a good conductor itself. Here again the peculiar laws of light radiation are illustrated, the light emitted at a given temperature being determined by the nature of the substance. Just as the pure thoria gives a poor light compared to the mixture with one per cent. ceria, so a pure zirconia rod, heated by the current, gives much less light than a rod containing a little thoria, ceria or similar oxide. Work done by Coblentz on the energy-emission of such rods shows the emission spectra, at least in the infra-red, to vary with the nature of the substance. In general, the spectra are not continuous like the spectra of metals and black bodies, but seem to occupy an intermediate position between these and luminous gases, which we know have usually distinct line spectra.

This recalls the subject of selective emission. Coblentz has shown selective emission in the long wave-lengths for a Nernst glower. This is shown in comparison with the emission of a black body, in curve No. 2. The two sources, when compared at the temperatures where they exhibit the same wave-length for maximum emission, differ very considerably in emission in the infra-red, the black body giving more energy at the blue end, and less at the red end of the spectrum.

This is still more noticeable in the curves for such substances as porcelain, magnesia and glass, as shown by Coblentz's curves (Fig. 3).

The curves of wave-length and radiant energy which are shown are, with slight modifications, taken from work of Lummer and Pringsheim and of Dr. Coblentz. The curve for the ideal, or black body radiator, gives a picture of the total energy and its distribution over the different wave-lengths. It is the peculiarity of the black body to radiate more energy of any given wave-length than does any other body at the same temperature. Therefore, in case of all substances acting as thermal radiators, the black body will always give the greatest brilliancy. Since this body at the same time radiates a maximum in *all* wave-lengths, it will be surpassed in light *efficiency* by any substance which is a relatively poor radiator in the invisible or non-luminous part of the spectrum.

In the energy curves shown it is to be noticed that the visible part of the energy is practically only that between 0.4 and 0.8 thousandths of a millimeter. Consider the solid lines in Fig. 4 for a moment. These show the emission of a black body at centigrade temperatures noted on the curves. Evidently the energy emitted rises very rapidly with the temperature: *i.e.*, as the fourth power of the absolute temperature. It will be noted also that the point of maximum energy or wave-length corresponding to maximum energy, shifts gradually towards the left, or towards the visible wave-lengths.

It is this rapid shifting of the position of maximum energy which makes the search for substances which can withstand even only slightly higher temperatures of such great interest.

The curves for the black body and for platinum (dotted lines) are not greatly different in general appearance, but the total amount of energy emitted at a given temperature from the black body is shown to be more than for the platinum, and it can be seen that at about the same temperature the platinum is the more economical light source. Professor Lummer has said that at red heat, bright platinum does not radiate *one tenth* the total energy which the ideal black body radiates at the same temperature, and at the highest temperature still less than one half. The deviation of platinum from the black body law is a step in the direction of getting improved light-efficiency without corresponding increase of temperature. This method is practically without limit in its extension, for there seems to be no limit to the forms of energy curves which different substances may possess. The curves are apparently determined not only by physical state, but also by chemical composition of the emitting substance.

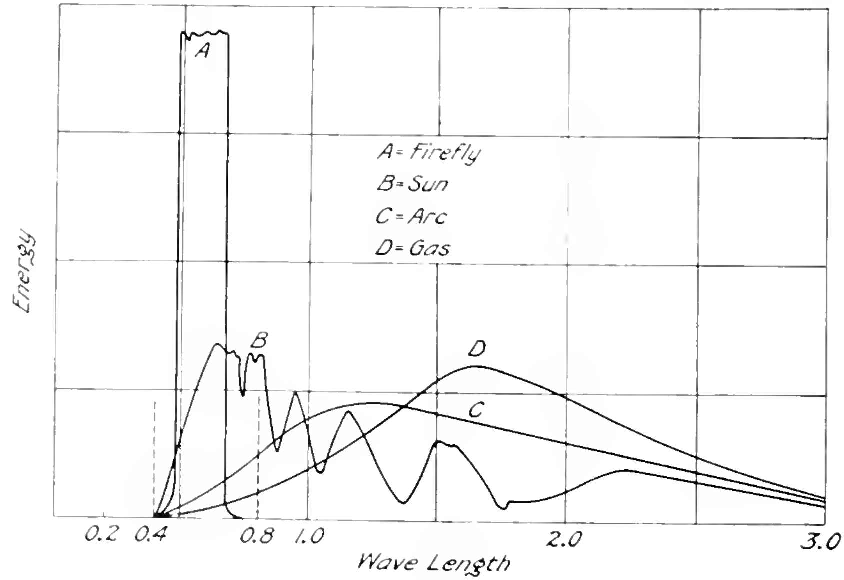


Fig. 5

In the production of artificial light, the tendency will always be in the direction of increasing the practical efficiency; *i.e.*, reducing the cost of light. We have seen that there is still much room for this. In the case of the kerosene oil lamp we know that much less than one per cent. of the energy of combustion of the oil is radiated as light from the flame. In the case of the most efficient source—the electric incandescent lamp at *highest* efficiency—we are still far from ideal efficiency. A still higher temperature would yield a yet higher efficiency. We do not know exactly how much light might possibly be yielded for a given consumption of energy, but one experimenter concludes that it is about ten candles per watt. Fortunately, it is not now clear just how the chemist is to realize all the advances which he will make in more efficient lights.

No consideration of this part of the subject is complete without a brief reference to the efficiency of the firefly. The source of his illumination is evidently chemical. This much is known about the process:

The light-giving reaction is made to cease by the removal of the air, and to increase in intensity by presence of pure oxygen. It is extinguished in irrespirable gases, but persists in air some time after the death of the insect. Its production is accompanied by the formation of carbon dioxide. These all indicate a chemical combustion process. Professor Langley has shown that such a flame as the candle produces several hundred times as much useless heat as the total radiation of the firefly for equal luminosity. In other words, the firefly is the most efficient light source known. This is illustrated by the energy distribution curves from several light sources taken from Professor Langley's work (Fig. 5). The difficulties attendant upon the accurate determination of the curve for the firefly are so great that we ought not to expect very great accuracy in this case. These curves, which in each case refer to the energy after passing through glass, which cuts off energy of long wave-lengths, represent the same quantities of radiant energy. While the sun is much more efficient than the gas flame or carbon arc, it still presents far the largest part of its energy in the invisible long wave-lengths (above 0.8), while the firefly seems to have its radiant energy confined to a narrow part of the visible spectrum.

COMMERCIAL ELECTRICAL TESTING

Part V

By E. F. Collins

Technical Superintendent

General Electric Company

Commutating Poles

The commutating pole produces the necessary flux for neutralizing the effect of armature reaction, and prevents that shifting of the electrical neutral point between no load and full load which occurs in direct current machines not equipped with commutating poles; and, in addition, aids the current reversals in the armature coils at commutation. To obtain the reversal without sparking, with normal load current flowing, a definite number of ampere turns is required. In many cases, fractional turns are necessary in the commutating field winding; but as only whole turns or half turns are possible for mechanical reasons, a shunt is connected across the terminals of the commutating field winding and adjusted in test to shunt the current in excess of that required. As the electrical neutral does not shift, the brushes are set on the no-load electrical neutral, the adjustments made, and the rocker arm chisel-marked for that setting. Because of this position of the brushes, the machine is sensitive to conditions that under-excite the commutating poles, or make them inactive. Such conditions may cause the neutral to shift, resulting in bad sparking at the brushes or even a flash over, particularly in the case of machines of 500 volts or over.

Consider, for instance, a 300 kw., 500 volt generator, with a heavy german silver shunt across the terminals of the commutating field winding. If the machine is short circuited, the inductance of the commutating field coils forces the instantaneous heavy overload current through the non-inductive german silver shunt and leaves the commutating field without sufficient excitation to neutralize armature reaction. The electrical neutral immediately shifts and bad commutation results. To eliminate this trouble, an inductive shunt is used across the terminals of the commutating field winding, and must always be in circuit when the machine in test is under load. If a short circuit occurs, the inductance of this shunt, being greater than that of the commutating field winding, forces the heavy line current through the field winding and tends to keep the compensation normal for all conditions of load.

Inductive Shunt

An inductive shunt is used on all machines of 500 volts or more, of a normal current rating of 400 amperes or greater. As a test is necessary to determine exactly how much current must be shunted from the commutating field, the inductive shunt is designed with an inductance greater than that of the commutating field winding and with low resistance and ample current carrying capacity. Any additional resistance necessary is obtained by connecting german silver in series with the inductive shunt, the length and resistance of which is varied till an adjustment is obtained that gives practically perfect commutation throughout the whole load range for which the machine was designed.

Location of Electrical Neutral

After a commutating pole machine has been brought to normal voltage at no-load, the no-load electrical neutral must be located. To do this, a fibre brush of the same size as the carbon brushes on the generator in test must be procured. This brush should have two holes drilled through it, each of which will take a No. 12 bare wire; the spacing between the holes being equal to the distance between adjacent commutator bars. The wires should be small enough to move freely through the holes, otherwise they may stick and make poor contact on the commutator, or become wedged and bear on the commutator so hard as to score it badly. One carbon brush should be removed from its holder and the fibre brush inserted in its place, with the two wires in the brush connected to a low reading, or millivoltmeter. With normal volts no-load on the generator, the brushes should be shifted till the instrument needle has passed through the zero point, and then back again until the instrument again indicates zero, to make sure that the actual zero has been found. Pencil mark the rocker arm for this shift and then move the fibre brush to each of the other studs successively, shifting the brushes, if necessary, till zero reading is obtained, and pencil-mark the rocker arm for each stud. If a different shift is required to locate the neutral of the different studs, shift the brushes to a position which is the mean of all the different positions. With the brushes set in the mean position and the inductive shunt properly connected, put on normal load and note the commutation. If commutation is not practically sparkless at normal load and rated overload, take off the load and field excitation, and connect a german silver shunt across the commutating field terminals. If the machine requires an inductive shunt, the german silver and inductive shunts are connected in series. With the total shunt resistance great enough to shunt not more than 10 per cent. of normal load current, full load is applied and commutation noted. The length of the german silver is changed and the commutation is tested until an adjustment has been obtained which gives the best commutation throughout the range of load required. An ammeter is then connected in and the number of amperes flowing through the shunt circuit read and recorded. In case satisfactory commutation cannot be secured, the wiring, spool assembly, pole and brush spacing, air gap, polarity, spacing of equalizing rings, etc., should be checked. If these are all found to be correct, the fibre brush should be used again and the full load neutral of each stud tested. If an appreciable voltage is obtained between adjacent bars, the brushes should be carefully shifted until zero voltage is obtained, and the shunt across the commutating field readjusted. With the best shunt adjustment possible, the fibre brush should be used on each stud, and readings made of the current shunted and the shift of the brushes from the no-load neutral.

If the full-load electrical neutral of one or more studs is found to differ appreciably from that of the others, the commutating pole spacing, brush spacing, and air gaps of those poles and studs which affect the neutral in question should be carefully checked.

When a final adjustment has been obtained on any commutating pole machine of 200 kw. or greater, the fibre brush should be used on each stud and the results with full load recorded.

In general, shunting current from the commutating field will shift the load neutral of all studs away from the no-load neutral by the same distance. Shunting less current will shift all neutrals toward the no-load neutral. Where possible, all adjustments should be made with the brushes on the no-load neutral, and the brushes should be left permanently in that position. The rocker arm of all commutating pole machines should be plainly chisel marked, when the final adjustment has been made. When satisfactory commutation has been obtained, a heavy load should be thrown on and off suddenly and a record made of the resultant commutation and general behavior of the machine. If the machine has an inductive shunt, and flashing or violent sparking is produced by throwing a heavy load on and off quickly, readjusting the air gap of the inductive shunt should be tried.

With a given winding on the core, the inductance of the shunt may be varied by changing the gap, and the relative inductance of the shunt and commutating field winding be thus adjusted. If the current in the shunt circuit quickly falls to zero when a heavy load is thrown off by tripping the breaker, and the brushes show sparking, there is too little inductance in the inductive shunt and its air gap should be decreased. The air gap should be adjusted to give the minimum sparking when the machine is operating with a highly fluctuating load.

Baking Commutator

To bake the commutator on a commutating pole machine, the brushes should never be shifted under load to produce sparking and heating. They should always be shifted at no-load to insure against setting them beyond the safe limit of no-load commutation, thus preventing flash-over should the load be suddenly removed. When baking a commutator, it should also be remembered that the armature must not be short circuited through the commutating pole winding, as in this case the majority of machines will build up as series generators and the armature current cannot then be controlled.

DIRECT CURRENT MOTORS

The connections and wiring of all motors should be carefully examined, with particular reference to the field. At starting, the speed of the machine must be carefully followed with a tachometer, and the circuit breaker immediately opened if the speed rises above the prescribed limit.

With the starting rheostat or water box in the off position, the terminals of the rheostat or box must be attached across the open main switch, with the circuit breaker closed; the lower terminal being attached first. The field switch should then be closed and the pole pieces tested with a piece of iron for excitation. The resistance across the main switch should then be gradually cut out and, if the speed is all right, the main switch closed.

If the motor runs above normal speed the wiring should be carefully examined to see that the field is connected across the circuit. Sometimes by mistake the field is connected across the main switch; in which case as soon as the starting resistance is cut out the field current falls rapidly and the motor speeds up excessively. To test for wrong connection, read volts field during starting and, if the field is wrongly connected, the volts field will drop as the starting rheostat is cut out.

If a potential curve cannot be taken on a motor with a multiple wound armature by running it as a generator, a "motor potential curve" may be taken by the following method: The machine is run as a motor with the field self-excited, the field current is held constant, and a constant voltage is applied to the armature, using only two adjacent sets of brushes on the commutator. A careful reading of the speed is then taken. The brushes on the next pair of studs should be placed on the commutator, and the speed again taken with the same voltage and field current as before; this procedure being repeated for all pairs of adjacent brushes. For a direct current generator, the speed should vary directly with the voltage if a potential curve is taken as described. This method should never be employed unless it is impossible to drive the machine as a generator, as it is very difficult to read the tachometer sufficiently accurately.

With no load, normal voltage, and full field, a speed reading is taken, the brushes being shifted so that when full load is on, the speed is not less than 5 per cent. below nor more than 2 per cent. above normal speed. At the end of the speed run the machine is loaded, the brushes shifted if necessary, and the commutation noted.

On compound wound motors, a shunt is adjusted across the series field to give a speed within 4 per cent. of the correct speed at rated load. Speed curves and running light should be taken with the series field disconnected.

Running light should be taken at hot full load speed.

Commutating Pole Motors

The electrical neutral on commutating pole motors is determined by shifting the brushes until the same speed is obtained in both directions with the same value of field current. This position of the rocker arm is marked. In double speed motors of this type, the neutral should be obtained at the high speed.

Machines sometimes hunt with full commutating pole field, thus preventing the location of the neutral from being obtained. In this case, the field current should be slightly shunted, even if commutation is affected. Good commutation is rarely obtained in the unstable condition.

In testing motors sent out as single units, of which the direction of rotation is not known, the electrical neutral should be located by shifting the brushes at no-load, till a position is found that will give the same speed in both directions of rotation. The fibre brush method should not be used. To perform this test quickly, reversing switches are used in the series and shunt field circuits. Care must be taken, when shifting the brushes, to avoid a dangerous rise of speed.

When the proper no-load shift has been found for full commutating field, normal load is applied and the commutation and speed noted. If the speed has increased under load or the commutation is not sparkless, a german silver shunt is used across the commutating field and adjusted for commutation, the speed for each change in the shunt being noted to ascertain whether the speed is decreasing under load. When the final shunt adjustment is obtained, a speed curve reading is taken and the speed and commutation in both directions of rotation, at no-load, full load and whatever overload is required are recorded. At the conclusion of all tests required, while the machine is hot, a hot speed curve covering the same range of load as used in the cold curve is taken. In the case of two-speed machines, this curve should be taken at both speeds. Additional no-load and full-load readings should be taken at full field. If a falling or constant speed is obtained, and commutation is satisfactory, no shunt is necessary; otherwise, a shunt must be placed across the commutating field and adjusted to give these speeds.

Commutating pole variable speed motors must have the shunt in the commutating pole field adjusted for the highest rated speed. Speed curves and running light tests should be made at both speed limits.

Shunt wound variable speed motors have the brushes set for commutation at the speed limits. Speed curves and running light tests should be made at both of these speeds.

Some compound wound variable speed motors are not designed to run light; consequently, before starting, the smallest load the motor is designed to carry should be ascertained. Commutation should be adjusted at the various speeds, series full field readings being taken and the speed carefully recorded. Speed curves should be taken at the different speeds; also running light, with the series field disconnected.

Standard Efficiency Tests are made by the method of losses.

Employing the same nomenclature as that used in calculating the standard efficiency of direct current generators, a motor efficiency is calculated as follows:

$C_4 = C_L - C_6$

Watts input $W_A = C_L V_L$

W_1 = Core loss taken from the core loss curve corresponding to $V_L - CR$

Then $\Sigma W = W_1 + W_2 + W_3 + C^2{}_4 R_4 + C^2{}_4 R_5 + C^2{}_6 K_6 + (C_6 V_L - C^2{}_6 R_6) + C^2{}_8 R_8 + C^2{}_9 R_9 + C^2{}_{10} R_{10} + C^2{}_{11} R_{11}$

as before.

Watts output $W_b = W_a - \Sigma W$ and

$$E = \frac{W_b}{W_a}$$

Since motors are always rated according to horse-power output

$$H.P. = \frac{W_b}{746}$$

If, as in the case of direct current generators, only a running light is taken and it is desired to combine the resistances of the series and commutating pole fields with their respective shunts and to combine the losses in the shunt field and rheostats, then

$$\Sigma W = \text{Running light} + C^2{}_4 R_4 + C^2{}_4 R_5 + C_6 V_L + C^2{}_L R_{SF} + C^2{}_L R_{CF}$$

In the case of shunt motors

$$\Sigma W = \text{Running light} + C^2{}_4 R_4 + C^2{}_4 R_5 + C_6 V_l$$

The remarks made under the subject of direct current generators in reference to the calculation of brush friction, brush contact resistance and hot resistances, as well as to *all other* efficiency calculations, apply in the case of motors.

It will be seen from Fig. 23 that motor efficiencies are plotted with amperes line as abscissæ and per cent. efficiency and horse-power output as ordinates. The horse-power curve should be produced to intersect the axis of X at running light *amperes line*.

For NORMAL LOAD HEAT RUN the machine is run under load until it has reached constant temperatures, and these are then recorded. All series field shunt adjustments must be made to give the required regulation at the specified load.

For OVERLOAD HEAT RUN the machine is brought to normal load temperatures and the required overload is then applied for the specified time and the temperatures recorded.

Direct Current Series and Railway Motors

The principal type of series motor is the railway motor. Other types, however, are built for use with hoists, air compressors, pumps, etc. As all these motors are designed for intermittent service, the test, unless otherwise specified, is a one hour run at full load, with the brushes set on the neutral point. The load must *never* be taken off a series motor unless the armature circuit is first opened, otherwise the motor will run away. For the same reason a series motor should always be started under load. All running light tests must therefore be made with the field separately excited.

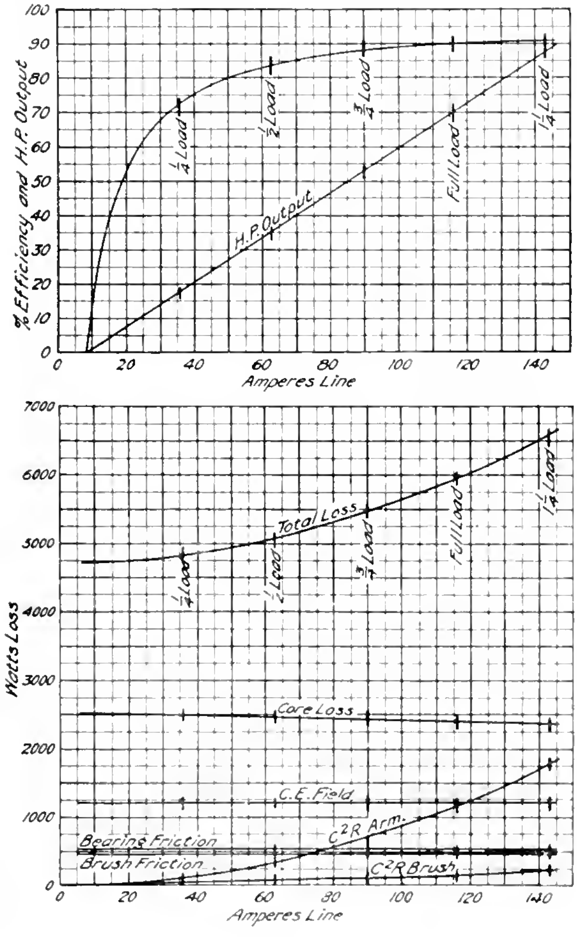


Fig. 23
Efficiency and Losses on a 70 h.p., 6 Pole, 850 R.P.M 500 Volt D.C. Motor
(Plotted to values of Table IX, February REVIEW)

As the tests on railway motors are very complete and the general method applies to tests on any series motor, those on railway motors will be discussed more or less in detail. Hot and cold resistances must be taken on all railway motors and high potential applied both while the motor is cold and hot.

GENERAL TESTS consist of sufficient preliminary tests to warrant engineering approval or disapproval for production. It is impossible to definitely define the heading, since the tests may include only a few minor tests, or they may include complete and special tests. For instance, it may be necessary to make slight changes in either the construction or design of a standard motor in order that it may meet special requirements. After these changes have been made, tests are conducted to make sure that the motor will meet such conditions satisfactorily. These tests are included under general tests, and if after completion they are found to be satisfactory, engineering approval is given for the production of the machine in question.

COMPLETE TESTS consist of special tests, thermal characteristics, commutation and input-output. With the exception of commutation, the other tests under this heading will be considered separately.

Commutating tests on series railway motors should be made by holding normal voltage and operating the machine at loads varying from $33\frac{1}{3}$ per cent. to 200 per cent. normal load.

On series commutating pole motors, interruption tests are taken. These tests consist in opening and closing the motor circuit while the machine is running at various loads and speeds. The machine should stand such tests without arcing over at line voltage as high as 125 per cent. normal. The loads are varied from $33\frac{1}{3}$ per cent. to 200 per cent. normal. Mill motors are tested for commutation by suddenly reversing the direction of rotation under various loads.

Development tests consist of general tests and special tests, and are made when an entirely new type of machine is being developed.

SPECIAL TESTS consist of speed curves, core loss, and saturation tests.

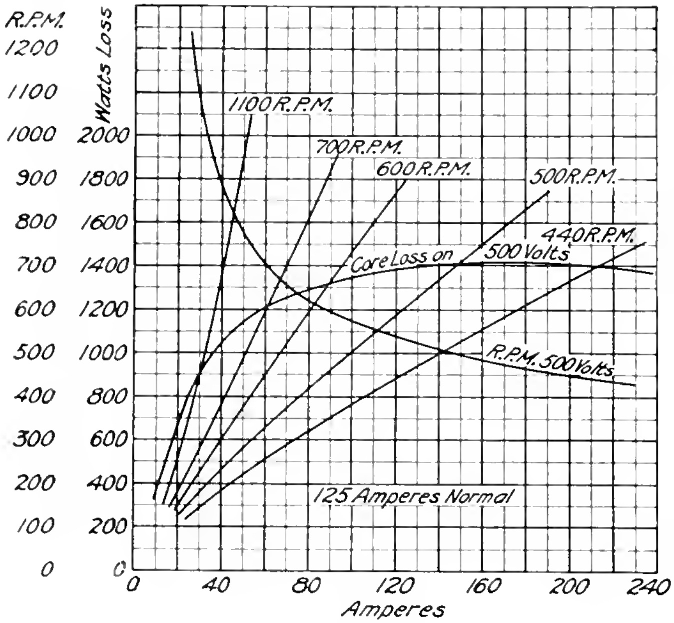


Fig. 24
Core Loss and Speed Curve of a 50 H.P., 500 Volt Railway Motor

In taking a speed curve two similar motors are placed on a testing stand and the pinion of each is meshed in the same gear mounted on a shaft. One motor drives the other as a separately excited generator and is run loaded until the motor is heated to about 50° C. rise. The speed curve is then taken on the motor rotating in first one direction and then the other, the voltage being held constant. The resistances of armature and field should be measured both before and after taking the curve.

Core loss should be taken by the belted method, as on any other machine, except that the test should be made at about five speeds. (Fig. 24.) The lowest speed should correspond to about 175 per cent. full load amperes (taken from speed curves) and the highest at about 200 per cent. full load speed. During this test the machine is separately excited.

A saturation curve may be taken on a series motor just as on any other machine by separately exciting the field. Saturation curves at different speeds may be obtained from data taken during the core loss test.

The speed curves, core losses and saturation are calculated as previously explained. The speed curves and core losses should be plotted on the same sheet against amperes line as abscissæ and revolutions per minute and watts as ordinates. From these two sets of curves another curve can be developed, which will give the core loss of the motor at any speed or current.

The thermal characteristic should be obtained by making a series of heat runs at varying current values for a sufficient time to get a temperature rise of 75° C. All runs should be made at the same constant voltage, the current value for each run varying from 50 to 150 per cent. normal. If a sufficient number of heat runs are taken on a sufficient number of motors of the same class, type and form, the horse-power rating for 75° C. rise may be obtained for any length of run from one-half hour to continuous running. Before starting a heat run, cold resistances and temperatures should be taken. After the motor has run continuously for the specified time, with all covers off and all openings unrestricted and with amperes and volts held constant, it is shut down, hot resistances measured and all temperatures taken. The results of the thermal heat run should be plotted, one curve for armature and one for field, against times in hours as abscissæ and degrees centigrade rise as ordinates. Lines should be drawn through zero and the plotted points corresponding to the different loads, the intersections of these lines with the line of 75° C. rise giving the respective values of time that the motor takes to attain 75 degrees rise with that load. From these curves another curve should be plotted with time as abscissæ and amperes load as ordinates. This is an ampere-time curve for 75° C. rise. On the same sheet on which the ampere-time curve is plotted, a curve should be drawn with time as abscissæ and horse-power as ordinates, the horse-power being calculated from the standard 75° C. characteristics. (Fig. 25.)

In taking a load running test, as in the speed curve test, two motors are geared together on the same shaft (Fig. 26), one running as a motor at the rated voltage and full load current and driving the other as a separately excited generator. The separately excited field of the generator is in series with the motor field, thus giving normal full load excitation. The armature of the generator is

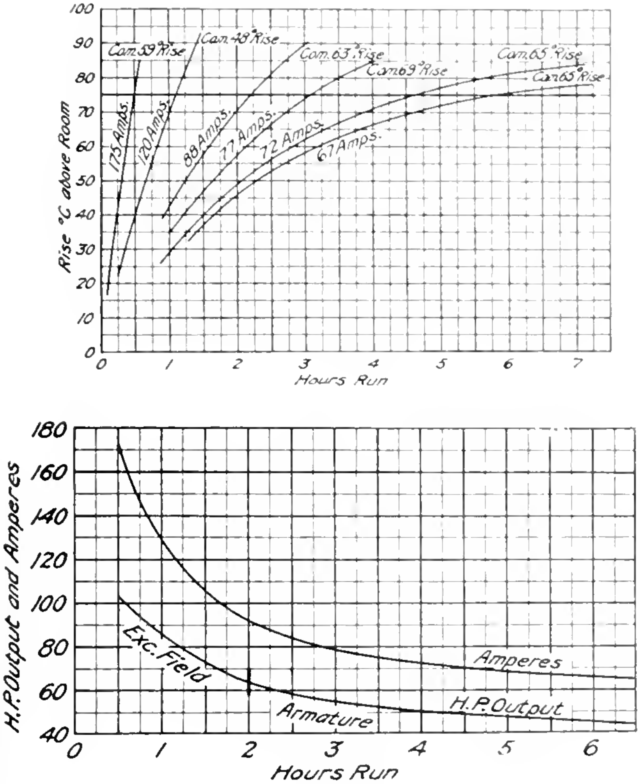


Fig. 25

Thermal Characteristics of a 75 H.P., 600 1200 Volt Railway Motor

connected to a water box, the resistance of which is varied until full load on the motor is obtained. The run is made for one hour, after which temperatures are taken.

Resistances are measured and high potential applied both before and after the test and before starting. The speed should be checked in both directions of rotation.

One out of every fifty of all types of motors should receive the one hour load run. All 600 volt commutating pole motors, with the exception of those receiving the one hour load run, should be run under load for ten minutes in each direction of rotation. Other motors the characteristics of which are well established should receive "commercial tests".

Commercial tests consist in running a motor light for a short period. It is the practice to run four motors in parallel, the fields being connected in series and separately excited by a current equal to the full load current of the motor. (Fig. 27.)

With normal voltage held onstant across the armatures, the motors are run light for ten minutes in each direction of rotation, readings of speed, and armature and field currents being recorded.

With rated voltage across the motors, the fields should be weakened until about twice normal speed is attained. Under these conditions the machine should be run in each direction for five minutes, the same readings as listed above being taken.

Resistance measurements and high potential tests must be made before and after this test.

Care must be taken that the resistance and speed at 25 degrees C. come within the prescribed limits already mentioned.

On all series motors, *with the exception of railway motors*, standard efficiency tests are made by the method of losses and the calculation of the efficiency is identical with that for any other motor. In this case, of course, amperes armature equal amperes line.

In making an input-output test the motors are geared and connected as for the load heat run and are usually run under full load for one hour up to ordinary working temperatures to get the bearings in good running condition. Before the load is put on, careful measurements of the armature and field resistance of the motor and of the armature of the generator are taken by the drop in potential method. Three different measurements should be made of each, with as many different values of current near normal load current.

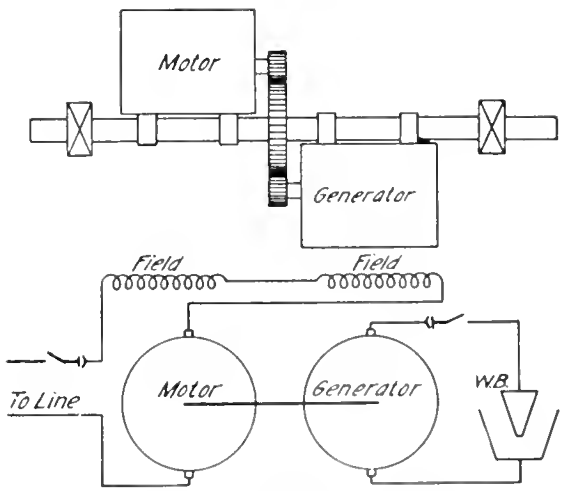


Fig. 26

Connections for Load Running Test on Railway Motors

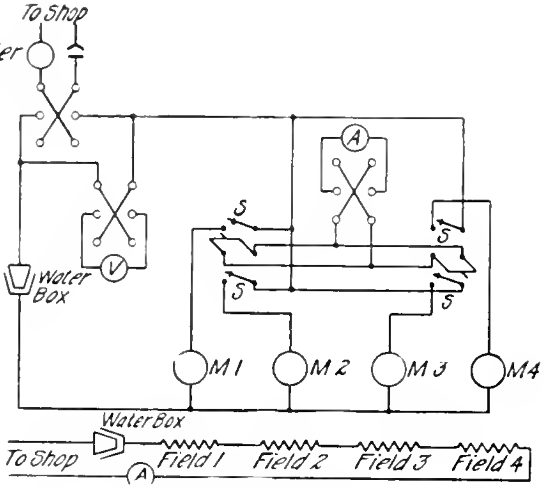


Fig. 27
Connections for Running Light on Railway Motor

Holding normal voltage constant, 12 or 15 different loads ranging from as low as possible to 150 per cent. load should be put on, the direction of rotation being such that the motor tends to lift from its bearings. Readings at each load should be taken of the amperes, volts armature and speed of the motor, and amperes and volts armature of the generator. The direction of rotation should then be changed and several check points taken in speed and amperes, after which the machine should be shut down and hot resistance measurements made.

Table X and Fig. 28 show the method of working and plotting the data obtained from the input-output test. Unless otherwise specified, the tractive effort and miles per hour are calculated for 33 in. wheels. The formulæ used are:

$$\text{Miles per hour} = \frac{\text{R.p.m.} \times \text{diam. of wheels in inches} \times \pi}{\text{Gear ratio} \times 1056}$$

$$\text{Traction effort} = \frac{\text{Amps.} \times \text{volts} \times \text{efficiency} \times 252}{\text{Miles per hour} \times 500}$$

The gear ratio is that between the gear and pinion.

From these characteristics new ones should be plotted, as shown in Fig. 29, the C^2R being corrected for 75° C.

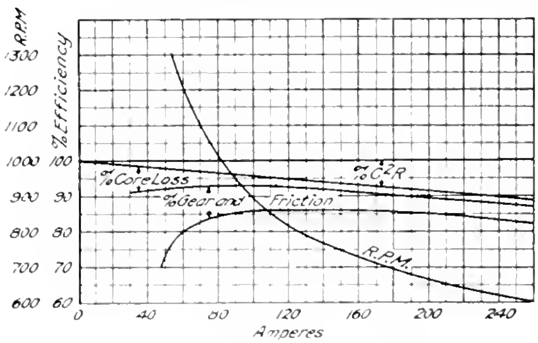


Fig. 28
Input-output Curves for a 75 H P., 600 Volt Railway Motor

TABLE X

SPEED, TRACTIVE EFFORT AND EFFICIENCY OF A 100 H.P. 600 V. RAILWAY MOTOR

Input Volts	Input Amps	C^2R %	Core Loss %	Gear + Friction %	Efficiency %	Miles per Hour on 33" Wheels Gear Ratio 3.35	Tractive Effort
600	40	1.7	5.3	30.0	63.0	45.0	170
600	60	2.5	4.1	14.0	79.4	35.4	407
600	80	3.3	3.4	9.0	84.3	29.6	687
600	100	4.2	3.0	7.5	85.3	26.2	984
600	120	5.0	2.6	6.5	85.9	23.8	1310
600	140	5.9	2.3	5.7	86.1	22.5	1615
600	160	6.7	2.1	5.0	86.2	21.3	1960
600	200	8.4	1.8	5.0	84.8	19.5	2630
600	240	10.0	1.5	5.0	83.5	18.1	3350
600	280	11.7	1.3	5.0	82.0	17.2	4040

Resistances at	75°C.
Armature	.107
Exciting Field	.076
Commutating Field	.050
Brush Contact	.017
Total	.250

TABLE XI

INPUT-OUTPUT OF A 100 H.P., 600 V. RAILWAY MOTOR

Motor	Volts	600	600	600	600	600
	Amps.	60.5	94.0	134	178	249
	R.P.M.	1216	935	790	700	610
	Watts Input	36300	56400	80400	106800	149200
	C^2R {Arm. + Brushes + Exc. Fld. + Comm. Field	935	2260	4590	8100	15800
	(A) = Watts − (C^2R)	35365	54140	75810	98700	133400
	(A) − (Core Loss + Fric.) = Output	29382	48180	69410	90755	123150
	Efficiency	80.9	85.4	86.4	85.0	82.5
Generator	Volts	602	592	580	551	522
	Amps.	38.5	70	105.5	142.5	203
	Watts	23170	41400	61150	79400	106000
	C^2R {Arm. + Brush + Comm. Field	248	820	1860	3410	6900
	(B) Watts + C^2R	23398	42220	63010	82810	112900
	(A − B) ÷ 2 = Core Loss + Friction (1 Mach.)	5983	5960	6400	7945	10259

		Motor	Generator
Resistances	Armature	.1082	.1015
	Exciting Field	.0792	—
	Comm. Field	.0522	.0492
	Brush Contact	.0170	.0170
	Total	.2566	.1677

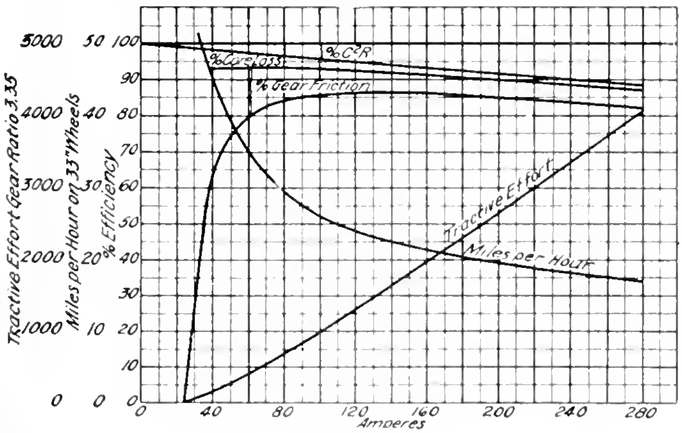


Fig. 29
Speed, Tractive Effort, Efficiency on a 75 H.P. 600 Volt Railway Motor

rise, and the gear loss assumed as 5 per cent. at full load. If the gear loss derived from test has to be changed at full load, it should be changed in the same ratio throughout the curve. (See Table XI.)

Cooling off tests are made by running the motor under full load, with covers off, for one hour, shutting down and reading temperatures as the machine cools down. For the first hour after the machine is shut down, the temperatures of the following parts are read every fifteen minutes: armature, commutator, field, frame, air in the motor, and room. After the first hour temperatures should be taken every half hour until the temperature of the hottest part is not more than 25 degrees C. above the surrounding atmosphere.

The results of the cooling off test should be plotted to time as abscissæ and degree C. rise as ordinates. The curves for armature, field, commutator, frame, and air in the motor, should all be plotted on one curve sheet.

THE JOHNSONVILLE HYDRO-ELECTRIC DEVELOPMENT OF THE SCHENECTADY POWER COMPANY

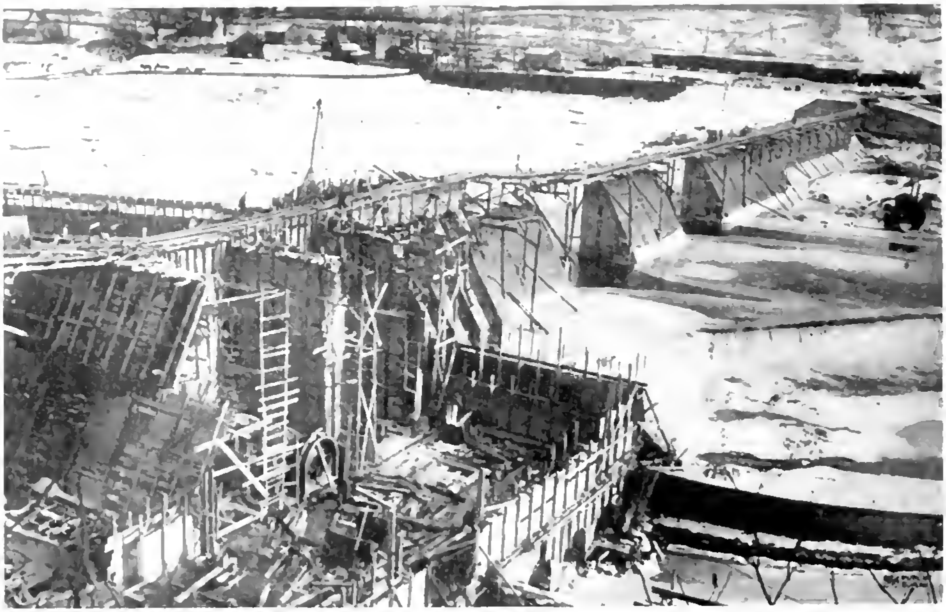
By John Liston

The rapidly extending use of electricity, especially in industrial applications, together with the high efficiencies now obtained in water wheels and generators, have combined to stimulate the development of those water powers affording either high heads or great volume wherever they have been found to be within practicable transmission distance of large centers of population.

As the field for the construction of larger hydro-electric plants becomes restricted, the small power station utilizing low or variable heads and designed either as an auxiliary to the larger plants or for the independent generation and distribution of electrical energy, becomes of increasing importance to the engineering fraternity.

In the Eastern States where the larger power sites have been to a great extent either developed or pre-empted, the construction of small power stations is already becoming an important factor in the future of hydro-electric development.

The Johnsonville power station on the Hoosic River is located at one end of a spillway dam constructed primarily to provide additional storage water for a larger power house at Schaghticoke, N. Y., which was described in the April, 1909, issue of the General Electric Review. The Schaghticoke plant utilizes a head of 150 ft. for generating 12,000 kw., which is transmitted on twin circuit steel towers at 30,000 volts, three-phase, 40 cycles, to Schenectady, N. Y., a distance of 21 miles.



General view of dam and power station during construction, showing turbine casing installed in north flume

Some water storage is secured by the dam at Schaghticoke, back of which an area of 145 acres is flooded, giving a capacity of 44 million cu. ft., but the main reservoir is at Johnsonville, as indicated above. The relative location of these dams and that of the transmission line connecting the two stations is shown in Fig. 4.

The pond back of the Schaghticoke dam is sufficient to hold one day's supply of water and insure the operation of the plant at any load factor, but does not provide sufficient storage capacity to carry the plant over periods of low water. It was therefore decided to construct another dam, at a point about 5 miles up the stream. This dam is located at Johnsonville, N. Y., about 15 miles northeast of the city of Troy, the drainage area of the Hoosic valley back of this point being about 550 square miles. The new dam backs the water up stream for a distance of 5 miles to the town of Buskirk, thereby flooding an area of 850 acres and giving an additional storage capacity of 332 million cu. ft. This, added to the pondage originally provided, gives a total available water storage capacity of 376 million cu. ft., or sufficient to supply a flow of 250 cu. ft. per sec. continuously for a period of 20 days.

The Johnsonville dam (see Fig. 1) runs approximately north and south at right angles to the flow of the river, and is located just above an earlier timber dam which was formerly utilized for power to drive a local mill. In exchange for the cession of riparian rights, the mill has been provided with motor drive and receives current from the new generating station.

High water during construction, showing water passing over the unfinished sections of the dam spillway

The development comprises a power house and sluice gates located on the north shore at the end of a spillway dam which extends to the south shore and ends in a heavy masonry abutment. This abutment is extended up

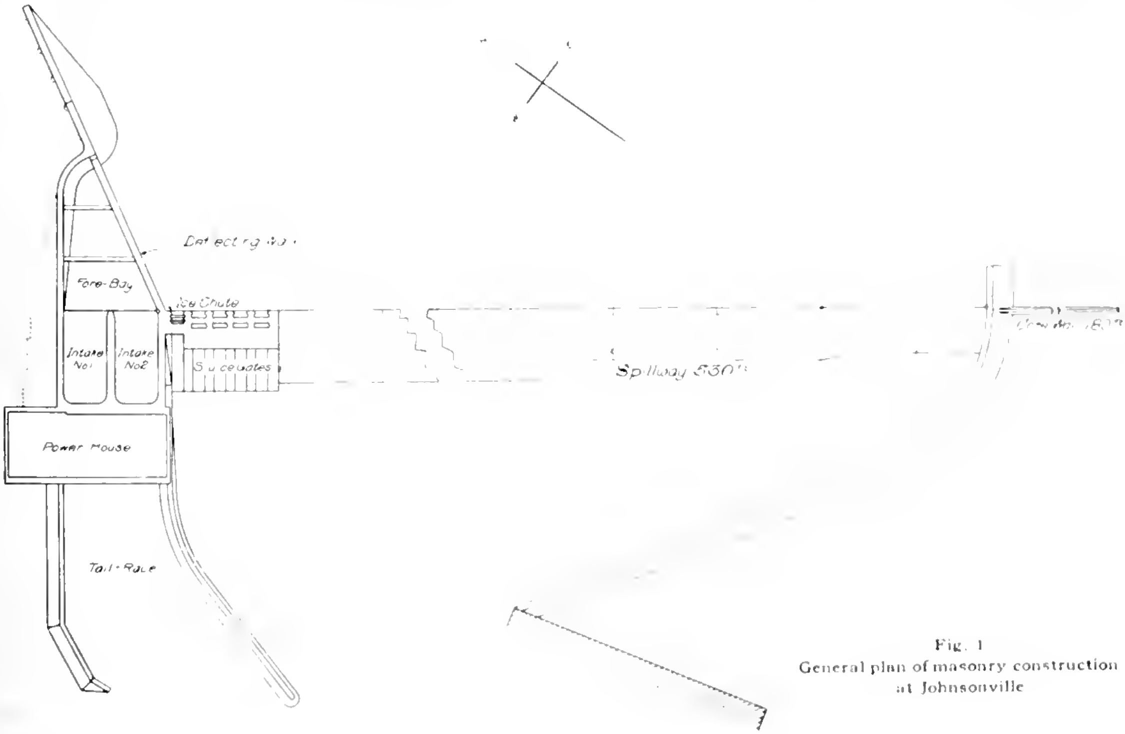


Fig. 1
General plan of masonry construction at Johnsonville

stream from the dam for a short distance in a straight line, while below the dam it curves towards the center of the stream, thereby deflecting the water from that portion of the south shore immediately below the dam and protecting the bank from erosion at that point,

Tail race and sluice gate diverting wall during construction

even in times of maximum flood. In this way it prevents injury to the mill buildings, which are located 120 feet below the new dam and beside the old crib dam already referred to.

The north shore of the river is clay hard pan but the dam rests on bed rock, undercut for its entire length. The south shore, however, is covered to a considerable depth with soil, and in order to prevent seepage around the end of the dam, a concrete core wall 180 ft. long was constructed, running on bed rock from the abutment at the end of the dam back to the high ground, as shown in Fig. 1. The core wall has a maximum height of 25 ft., and is covered by an earth embankment.

The dam is made of solid concrete and is built up in eleven sections with expansion joints every 50 ft.; it is of the ogee type with a total spillway length of 530 ft., a maximum height of 40 ft., and its greatest thickness at the base, of about 30 ft. Both the height and thickness of the dam diminish near the south shore where the river bed is higher.

The surface of the reservoir can be raised 3 ft. by means of flash boards, the crest of the dam being provided with brass tubes sunk 6 in. into the concrete and serving as sockets for the flashboard rods.

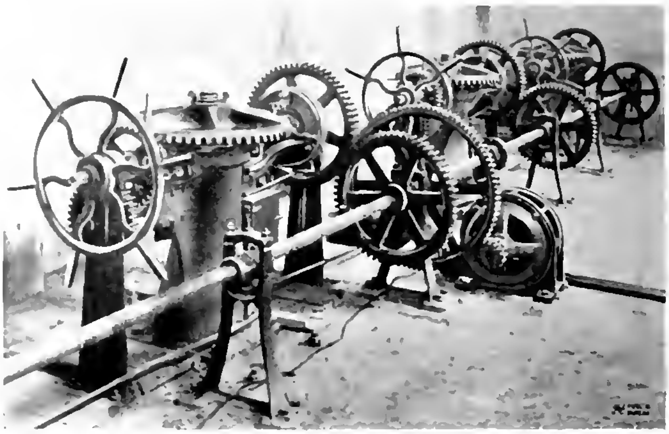
At the north shore end of the dam, 4 sluice gates and an ice chute are located. The sluice gate masonry is of concrete having a maximum thickness of 38 ft. at the base and provided with heavy buttresses on the down stream side.

The gates are of cast iron and are ordinarily operated through gearing by a 10 h.p. motor, which is coupled to one gate at a time by means of an automatic selector cut-out and a mechanical clutch.

To prevent injury to the apparatus the motor is controlled by a panel board located in the power house and equipped with circuit breakers and reversing contactors, so that when a gate strikes bottom the motor is automatically cut out of circuit. Handwheels are provided for use in the event of injury to the motor, and all the gate contrelling mechanism is housed in a concrete chamber which caps the gate masonry and is at a sufficient elevation above the crest of the dam to prevent injury during floods.

The gate openings are 6 ft. by 9 ft. each, and with the reservoir full their combined capacity is 8000 cu. ft. per sec. The gate masonry is grooved for stop logs so that the openings may be shut off and the gates inspected or repaired.

Between the sluice gates and the power house is a log and ice chute, having its sill 3 ft. below the crest of the dam; when not in service it is closed by means of 2 sets of stop logs set in side grooves. Running diagonally up stream from the ice chute to the north shore is a deflecting curtain wall



Sluice gate operating mechanism

about 160 ft. long, under which are 3 submerged openings that admit the water to the forebay. The top of this wall is 3 ft. above high water, and the inlets are 5 ft. below the crest of the dam and 2 ft. below the sill of the ice chute, so that floating ice, logs and other debris are diverted to the ice chute. The forebay portion of the wall has to withstand ice pressure from both sides,

View looking up stream showing finished power house and sluice gate masonry

and is therefore reinforced in both vertical faces and braced by two reinforced concrete beams spanning the triangular shaped forebay and tying the deflecting wall to the retaining wall which supports the clay hard pan bank of the north shore.

View looking down stream, showing dam equipped with flash boards and intake to forebay

The water from the forebay, after passing through screens and gates and under a curtain wall, enters two flumes, each $20\frac{1}{2}$ ft. wide, $27\frac{1}{2}$ ft. long, and 35 ft. high; the walls of which are of reinforced concrete 4 ft. thick, and designed to withstand the thrust of the water with both flumes full, or one full and the other empty. The reinforcing is carried back to the north shore retaining wall on one side and to the dam on the other, in order to give the necessary stability. The curtain wall over the intake gate is located directly across the intake and supports the upper part of the flume gate framework; it is 3 ft. thick at the top and extends downward from the deck of the flume for 17 ft.

The flume gates are made of structural steel, each approximately 18 ft. high and 21 ft.

wide; they operate in angle iron seats set in the concrete sides and owing to their great size have additional support in the form of two steel beams for each gate, which extend vertically from the floor of the flumes to a concrete girder at the bottom of the curtain wall. Each gate weighs about 7 tons and is raised or lowered by means of two steel screws connected to a pair of handwheel operated hoisting stands at the top of the flumes. In order to facilitate the raising of the gates, 24 inch by-pass valves are used to first fill the flumes and thus balance the water pressure.

As the Johnsonville dam is primarily intended to store water for the Schaghticoke power house, it is evident that the auxiliary power plant at the dam must frequently work under widely varying heads, and the turbines are therefore designed to operate under heads ranging from 24 ft. to 39 ft.

In each flume there is mounted a 57 inch double runner reaction turbine of the horizontal Francis type, as shown in Figs. 2 and 3. The wheels discharge into a common draft chest located between the runners and the amount of water which is admitted to the wheels is controlled by wicket gates mounted in a ring around the runners and operated by a common rotating shaft which is geared to the governor in the generating room.

When operating under a 35 ft. head the turbines develop 3000 h.p., and when the water is drawn down to a 24 ft. head the output is reduced to 1750 h.p.; the speed, however, remaining constant at 150 r.p.m.

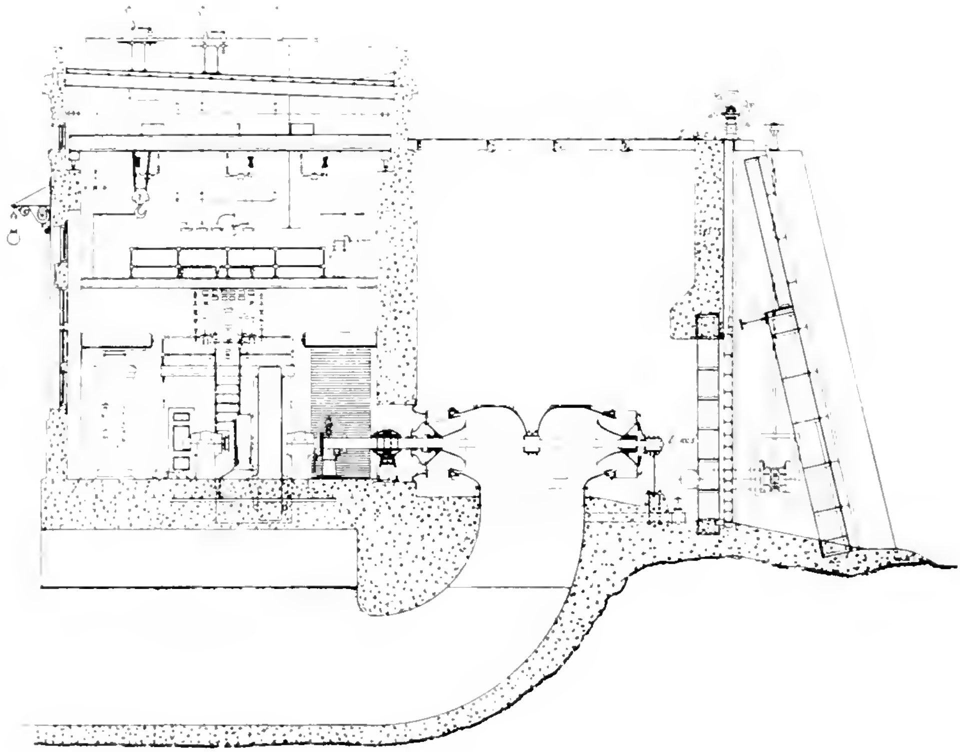


Fig. 2. Sectional view of power house and flume showing compact arrangement of the equipment

The walls which separate the wheel pits from the generating room are 4 ft. thick and made of reinforced concrete; the turbine shafts entering the power house through cast-iron watertight bulkheads, ring concreted in the wall. Each turbine is controlled by a standard "Lombard" oil pressure governor, belt connected to the generator shaft and geared to the wicket shaft, as shown in Fig. 3. The governor is ordinarily automatic in operation, but hand control is provided for in the event of injury to the governing mechanism.

A tubular glass water gauge located in the power house and set vertically between the governors at all times indicates the operating head.

The power house is constructed of reinforced concrete and steel, the approximate inside dimensions being 80 ft. long, 30 ft. wide, and 40 ft. high, the general arrangement of the interior being as shown in Figs. 2 and 3.

Although the capacity of this station is only 3600 kw., the construction throughout is of the most substantial nature and every device of approved value for maintaining high efficiency and uninterrupted service has been installed. The two transformers are located at the north end in separate fireproof compartments with steel curtain doors, and the switchboard is erected on a gallery between these compartments. Above this gallery is a floor extending across the building on which are located the generator and line motor operated oil switches, instrument transformers, aluminum lightning arrester equipment, and the high tension wiring. All the low tension equipment is located in a brick walled compartment beneath the switchboard gallery.

A 15-ton overhead traveling crane is included in the station equipment, and there is also a portable motor-driven air compressor set for cleaning the machinery; the direct current for the motor being supplied by the exciters.

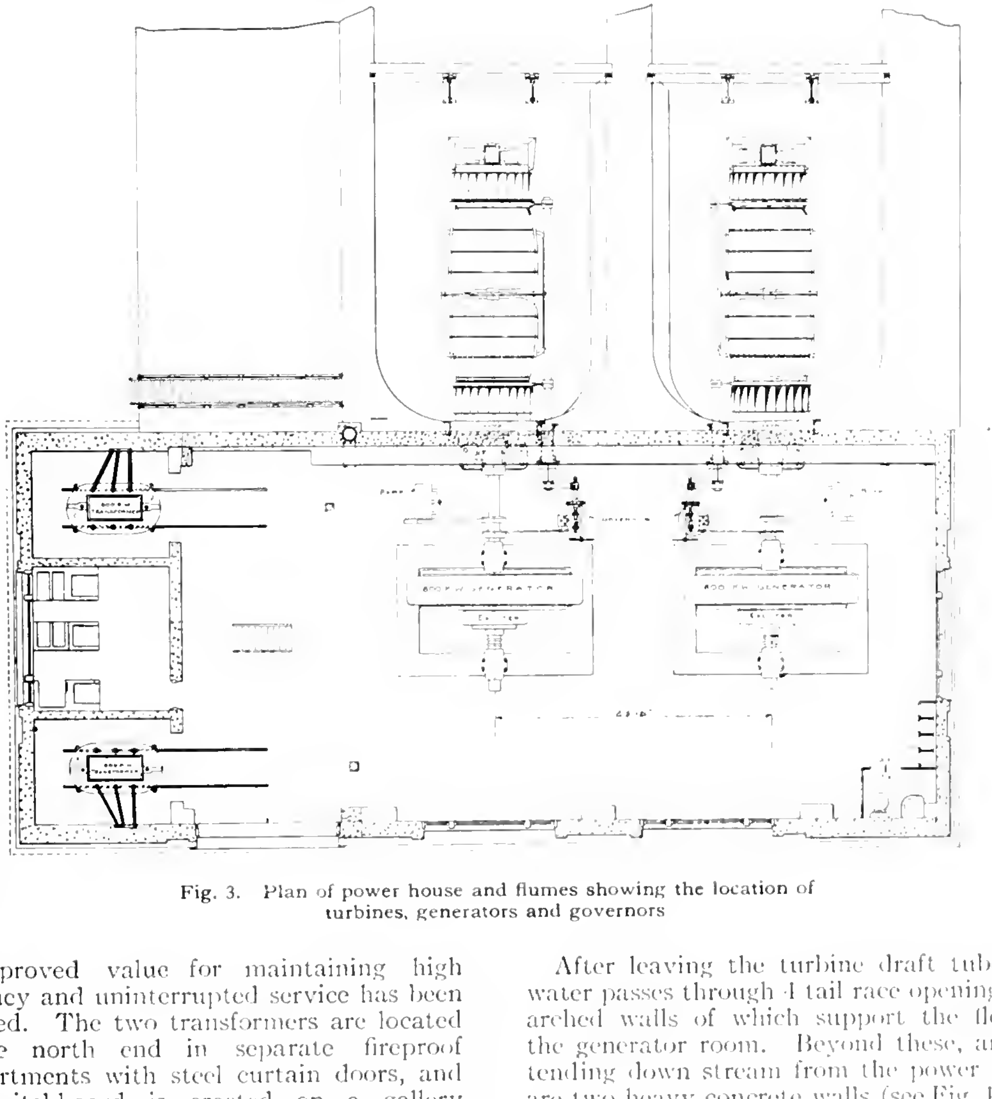
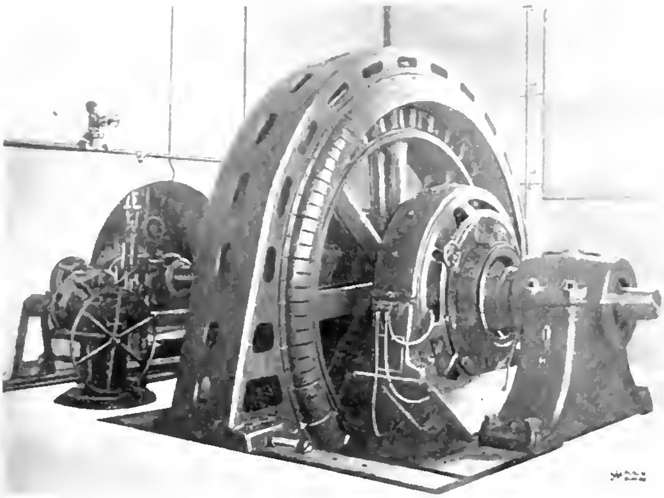


Fig. 3. Plan of power house and flumes showing the location of turbines, generators and governors

After leaving the turbine draft tubes the water passes through 4 tail race openings, the arched walls of which support the floor of the generator room. Beyond these, and extending down stream from the power house, are two heavy concrete walls (see Fig. 1), one about 100 ft. long with a maximum height of 24 ft., which forms a support to the north bank of the river at this point and protects the road to the power house from the effects of erosion. A lower wall about 120 ft. long, and curving toward the center of the stream, serves to divert the flow from the ice chute and sluice gates away from the tail race.



One of the two 1800 Kw. Type ATB 3-phase 40 cycle 4400 volt generators with self-contained exciter

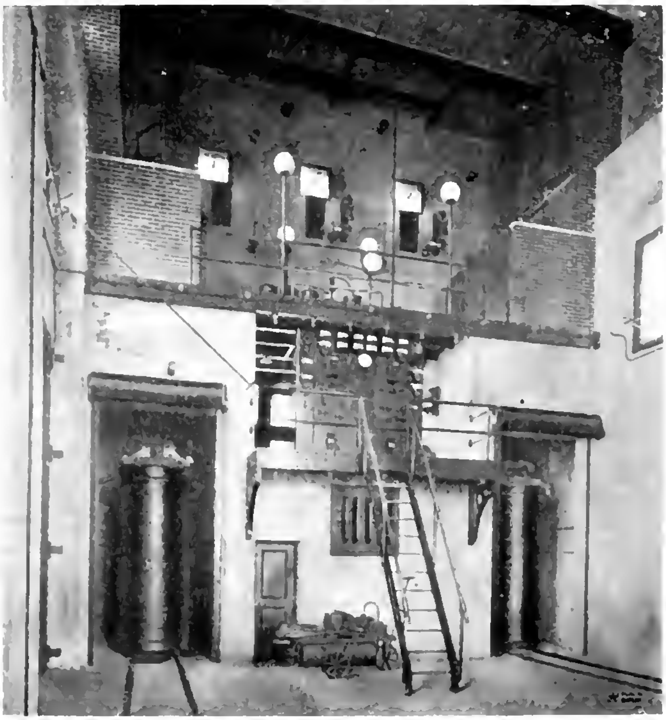
The total amount of excavation for the construction of the dam was about 6500 cu. yds. of earth and rock, and the concrete used in the main dam totals about 12,000 cu. yds., more than 1600 cu. yds. being used in the gate section alone. Work was begun in June, 1908, and current was first sent over the line in June, 1909.

The accompanying illustrations show the compact arrangement of machinery and controlling apparatus which can now be realized in even the smallest modern hydro-electric plant, and the efficiencies which may be obtained in the operation of properly selected generators and transformers are indicated by the following description of the apparatus installed at Johnsonville.

The generator equipment consists of two 1800 kw., three-phase, 40 cycle, 4400 volt generators delivering 237 amperes at 150 r.p.m., direct coupled to the turbine shafts. The machines are of the horizontal shaft, two-bearing, revolving field type, designed for water-wheel drive and are provided with an exciter mounted on the generator shaft between the armature and the collector rings. The field windings are tested for 1500 volts and the armature windings for 9000 volts. The temperature guarantee for full load run of two hours, at 100 per cent. power factor, is 40 deg. C. rise, and at 25 per cent. overload, 55 deg. C., these guarantees being based on a room temperature of 25 deg. C. The machines will operate at 2000 kw., 90 per cent. power factor for two hours with a temperature rise not exceeding 55 deg. C. The generators have the following efficiencies: full load, 95 per cent.; ¾ load, 94 per cent.; ½ load, 92 per cent. These efficiencies are based on 100 per cent. power factor, and the regulation under these conditions is within 8 per cent.

The total weight of combined generator and exciter is 119,200 pounds, and the fly-wheel effect 726,000 (WR^2). The armature windings are all "Y" connected, with the neutral brought to the terminal block, and the generators are operated in parallel with those in the Schaghticoke station.

In these machines the mechanical design is such that they may be run momentarily at

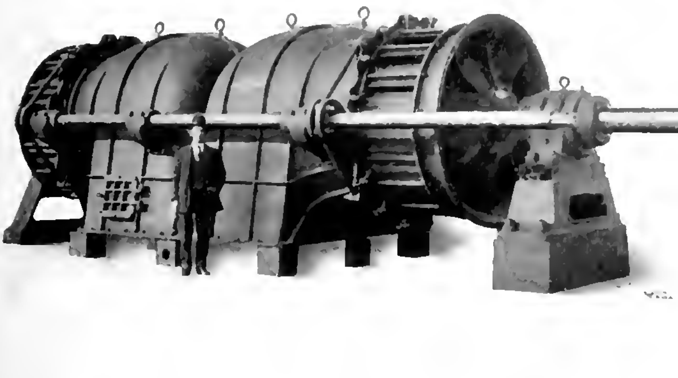


Interior view showing north end of power house and the general arrangement of transformer cells, switchboard, and high tension gallery

300 r.p.m. (or double speed) without danger of any displacement of parts, or other injury. The generators are controlled by means of field rheostats arranged for magnetic operation from the switchboard, from which point the turbine governors can also be controlled.

The exciter equipment comprises two 8 pole, 60 kw. exciters operating at 150 r.p.m. and delivering a full load current of 480 amperes at 125 volts. The exciter is compound wound and tested to deliver the same voltage at full load as at no-load, the series field being provided with a short circuiting switch for cutting it out of circuit. The exciters are also guaranteed to withstand temporary operation at double speed. Each exciter has sufficient capacity to excite both alternators and operate the auxiliary machinery.

Two 40 cycle, 1800 kw., 32000 4400 volt transformers are used, requiring 1300 gallons of oil and a water circulation of 14 gallons per minute. The water for cooling is piped to the transformers from the wheel pits, and the cooling coils are tested to withstand a pressure of 250 lbs. per sq. inch. The temperature rise for a full load run of 24 hours does not exceed 35 deg. C., while a 25 per cent. overload maintained for the same length of time will not produce a greater rise than 55 deg. C.



A complete turbine unit showing wicket gate arrangement for controlling inflow of the water

The regulation on non-inductiv loads is 1.5 per cent. and with 80 per cent. power factor it is 3.6 per cent. The total weight of each transformer, including oil, is 38,000 pounds. Each unit is able to withstand an instantaneous short circuit at its high potential terminals when connected to the 3600 kw. of generator capacity (or the total normal capacity of the power house) without displacement of or damage to any of its parts.

Fig. 4. The Johnsonville-Schaghticoke Transmission Line

Practically the entire output of the Johnsonville station is transmitted at 32,000 volts, three-phase, 40 cycles, to the Schaghticoke power house over a single circuit line of light structural galvanized steel towers 5.8 miles long. It is there tied in with the circuits running to Schenectady.

A short 4000 volt line extends across the river to Johnsonville on the south bank, where it acts as a local feeder for a mill consuming about 150 h.p., and will also in the near future supply a lighting circuit for Johnsonville and Valley Falls.

In the event of shut-down at Johnsonville, for any cause, current can be fed back from Schaghticoke to supply local requirements and for the operation of the station auxiliaries.

The conductors leave the power house through perforated plate glass windows in the high tension gallery, the electrolytic lightning arrester cells being located in the building, and the horn gaps and discharging mechanism on the roof.

All of the towers, 54 in number, are of the same structural form as the ones illustrated herewith, and the average spacing is between 500 and 600 feet. They will withstand a side strain of 3000 pounds at the cross arm 47 ft. from the ground, are 16 ft. square at the base, and weigh about 1500 pounds. The conductors are No. 2 B.&S. solid copper wire spaced 5 ft. 6 in. apart, and the lightning guard wire is No. 2 B.W.G. galvanized iron, running along the peaks of the towers 2 ft. 9 in. above the cross arms. On account of the lightness of the conductors no attempt was made to string the line at high tension. The conductors were, therefore, run at 600 pounds average tension, corresponding to about 18 ft. sag for standard spacing.

The end of the line showing transmission towers turning angle on the hillside back of the Schaghticoke power house

Heavy towers of the same general dimensions are used to negotiate angles in the line, and General Electric multiple disc suspension and strain insulators have been used throughout.

The entire development was designed and constructed by Messrs. Viele, Blackwell & Buck of New York, the hydraulic machinery was supplied by S. Morgan Smith Company of York, Pa., and all the electrical apparatus by the General Electric Company.

In conclusion, it might be well to note the benefits actually derived from the operation of this auxiliary power plant, located at what is practically an impounding dam primarily intended to supply additional storage water for a larger existing station. We find that at the present load factor of 50 per cent. the total output of both stations during an average year is equal to 67,600,000 kw. hr., and of this total 13,120,000 kw. hr. is delivered by the Johnsonville power house.

Standard transmission tower used between Johnsonville and Schaghticoke

STORE LIGHTING

By F. L. Healy

Among the many rapid strides which have been made in illuminating engineering, perhaps no one particular branch of the art has received more careful attention than the artificial lighting of stores.

The chief reason for this was the necessity of overcoming the color distortion which was characteristic of certain forms of artificial illuminants.

Until recently the ordinary enclosed arc lamp has best served the purpose very well, but it remained for the intensified arc lamp to provide that white light and soft and even illumination to which the eye is so accustomed.

A striking illustration of the value of intensified arc lamps for store lighting is furnished by the new store of C. G. Gunther Sons Co., of Fifth Ave., New York City, dealers in high grade furs. When changing their headquarters from the old down-town store to the new building, the utmost care was taken to obtain the best available equipment for a rapidly extending business. Past experience had taught them that sales were seldom, if ever, as good when artificial light was used, as when daylight was employed for lighting, due to the fact that the goods did not show up as well under the former as under the latter.

Determined to remedy this if possible, a series of exhaustive tests was conducted on all the latest forms of illuminants and so-called white lights, with the result that the intensified arc lamp, although the last one tried, was immediately chosen, as its true daylight qualities and superiority over any other illuminant were at once appreciated.

Fig. 1. Main Floor of C. G. Gunther Sons Co., New York City
Lighted by General Electric Intensified Arc Lamps

That these lamps fully come up to expectations, is realized on entering this new store on Fifth Avenue, where they are installed throughout.

The main floor has a very high ceiling which gives the large display room a commodious appearance. The finish is a rich dark brown walnut and it is doubtful if a better background could be obtained for the display of costly furs and hats. On the upper floor are other reception and fitting rooms, in which an elaborate line of complete garments and furs is displayed.

Figs. 2 and 3. R. H Stearns, Boston, Mass , Lighted by General Electric Intensified Arc Lamps

After a general survey of the store, attention is naturally turned to the lighting scheme, which accords so well with the highest type of store furnishing, and it is then that the intensified arc lamp is really appreciated at its true worth, as the illumination is particularly effective. Men in the fur business state that people will not trust to artificial light in selecting furs, as under a light of imperfect color, the finest grades of sable and other costly skins lose their lustre and have the flat unattractive appearance of skins many times cheaper. This is the point—the ordinary artificial illuminant does not give the fur dealer a fair chance to show his goods to advantage, and what is equally important, the buyer is not able to distinguish the high grade furs from the low, or even to match skins of apparently the same color. The Gunther people say that the light from the intensified arc lamp is the nearest approach to daylight that they have ever seen.

The light itself is exceptionally well diffused; there is not a bit of glare in the store—just a soft even light throughout. This excellent diffusion relieves one from the ordinary annoyance experienced when the source of light comes within the range of vision. Another point worthy of mention is the steadiness of the light. There is no apparent wandering of the arc, no flickering. One wonders if the lamps are in reality arc lamps.

Although efficiency was somewhat of a secondary consideration, the Gunther firm is ready to admit that it is getting a great deal more light at a lower cost than it was in the old store. The lamps themselves are particularly attractive in appearance, being equipped with an ornamental casing of a very attractive design.

Fig. 4. Second Floor, C. G. Gunther Sons Co., New York City

A somewhat similar installation, in the new store of R. H. Stearns of Boston, Mass., is shown in Figs. 2 and 3. Here also the intensified arc lamp was finally installed after a competitive test and, as will be noted from the photographs, the results are indeed very satisfactory. Note how all the finesse of expensive embroideries and imported laces is brought out in all its beauty. The illustrations do not reproduce the color effect, but it is easy to see from the detail shown, that as an example of ideal store lighting, these lamps are without an equal.

STARTING COMPENSATORS*

By E. F. Gehrkens

Transformer Engineering Department

General Electric Company

Some form of starting device, the function of which is to limit the current taken from the line by the motor in starting, is

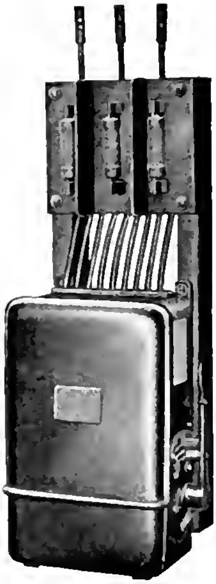


Fig. 1. Single Tap Compensator, Type CR, Form F.

used for alternating as well as for direct current motors, and for both the induction and synchronous types; but, as the starting compensator is used principally in connection with the squirrel cage type of induction motor, the present discussion will refer only to the various methods now in use for starting this kind of machine. An induction motor designed to meet the best condition of normal operation, should have as low an impedance as practicable, but a motor of this description necessarily takes a very large current in starting, this current being inversely proportional to the impedance; the starting torque is consequently high, and, being in the majority of cases much higher than necessary, some sort of a device is usually provided to limit the current to a reasonable amount which is still sufficient to produce the torque necessary for starting. The starting devices at present used for this purpose may be classified as follows, *viz.*:

Starting Compensators,
Starting Reactances and
Starting Resistances.

An induction motor requires a certain amount of current to start, and, to obtain this current, since the applied voltage is the only factor susceptible of adjustment, it is immaterial, as far as the starting of the motor is concerned, whether this result is secured by means of a resistance, a reactance, or a compensator; or whether the voltage necessary to produce this current is applied at once or gradually.

The compensator, however, is used almost exclusively, the reason for this being that for a given condition of starting, the current taken from the line with a compensator is always less than with either a resistance, or a reactance. These latter devices have the disadvantage of taking the same amount of current from the line at 100 per cent. voltage as they deliver to the motor at a lower voltage, the reduction in the voltage being dependent upon the resistance of the device, whether ohmic or reactive. They therefore simply serve to reduce the current taken from the line by limiting it to the amount actually required by the motor to start.

A starting compensator, however, consists of an inductive winding with taps, together with a switch for connecting the motor thereto. By the operation of this device a reduced potential is impressed upon the motor to bring it up to speed. With the switch in the starting position, the arrangement is equivalent in effect to

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* Since the above article was written, starting compensators have been redesigned so as to incorporate a number of improvements, and Fig. 1 does not therefore show an up-to-date device. A detailed description of the improved compensator will, however, be given at some future date. The starting curves of the motor are not exactly correct for a motor of our present design, in that the new motors require a smaller starting current than the one tested. This change in the design of the motor, however, in no way affects the conclusions drawn from the tests; *viz.*, that regardless of the design of the motor, there is no practical value in starting a motor by means of a multistep compensator except in a few special cases.

a step down transformer, and the product of potential times current on the line circuit is approximately equal to potential times current on the motor circuit. To illustrate: Assume that 50 per cent. of the normal voltage is sufficient to start the motor. With this potential, the motor takes one-half of the current that it would take if thrown on the line direct, *i.e.*, one-fourth of the volt amperes. Assuming the current taken from the line by the motor if thrown on the line direct as 100, the use of a starting resistance or a reactance would reduce it by one-half or to 50, and the use of a compensator would reduce it by three-fourths, or to 25.

The actual relation between the starting currents for a 100 h.p., 25 cycle, 440 volt motor, is illustrated graphically by Figs. No. 2 and No. 3, the former showing the current taken with the motor starting up with 100 per cent. load, and the latter with about 25 per cent. load. Both curves serve to show the decrease in the line current by the use of the compensator, but especially when starting the motor with no load or light load.

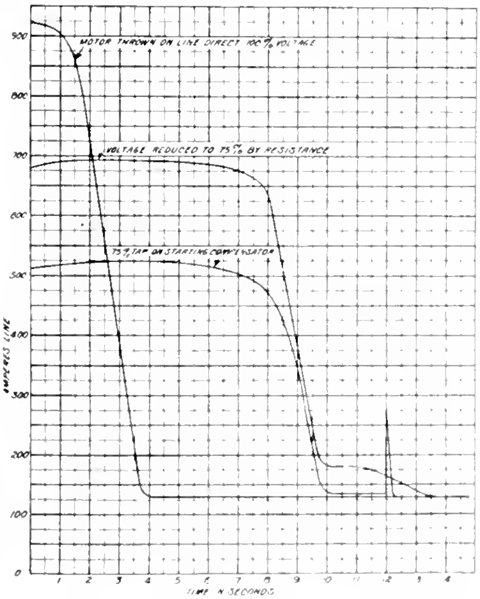


Fig. 2. Starting of 1 6-100-500-440 Volt Form K Motor with 100 per cent. Load

(Rise at end of compensator curve is due to throwing switch from tap to full load voltage.)

To fulfil the purpose for which the compensator is designed, the switch must be left in a starting position long enough to allow the motor to attain practically full speed. This usually requires from five to twenty seconds, and, at the end of that

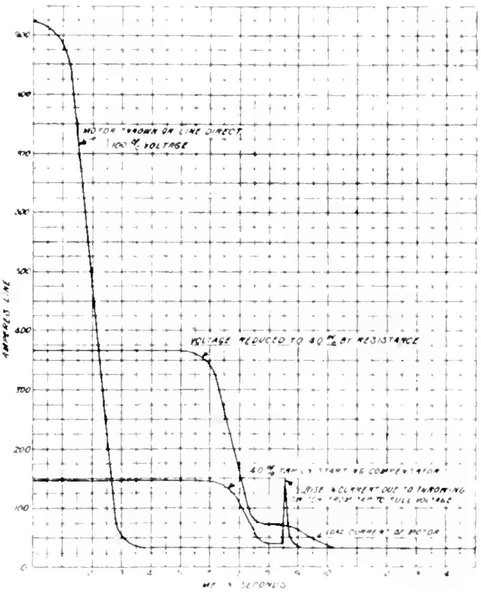


Fig. 3. Starting of 1 6-100-500-440 Volt Form K Motor with 25 per cent. Load

time, the switch should be thrown quickly into the running position. If the switch is thrown before the motor has attained speed, the current broken on the starting side, and the instantaneous current taken from the line on the running side, are much larger than when the full time allowance is given. The latter is also the case if the switch is not thrown quickly, as the motor must necessarily drop in speed during the time the switch passes from the starting to the running position. This, therefore, not only defeats the purpose for which compensators are designed, but the excessive current is also detrimental to the switch.

Starting compensators are arranged in one of two ways, first, so that one reduced voltage may be applied to the motor terminals, and second, so that several successive voltages may be so applied. The former, or single tap compensator, is the simpler in construction, and is suitable for the majority of installations. The latter, or multi-tap compensator, has advantages only when the static friction of the load varies from day to day, or for the starting of a *synchronous* motor operating under conditions that require very low starting torque and when it is desired to take advantage of this condition in avoiding undue line disturbances. Under these conditions a comparatively low voltage is required for starting and bringing the synchronous motor up to synchronous speed, then, by adjusting the field current to each increase in voltage, the current taken from the line in passing from the starting tap to the full line voltage is reduced to a minimum. As inferred, this method cannot be used to advantage where comparatively large starting torque is required, nor does it apply to the induction motor, in which machine field current adjustment is not possible.

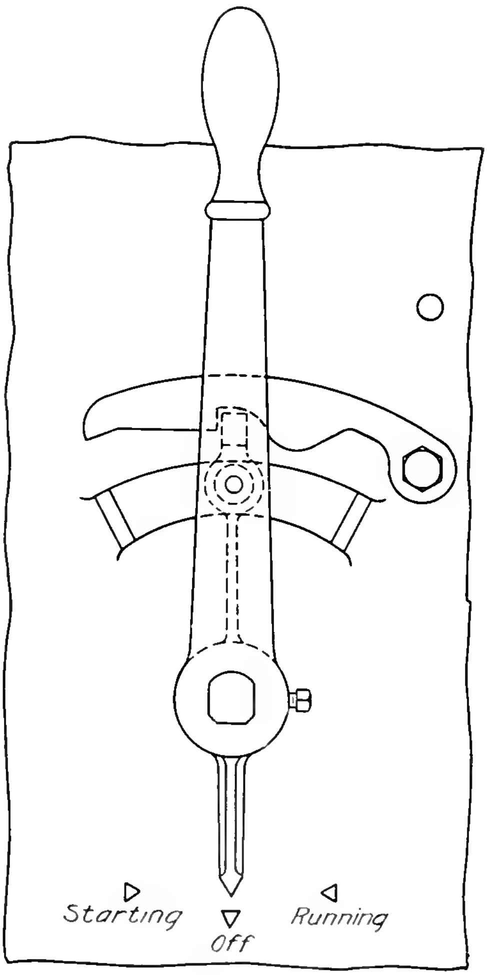


Fig. 4. Single Tap Compensator Switch with Latch

The multi-tap compensator switch is usually arranged so that the movement of the handle is continuous, starting with the "off" position, and passing through the successive steps to the full voltage position. This arrangement allows an operator to throw the switch through the starting and into the running position in so short an interval that the motor will not have had time to start before full voltage is applied. Also, because of the large number of contacts to be made at each point of the switch, a considerable amount of force is required to operate it, and, on account of the smaller angular distance between the various positions, the operator is likely either to throw the switch too far, or to operate it so slowly as to cause serious burning of the contacts.

In the single tap compensator, these difficulties can be entirely overcome by arranging the switch so that the "off" position is in the center, the starting position at one extreme end and the running position at the other extreme of the throw of the handle.

By arranging the switch in this way, the operator has a positive stop at both the starting and running points, and he will be more likely to throw the switch full into the proper position, and leave it in the starting position a greater length of time than if the entire operation could be completed with one sweep of the handle. With a compensator arranged in this manner, proper operation is assured by the addition of a latch as shown in Fig. 4. This not only prevents the operator from throwing the switch into the running position before it has passed through the starting point, but also compels him to throw it over quickly, which reduces the burning of the switch contact and also lessens the momentary increase in the current taken by the motor when thrown from the tap to the line direct.

As previously stated, the design of the squirrel cage type of motor is such that no adjustment of any kind whatever can be made for the purpose of producing the best starting conditions, with the exception of that of the voltage applied to the motor terminals; and because of the inflexibility of the system, it is immaterial how this voltage is applied, the only requirement being that the voltage be sufficient to give the current necessary to overcome the static friction of the load. As no adjustment in the motor itself is possible, the application of any voltage below this is of no advantage in any way, except that it heats the armature winding, and by thus increasing the resistance, a slightly greater

This conclusion, that there is no practical advantage in the application of a gradually increasing voltage to a squirrel cage type of induction motor, is shown by the curves and is the result of a series of starting tests which were taken with different load conditions on a 15 h.p., 60 cycle, 220 volt, three-phase motor, and on

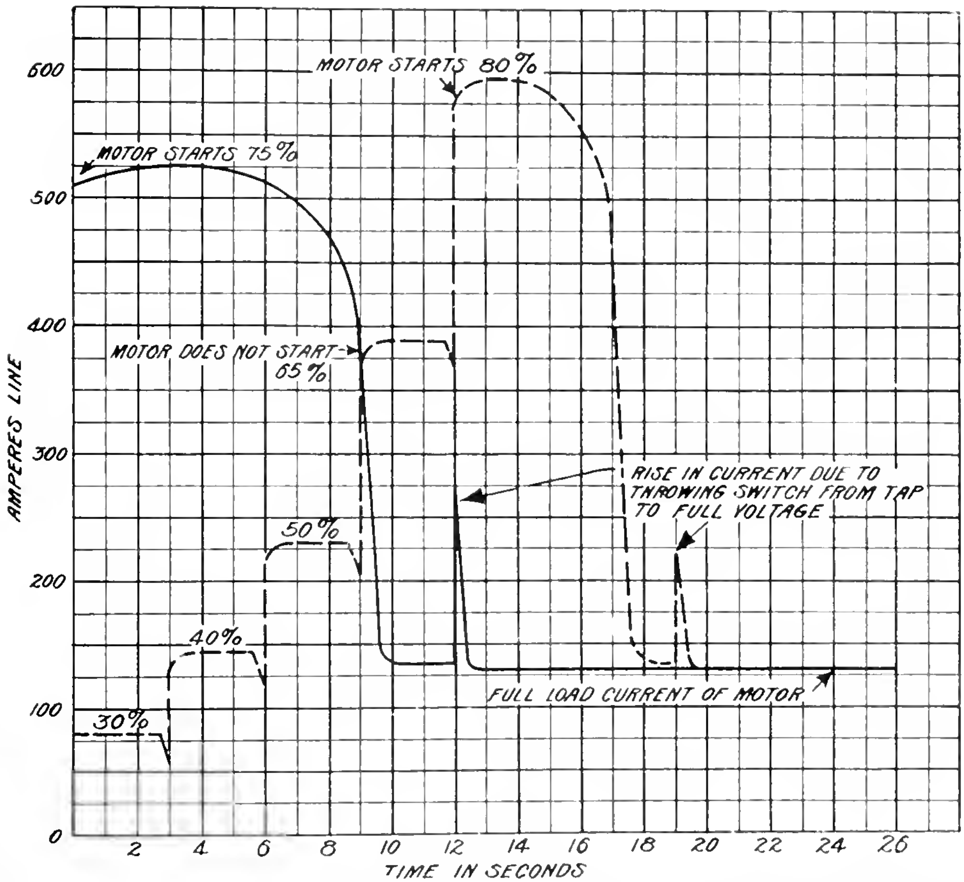


Fig. 5. Starting of I-6-100-500-440 Volt Form K Motor with 100 per cent. Load, Using Multi-Tap Compensator, and Single Tap Compensator. Multi-Tap Compensator, 30, 40, 50, 65 and 80 per cent. Taps; Test Indicated by Broken Line. Single Tap Compensator, 75 per cent. Tap; Test Indicated by Solid Line

torque may be obtained. Furthermore, the characteristic of a well designed induction motor is such that the voltage necessary for starting is also sufficient to bring the machine to practically full speed without further increase, so that the application of an intermediate voltage between that necessary to start the motor and full line potential is of no advantage.

a 100 h.p., 25 cycle, 440 volt, three-phase motor, using multiple tap and single tap starting compensators of the proper size for each machine.

In this investigation, the compensators were connected in series with each other and between the line and the motor, while a graphic recorder was connected in series with one leg of the line. Six starting tests were taken for each condition of load, and with the best arrangement of compensator taps, one being tested while the other was cut out of circuit by throwing its switch into the running position.

The tests were taken with each compensator alternately, and the results on the 100 h.p. motor starting under full load conditions are shown in Figure 5. A large number of tests under different load conditions were taken, but these shown are representative, and being taken with a comparatively large load on the motor, would be better suited to show the advantage of the multiplicity of starting taps, if any existed. A study of the curves will show, however, that the amount of current taken from the line to start the motor under a given condition of load is the same regardless of whether this voltage is applied gradually or instantaneously.

Attention is also called to the large currents which the switch of a multi-tap compensator is required to break. In the present instance, for a single start, the switch was required to rupture currents which were respectively 60, 110, 175 and 300 per cent. of the full load running current of the motor, whereas, with a single tap compensator, the maximum current to be broken was but a trifle over full load current.

In the majority of installations of induction motors, however, the load to be started, and consequently the voltage necessary to start, is approximately constant from day to day, and a single tap compensator, or rather one having a number of taps, any one of which can be selected for use, is therefore perfectly satisfactory after the proper tap for the particular installation has once been fixed upon.

The advantage of the single tap compensator can therefore be readily appreciated, as it is simpler in design and operation, and the desired results more likely to be obtained even when operated by inferior class of labor. The cost of maintenance is also reduced as not only are the number of ruptures of current decreased to a minimum, but the burning of the contacts and their renewal are also lessened, this reduction being in proportion to the decrease in the number of contacts, and therefore the number of ruptures of current, and also on account of the breaking of a much smaller current.

A NEW TYPE OF METER FOR MEASURING THE FLOW OF STEAM AND OTHER FLUIDS

By A. R. Dodge

The ever increasing demand for more economical generation and consumption of steam makes it imperative that the up-to-date engineer shall avail himself of every possible means for determining the behavior of apparatus that is employed for these purposes.

For many years the electrical engineer has had instruments at his command by the use of which he could determine exactly the performance of the various electrical machines. On the other hand, despite the fact that the utilization of steam and the science of steam engineering antedates the practical, commercial application of electricity by half a century or more, the steam engineer has been provided with no such instruments, and has had to content himself with the simple knowledge that he was generating enough steam to do a certain amount of work; just how much steam it was that he was actually generating he could not tell. It must be conceded that it is as important to measure the steam delivered to the prime mover as it is to determine the output of the electric generator. This point is fundamentally important, but up to the present time there seems to have been no large amount of work spent on the development of instruments which possess the desired properties of being easy to install and of accurately measuring the rate of flow of steam.

The former efforts in this direction are covered by two general types.

About ten years ago a device for measuring steam flow was brought out in which a diaphragm containing an orifice was inserted between flanges in the steam pipe, and the difference of pressure between the two sides of the orifice was measured, from which pressure difference the amount of steam passing through the orifice was known from previous calibration. No attempt was made to correct for moisture or superheat, and there is a loss of steam pressure through the orifice at ordinary loads of about three pounds, which loss increases in pressure at overloads, limiting the output and efficiency of the steam distribution system. To install this device necessitates shutting off the steam for several hours; removing a section of piping and inserting a new section, together with new gaskets and diaphragm in the same available space as was occupied by the removed section.

The second type is known as the float type meter and consists of a vertical spindle which carries a disk, actuated by the steam, an arrangement somewhat similar to the safety valve of a steam boiler with the spring removed. The more the flow of steam, the more the spindle will lift due to the pressure difference on the top and bottom. The spindle is connected through the stuffing box to an external pointer, by means of which the opening of the valve, and hence the amount of steam passing through, is known from previous calibration. Either the disk or the surrounding chamber may be cylindrical, provided the other part is conical.

The stuffing box is a serious objection, as the friction is always an appreciable amount of the moving force available from the steam, and varies over a wide range. A leakage of steam through the stuffing box is also apt to occur. These two characteristics tend to make the readings inaccurate. Such meters owing to their relatively large size and cost are not practical for pipes above 6 in. in diameter.

In the meter to be described, these objections have been eliminated and an instrument developed which, without the use of weighing tanks, scales, or other special apparatus, will determine the amount of steam, air or other fluid flowing in a system of piping.

If the temperature and pressure of the gas is a constant, the amount of steam used in a machine or group of machines is, of course, proportionate to its velocity in feet per second. This velocity, therefore, constitutes a means of measuring this quantity if the velocity, itself, can be measured. It is a well known fact that velocity is converted into pressure by means of an inverted nozzle with practically no loss and always under the same law. The measure of this pressure, due to velocity, is the most reliable means we have of determining the velocity of steam in nozzles, which may be as high as 2500 ft. per second.

The velocity being thus determined from the pressure, the quantity of the steam is at once deducible, being proportional as stated above. A nozzle plug is screwed into the pipe at the point where the flow is to be measured and extends diametrically acro it. This plug (Fig. 1) carries two sets of openings; the first or "leading" set faces against the direction of flow, while the second or "trailing" set consists of three openings near the center of the plug, one of these latter being shown in the figure. The steam impinging against the leading set of openings, sets up a pressure in them which is equal to the static pressure plus a pressure due to the velocity head; while the

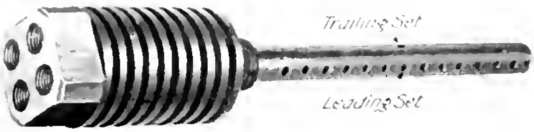


Fig. 1 Nozzle Plug

pressure in the trailing set is equal to the static pressure minus a pressure due to the velocity head. On account of the small diameter of this nozzle plug, no appreciable drop in steam pressure is caused by its insertion in the main, even if the velocity be very high.

Since the nozzle plug extends diametrically across the main, the difference of pressure set up in the two sets of openings will be proportional to the mean velocity of the gas. This pressure difference is transmitted through separate longitudinal chambers to the outer end of the plug and from there, by proper piping, to the meter, which consists essentially of a U tube of glass or metal partially filled with mercury (or other fluid of greater specific gravity than the fluid to be measured). The difference in pressure in the leading and trailing sets of openings is communicated to the two sides of the U tube and causes a difference in level in the two legs of the fluid column.

Meters suitable for measuring the rate of flow of steam are calibrated to read directly in pounds per hour, while those for measuring the rate of flow of air are calibrated in cubic feet of free air at a temperature of 70 degrees Fahrenheit.

If it is desired to operate the meter on steady flow, such as occurs in supplying steam to steady flow turbines, heating systems, manufacturing processes, etc., no recalibration is necessary after installing, as all meters are calibrated at the factory for this condition.

If, however, the meter is to be used on periodically intermittent flow, such as occurs in supplying steam to intermittent flow turbines, reciprocating engines, pumps, etc., it must be recalibrated after it is installed, unless the arrangement of the piping permits the insertion of the nozzle plug at a point where the flow is steady. For example: where an engine is supplied with steam by a long pipe line, the nozzle plug may be inserted near the boiler where the flow is steady.

No change whatever is required in the main piping system of the station to install the meter; it is only necessary to drill a small hole in the main for the nozzle plug.

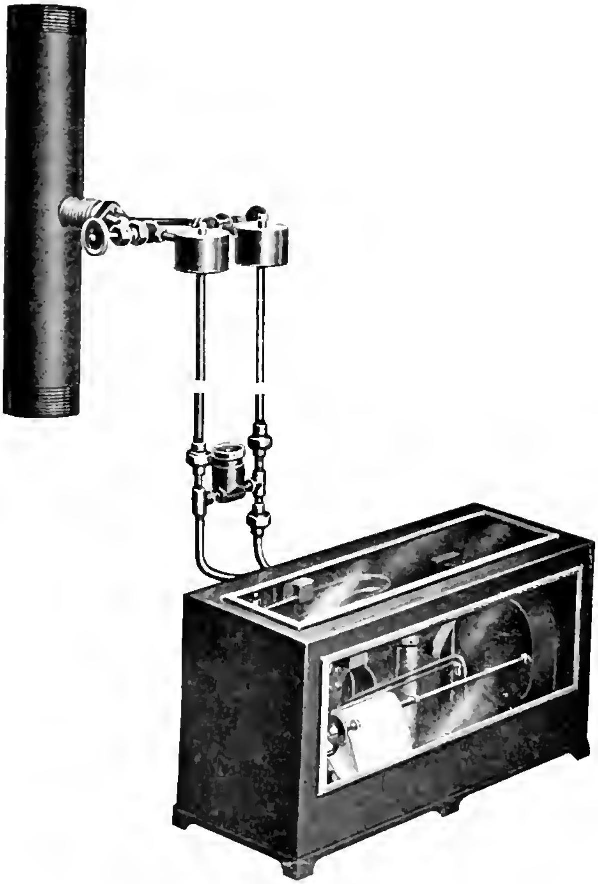


Fig. 2. Recording Steam Meter, Showing Connections to Pipe

RECORDING FLOW METERS

The recording flow meter for measuring the rate of flow of steam is a curve drawing instrument, giving an accurate record of the rate of flow in pounds per hour, in pipes of any diameter, at any degree of temperature, pressure, or moisture.

The meter consists of two cylindrical hollow cups filled to about half their height with mercury, and joined together at the bottom by a tube. This arrangement of cups and connecting pipe forms the U tube, which is supported upon a set of knife edges about which it is free to move as a balance.

Any difference of pressure in the two sets of openings in the nozzle plug is communicated to the cups through flexible steel tubing placed inside the case, and causes the mercury to rise in the left hand cup and fall in the right hand cup until the unbalanced columns of mercury exactly balance the difference in pressure.

By the displacement of the mercury, the beam carrying the cups moves downward on the left hand side of the knife edges. This side will descend until the moment of the weights on the right of the knife edges exactly balances the moment caused by the displacement of the mercury into the left hand cup. The motion of the balancing beam is multiplied by suitable levers and actuates the recording pen which moves in proportion to the amount of mercury displaced.

The time element of the meter consists of an eight day clock, which drives the drum feeding the paper. A paper feed of one inch an hour has been adopted as standard and one roll of paper is sufficient for about a month's record. All recording meters are equipped with a re-roll device, which is operated by spring mechanism, and is of sufficient capacity to accommodate one complete roll of paper.

Compensating Devices for Pressure and Superheat Variation

The velocity of the steam being measured may remain practically constant, while the pressure and temperature vary over a considerable range; to obtain the actual rate of flow in pounds per hour, it is necessary to compensate for the latter fluctuations.

This compensation is made automatically in the case of pressure variations, by a hollow spring, similar to the pressure spring in a steam gauge, which is connected so as to be influenced by the static pressure at the point where the flow is being measured. Any variation of the static pressure causes the spring to expand or contract, and this movement actuates a small correction weight in such a manner as to affect the deflection of the pen, so that the indicated rate of flow recorded by the pen is correct.

Compensation for temperature variation is made by an independent hand adjustment of the same correction weight that corrects the reading for pressure variations. This adjustment is made by increasing or decreasing the distance of the correction weight from its point of suspension; this distance is determined from a curve furnished with the meter.

INDICATING FLOW METERS

This type of flow meter will meet general commercial requirements where an indicating instrument is desired. It will be found especially useful for testing work, locating troubles due to leaks, etc. This indicating meter gives an accurate reading of instantaneous rate of flow of steam or air or any other

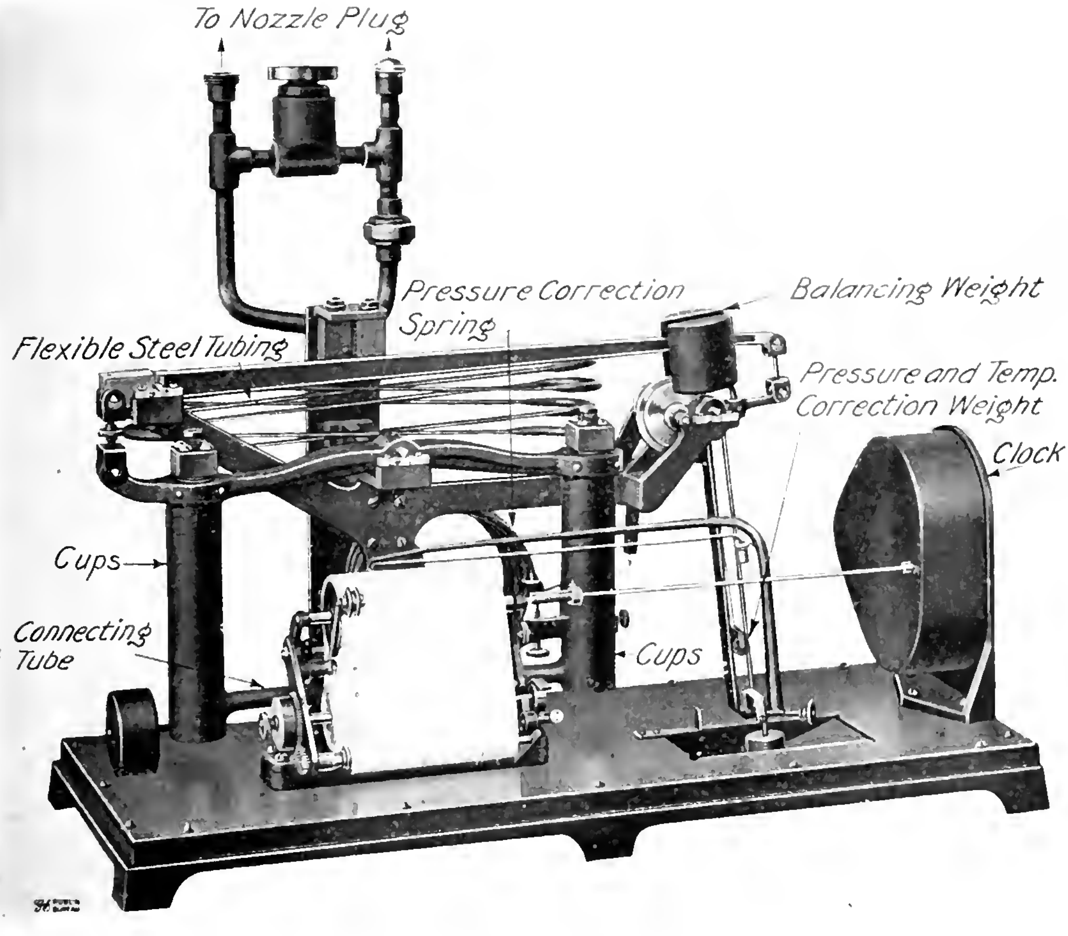


Fig. 3. Recording Steam Meter

gas, at any condition of temperature, pressure, or moisture. If used to measure steam flow, it gives a true indication of the instantaneous rate of flow in pounds per hour per square inch of pipe cross sectional area.

As it is portable, a single meter may be utilized to obtain readings in any number of different pipe lines through a station. It is only necessary that each pipe be provided

Meters for Constant Temperature and Pressure

In many stations steam is generated at practically constant pressure and temperature; this will be found to be especially true where a battery of boilers is supplying steam to one unit. For such conditions the automatic pressure correction is not essential, and the meter is adjusted by hand to suit the existing conditions of pressure and temperature.

with the proper nozzle plug to which the meter can be connected.

The meter consists of an iron casting which is cored out to form a U tube, which, as with the other types of meters, is filled for part of its height with mercury or water, and, as in their case, a difference of pressure in the nozzle plug causes a difference of level in the two

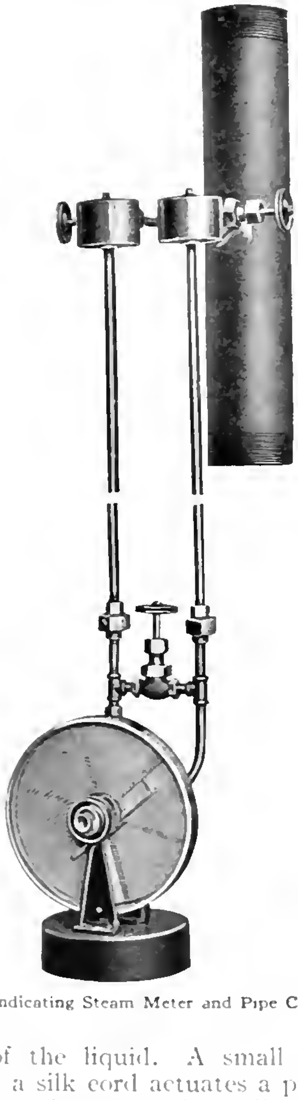


Fig. 4. Indicating Steam Meter and Pipe Connections

columns of the liquid. A small float suspended by a silk cord actuates a pulley over which the cord passes; the pulley, in turn, moving a small bar magnet on the end of shaft next to the dial in proportion to the change in level of working fluid in the U tube.

The indicating needle is mounted in a separate cylindrical casing. Another bar magnet is mounted on the inner end of the needle shaft, and is free to turn in the same plane as the magnet on the inside of the meter.

The mutual attraction of these two magnets keeps them always parallel, and by this arrangement the necessity of a packed joint

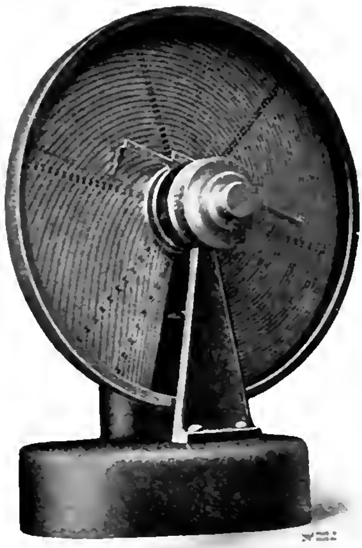


Fig. 5. Indicating Steam Meter

for transmitting the motion of the pulley to the indicating needle is eliminated.

The pipe, receiver and nozzle plugs are of the same general design as those used with the recording meter.

The proper adjustments for pipe diameter, temperature and pressure are readily made by setting the graduated cylinders which actuate the rack carrying the pointer. When these settings are made, the rack is rotated by hand until the pointer coincides with the indicating needle. The point on the graduated scale at the intersection of the needle and pointer gives the true instantaneous rate of flow per square inch of pipe cross sectional area.

Meters of both types have been in service in the Schenectady Works of the General Electric Company for several years, and their employment provides data for continuous records of steam and air used in the principal buildings, thereby indicating where avoidable losses may be eliminated.

A number have been installed in this country and Europe, and have been giving satisfactory service under various conditions.

TRANSMISSION LINE CALCULATIONS

Part VI

By Milton W Franklin

LINE ECONOMICS

The losses in a line are due only to resistance, but the line drop is a function of the line reactance as well as of the resistance so that the effective resistance must be considered and not only the ohmic resistance.

For a given voltage at the receiving end of the line and given power output at the generating end the most economical drop (resistance only) and power loss under certain conditions of cost of power, conductor, etc., may be mathematically computed.

Let E_R = Voltage at receiving station.

P = Kw. output at generating station.

L = Length of line in miles, length of a single conductor.

c = Cost per kw. year at generating station in dollars.

c_1 = Dollars per lb. conductor.

p = Interest rate on cost of conductors.

K_1 = Ohms per mil mile of conductor.

K_2 = Pounds per mil mile of conductor,

R = Total resistance of line (two wires) in ohms.

S = Cross-sectional area of conductor in circular mils.

x = Loss in terms of generated power.

Then line loss $= Px$ (1)

Annual cost of loss on line $= cPx$ (2)

Weight of conductors $= 2LK_2S$ (3)

Cost of conductors $= 2c_1K_2LS$ (4)

Interest per annum (conductors) $= 2pc_1K_2LS$ (5)

Line resistance $= R = K_1 \dfrac{2L}{S}$ (6)

Line drop (Ri components only) =

$$\frac{E_R \cos\theta x}{(1-x)} = \frac{1000\ PR(1-x)}{E_R \cos\theta}$$

Substituting value of R from 6 we get

$$\frac{E_R \cos\theta x}{1-x} = \frac{2000\ PK_1L\ (1-x)}{E_R \cos\theta\ S} \qquad (7)$$

$$C.S.A. \text{ of conductor} = S = \frac{2000\ (1-x)^2 PK_1L}{E_R \cos^2\theta x} \qquad (8)$$

The annual cost due to line loss and interest charges is then given by $(2)+(5) = cPx + 2pc_1K_2LS$ (9)

The annual cost per generated kilowatt is the total annual cost divided by the generated kilowatts, $= q$

$$q = \frac{cPx + 2pc_1K_2LS}{P} \qquad (10)$$

Substituting the value of S from (8)

$$q = \frac{cPx + 2pc_1K_2L\left[\dfrac{2000(1-x)^2PK_1L}{E_R^2 \cos^2\theta x}\right]}{P} \qquad (11)$$

Rearranging terms:

$$q = cx + \frac{4000\ pc_1K_1K_2L^2(1-x)^2}{E_R^2 \times \cos^2\theta x} \qquad (12)$$

Putting $K = \dfrac{4000\ pc_1K_1K_2L^2}{\cos^2\theta}$ in (12)

$$q = cx + \frac{K(1-x)^2}{E_R^2\, x} \qquad (13)$$

Differentiating q with respect to x gives

$$\frac{dq}{dx} = c + \frac{K}{E_R^2}\left(1 - \frac{1}{x^2}\right)$$

Putting $\dfrac{dq}{dx} = 0$ for the minimum value we get

$$x = \sqrt{\frac{K}{cE_R^2 + K}} \qquad (14)$$

In which $K = \dfrac{4000\ pc_1K_1K_2L^2}{\cos^2\theta}$ (15)

and x = the most economic loss

and $S = \dfrac{2000\ (1-x)^2PK_1L}{E_R^2 \cos^2\theta x}$ (16)

Equations (14) (15) (16) are to be used for single-phase lines.

If the preceding equations were worked out entirely with reference to the receiving end of line, the constants having the following significance:

P_R = kilowatts delivered (receiving end).

x = loss in terms of delivered kw.

E_R = voltage at receiving end.

$\cos\ \theta$ = power factor of load.

Then we would have:

$$q = cx + \frac{K}{E_R^2\, x} \qquad (17)$$

$$\text{and } \frac{dq}{dx} = c - \frac{K}{E_R^2\, x^2} = 0 \quad \text{or} \quad \frac{K}{E_R^2\, x} = cx \qquad (18)$$

which is the standard expression for interest = loss, a minimum for cost per delivered kw. with respect to line losses.

In a three-phase (three-wire) system the area of each of the three wires is one-half the area of the wires used in the corresponding single-phase case, so the weight of the metal is three-fourths of that used for the same drop and loss.

Substituting $\frac{3}{4}K$ for K in (10) will give $\frac{3}{4}K$ instead of K in (13).

This gives $$x=\sqrt{\frac{3K}{4cE_R^2+3K}} \quad (19)$$

The cross-sectional area of each conductor becomes

$$S=\frac{1000(1-x)^2PK_1L}{E_R^2\cos^2\theta\ x} \quad (20)$$

and $$K=\frac{4000\ pc_1K_1K_2L^2}{\cos^2\theta} \text{ as before} \quad (21)$$

Equations (19) (20) and (21) are to be used for a three-phase line when E_R receiving voltage is given and, P, power generated is given, x being in terms of the quantities at the generating end.

Single-Phase Line: E_R receiving voltage known. P_R kilowatts delivered.

$$x=\frac{1}{E_R}\sqrt{\frac{K}{c}} \quad (d)$$

$$S=\frac{2000\ P_RK_1L}{E_R^2\ x} \quad (e)$$

Three-Phase Line: E_R receiving voltage known. P kilowatts generated known.

$$x=\sqrt{\frac{3K}{4cE_R^2+3K}} \quad (f)$$

$$S=\frac{1000(1-x)^2PK_1L}{E_R^2\cos^2\theta\ x} \quad (g)$$

Three-Phase Line: E_R receiving voltage known. P_R kilowatts delivered known.

$$x=\frac{.866}{E_R}\sqrt{\frac{K}{c}} \quad (h)$$

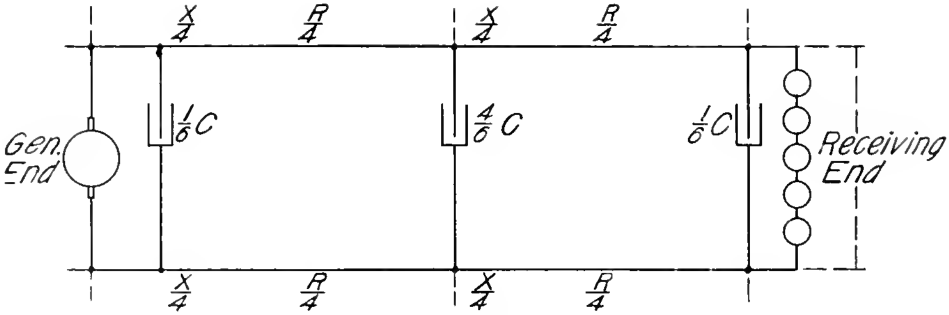


Fig. 14

The equations which apply in a three-phase system when we consider all quantities at the receiver end, are as follows:

$$x=\frac{1}{E_R}\sqrt{\frac{\frac{3}{4}K}{c}}=\frac{.866}{E_R}\sqrt{\frac{K}{c}} \quad (22)$$

$$S=\frac{1000\ PK_1L}{E_R^2\cos^2\theta\ x} \quad (23)$$

$$K=\frac{4000\ pc_1K_1K_2L^2}{\cos^2\theta} \quad (24)$$

A summary of the principal formulæ is given below:

$$K=\frac{4000\ pc_1K_1K_2L^2}{\cos^2\theta} \quad (a)$$

Single-Phase Line: E_R receiving voltage known. P kilowatts generated known.

$$x=\sqrt{\frac{K}{cE_R^2+K}} \quad (b)$$

$$S=\frac{2000(1-x)^2PK_1L}{E_R^2\cos^2\theta\ x} \quad (c)$$

$$S=\frac{1000\ P_RK_1L}{E_R^2\cos^2\theta\ x} \quad (i)$$

Should the formulæ on preceding page give a value of x which, when substituted in the equation for S, gives a value of S which differs considerably from a standard sized cable, then x will have to be recomputed for the selected standard sized cable.

The method is outlined below.

Suppose S = computed size of cable with value x, and we find the nearest size standard cable to be S_1 (circ. mils), it may be desirable to select this standard size cable S_1 and increase the loss of power slightly in preference to having a special cable drawn.

Let R_1 be the resistance in ohms (single wire) of the cable S_1, and let x_1 represent the new loss corresponding to this case, then

$$\frac{1000(R_1P)}{E_R^2\cos^2\theta}=\frac{x_1}{(1-x_1)^2} \quad (j)$$

$$\text{Let: } \frac{1000(R_1 P)}{E_R^2 \cos^2\theta} = a \qquad (k)$$

a can be easily calculated from our known values.

$$\text{Then } x_1 = \frac{(2a+1) \pm \sqrt{4a+1}}{2a} \qquad (l)$$

This formula for x_1 (the new loss) applies to single- and three-phase lines when the power P at generating end of line, E_R receiver voltage, and $\cos\theta$, power factor of load are given.

Should the power P_R delivered to receiver, E_R voltage at receiving end, and $\cos\theta$, power factor of receiving circuit, be given, then the new value of x_1 is calculated from the following formula (formula applies to single- and three-phase lines):

$$\frac{R_1 P_R}{E_R^2 \cos^2\theta} = x_1 \qquad (m)$$

Regulation of Line

The regulation of a transmission line is defined as the percentage variation in voltage at receiver end between no load and rated *non inductive* load.

In any but the shortest lines, the capacity may not be neglected, and various schemes have been proposed for calculating the capacity effect.

The total line capacity may be regarded as concentrated and shunted across the line at the central point.

This assumption introduces an error of about 1 per cent. in a 200 mile line.

A closer approximation is obtained by regarding the total line capacity as divided into two equal parts, one of which is shunted across the line at either end. This method of approximation is sufficiently accurate for most practical cases.

A still closer approximation is obtained by dividing the capacity into six equal parts and shunting one part across each end of the line and four parts across the center. This arrangement is illustrated in Fig. 14.

The line inductance and resistance are regarded as connected in series with the line and divided as shown in the figure. X is the total line reactance in ohms, R equals line resistance in ohms, and C is the line capacity in farads.

(To be Continued)

REGULATION OF THE PERCENTAGE OF CARBON DIOXIDE IN FURNACE GASES

By E. A. Barnes

Much has been written and published in the last year or so on the subject of CO_2 in its relation to boiler room practice, the writers having given much valuable information in explanation of CO_2, but little having been said of its practical application and the pitfalls attendant on its introduction into existing boiler rooms.

In order to meet with even moderate success, the firemen who are to do the work, as well as the engineer and superintendent of the plant, must be in harmony with the arrangement. It often happens that the introduction of CO_2 economy methods in a power plant is turned over to a technically educated engineer who, through lack of practical experience, commences by calling for unnecessary refinements, especially with relation to sampling tubes in the boilers.

He is also very insistent on taking samples from different passes in the boiler, and goes about the work as though the research and history of the CO_2 percentage in the boiler itself was the thing to be arrived at; this, not being understood in the operating department, at once leads to complication and lack of co-operation.

The primary object in introducing CO_2 analysis in a boiler room is to save a percentage of the fuel by scientific firing in place of the haphazard, unscientific firing that has been in use for so long. Tables prepared up to date show that this can be done, and the best way to accomplish the result is to have the simplest apparatus possible, and that which can be thoroughly understood and operated by the boiler room force.

As firing under conditions that make for the greatest economy is much more uncomfortable for the fireman by reason of the greater amount of heat radiated from the boiler fronts, fire doors, etc., some form of extra compensation, preferably in the form of a sliding scale premium system based on a fair allowance, must be worked out.

In the opinion of the writer the best place to introduce the sampling tube is at about the center of the damper box or main flue breeching leading to the stack. This sampling tube should be of ¾ in. or 1 in. common gas pipe, from three to six feet long, open at the ends and with a 1/8 in. slot through practically its entire length.

The pipe leading from the sampling tube to the rest of the apparatus need not be over 1/8 in. standard pipe, securely and permanently fastened to the boiler walls and equipped at the lower end with a suitable stop cock so that connection by means of a rubber hose can be made to the testing apparatus.

A number of sampling devices have been designed, but the integrating bottle is the simplest, being nothing more than an inverted bottle holding five gallons of water, and provided with a suitable drain and pinch cock so arranged that the flow of water from the bottle can be regulated to continue for a certain predetermined period. The subsiding of the water forms a partial vacuum and sucks in the products of combustion from the sampling tubes in the boiler. This bottle is removed periodically and gases therein tested with the regular Orsat apparatus, the average CO_2 percentage through this period being thus arrived at.

There is another instrument called the econometer, in which the weight of flue gas as compared with that of the atmospheric air is constantly indicated on a scale.

The inverted bell sampler, as its name indicates, is a glass bell inverted in a water-sealed glass chamber. This is designed to operate by clock work and is suitably balanced. The rate at which the bell is withdrawn from the water-sealed chamber depends, of course, on the adjustment of the clock and the duration of time over which the samples are to be taken.

There is also the automatic motor-driven Orsat with recording adjustments, of which there are several designs on the market.

All the latter automatic instruments require a great deal of supervision, and unless kept in thorough working order, their indications cannot be depended on. As before stated, the simplest form of apparatus appeals most strongly to the average plant. Various conditions of induced draft, forced draft, natural draft, automatic stokers, hand firing, etc., etc., all introduce factors that tend to change the results and call for different handling in different installations. In this article, we will consider only hand fired boilers having induced draft.

In a hypothetical case, we will assume that the CO_2 averages about 11 or 12 per cent., and things go along very nicely for months, when all at once it is called to our attention that certain boilers are not holding up their percentage. Investigation is made, and it is found that the fireman has the dampers shut down and everything apparently in good condition. The boiler brick work is examined and it is discovered that there are innumerable cracks in the brick work around the clean-out doors and on top of the boiler where the domes and drums protrude. As soon as these are cemented up with suitable cement the CO_2 percentage at once goes back to the normal condition. It is the excess of air entering in through these leaks that has caused the trouble. Without the tell-tale CO_2 percentage showing, this waste would go on unchecked indefinitely.

Where a number of boilers in the same plant are being fired by men on a premium system, it is necessary to have some form of counting apparatus for each boiler or set of boilers handled by individual firemen. If this is not done, the wise firemen will keep their dampers closed and burn a very light fire and get a high percentage of CO_2 during the shift, but will consume little coal. The other fellows, who are shoveling in continuously, have their doors open and not only their CO_2 percentage goes down, but they are doing all the work and not getting as much pay as the men who are holding back. The counters are intended to indicate the amount of fuel fired per man.

Another point that is well to bear in mind is that the boiler settings as specified by the boiler makers in many cases are not properly worked out for the excessive heat that has to be withstood inside of the fire box and boiler settings under the new conditions. It has been my experience that nothing but the highest grade of fire brick should be used, and that the fire box lining brick should be laid up in courses of two stretchers and one header alternately. It is also very desirable to have every fourth header brick specially long, say 18 in., so that it not only binds the inner skin of high grade brick, but hangs over and is toothed into the low grade brick that usually constituted the intermediate filling.

If these precautions are not taken the excessive heat will warp and burn away the inner lining, causing it to bulge and crack, and there is danger of letting down the main arch. These precautions may seem unnecessary, but if results are wanted they must be carried out.

With regard to the arches, they must also be built of the highest grade brick, and should be laid out in the drafting room full size—so many straight brick and so many wedge brick—so that the masons who do the work will lay them up in this way. If this is not done, the arch will fail because the masons will use straight brick clipped into position and fill in the top crown with a lot of spalls and fire clay mortar.

I have mentioned above that different plants require different treatment, and I know of one plant in particular in which chain grates are used, where the clearance allowed around the chains and back of the chains is so great that enormous quantities of excess air enter at these points, and a low percentage of CO_2 results.

Where chain grates and automatic stokers are employed all clearances must be cut down so as to reduce to the lowest possible percentage the amount of air that does not pass through the fuel bed.

Among other important things that should be found in an up-to-date fire room are colored glasses through which the fireman can examine their fires. It is only by firing often and light, and covering over the "rat holes" and preventing the ingress of excess air that the best results can be attained. It is also very necessary that the draft be cut down as much as possible.

THE PAY-AS-YOU-ENTER CARS ARE TIP-TOP

(From "Life")

Mr. Whitridge said he thought so much of the pay-as-you-enter cars that he had bought 375 of them since the type was tried on the first Third Avenue system.—Daily paper.

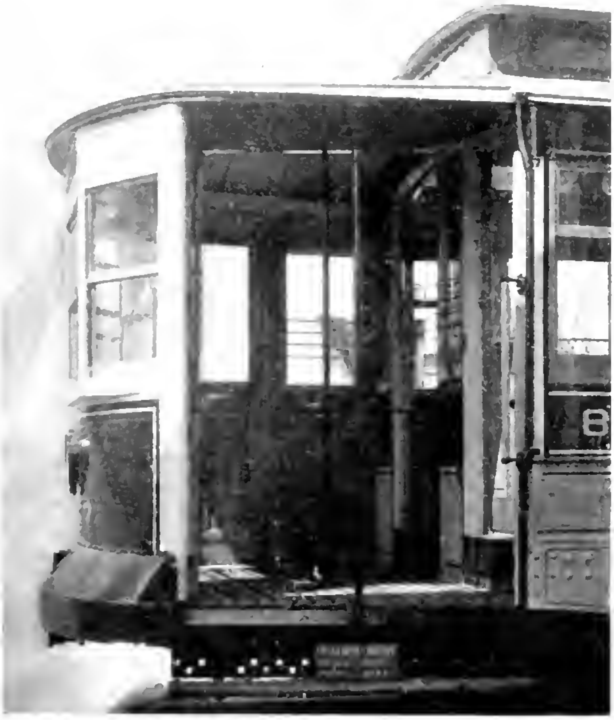
They are admirable; vastly better than the old style cars for the people who ride in them, as well as for the corporations that furnish them. They catch all the fares, which is right. They do away with constant progresses of the conductor through crowded cars, which is a great relief. They make for order, sense and better manners. They do away with the nuisance of smokers on the platforms and give the companies a better chance to exclude lighted cigars and cigarettes from the cars altogether. Publish it to the world that rides in street cars that the pay-as-you-enter cars are a great boon to mankind, and a remarkable mitigation of the sufferings of city populations.

The pay-as-you-enter cars have found favor with the street railway corporations of the larger cities and with the public, and since their introduction on the Third Avenue system, New York City, about two years ago, they have been put in operation on the more congested thoroughfares of Chicago, Baltimore and Detroit. It is also very likely that other large cities in the country will adopt these cars in the near future.

The logical arrangement of separate doors for entrance and exit, and in some cases the employment of the rear and front platforms respectively for these purposes, goes far towards eliminating the delay at stops due to interference between persons boarding and leaving cars of the ordinary enclosed type. The annoyance spared the passenger by this

Convertible Pay-as-you-enter Car for New York City Arranged for Winter Service single feature does much to commend the pay-as-you-enter car to his favor and thus win his fare.

Accidents are also largely prevented by the fact that the conductor is stationed at the



Conductor's Platform, Convertible Pay-as-you-enter Car

rear platform, in a position to render assistance to women and children boarding the car, to the crippled, and to those otherwise incommoded. He can also see at a glance whether his platform is clear, and can signal his motorman without delay and without danger of injury to his passengers.

The illustrations show one of the 300 pay-as-you-enter cars furnished the Third Avenue Railroad by the J. G. Brill Company last summer. This car is an adaptation of the Brill patented convertible car, and is the result of an effort to embody the prepayment idea with the open car arrangement. Fifty additional cars of almost identical design are now on order for the same system. These cars will be fitted with GE 210 volt, 70 h.p. motors.

OBITUARY

Mr. H. H. Buddy, Manager of the Power and Mining and Lighting Departments of the Philadelphia District of the General Electric Company, died on the morning of January 15th after an illness of but two days, his sudden death coming as a great shock to his many friends.

In 1885, Mr. Buddy, who was then about 17 years of age, entered the employ of the Accounting Department of the Thomson-Houston Electric Light Company, of Philadelphia, and he was later promoted to the Commercial Department of that company. Upon the organization of the General Electric Company, he was made the Manager of the Power and Mining and Lighting Departments of the Philadelphia District, which position he filled with marked ability and continued to occupy until the time of his death.

Throughout his business relations he secured and maintained the respect, confidence, and friendship of many of the prominent men connected with the large corporations in that territory, and the grief at his death was widespread.

Mr. Buddy was a member of the Merion Cricket Club of Haverford, the Art Club of Philadelphia, the National Electric Light Association, and an Associate Member of the American Institute of Electrical Engineers.

The funeral services were held at the house of a friend on Mt. Vernon Street, Philadelphia, and the interment was made at Haddonfield, New Jersey, where his wife and child were interred about 15 years ago. He is survived by a father, a sister and a brother.

BOOK REVIEW

THE THEORY OF ELECTRIC CABLES AND NETWORKS

By Alexander Russel, A.M. D.S.C.

D. Van Nostrand Co. 269 Pages Price $3.00 Net

This book appeals to students and to managers of the smaller central stations who are contemplating some underground installations. It is written from the English viewpoint and refers almost entirely to English and Continental methods of cable construction and installation.

The most valuable chapter in the book is that dealing with the dielectric strength. This and the following chapter on the "Grading of Cable" make clear the undesirability of using very small conductors for high potential work.

The references at the ends of the chapters are decidedly the best things in the book, since the somewhat scanty literature on the subject of cables is scattered through numerous publications in papers by various authors covering one or more branches of the subject.

GENERAL ELECTRIC REVIEW

VOL. XIII, NO. 4

APRIL, 1910

CONTENTS

ELIHU THOMSON

GENERAL ELECTRIC REVIEW

TRANSMISSION LINE PROBLEMS.

If collected, the literature dealing with transmission line problems would fill many volumes, and the subject has been treated from various points of view. As it lends itself readily to theoretical treatment, the question has been discussed mathematically to a greater extent perhaps than any other branch of electrical engineering.

In the February number of the REVIEW, Mr. M. W. Franklin shows how to derive the exact solution of the problem by means of the hyperbolic functions. The equations so obtained involve certain constants which include the geometrical properties of transmission lines, *i.e.*, their self induction and capacity, as well as the resistance and frequency, and necessitate the evaluation of the constants and of the hyperbolic functions before numerical results can be obtained from them.

The articles, by Mr. W. E. Miller, commencing in this issue, are of value because these constants, as well as the hyperbolic functions, have been computed at sufficiently close intervals to allow of ready and accurate interpolation by inspection, for all values of the constants and functions which lie within their range. Tables of these functions will be published in a supplement to the next issue of the REVIEW, which will contain the transmission line equations and examples showing how to use them. By the aid of the tables, numerical results can be immediately obtained from the equations by multiplications of two, or at most three complex quantities, and two simple divisions. No capacity, self induction or resistance need be found, because these are included in the constants.

As the wires in transmission lines are very often strung equally spaced with their axes lying in a plane, as well as at the corners of an equilateral triangle, the constants have been calculated for both methods.

The great advantage of using an exact solution of the problem is that the electrical conditions can be as readily determined at any point of the line as at the generator or receiving end, so that if a branch line is connected at any point, the electrical characteristics at its junction with the main line can be immediately obtained.

Apart from this practical aspect of the case, it is of some educational value to see how the volts, amperes and power-factor vary along lines of great length, for which approximate solutions are not reliable. The length at which most approximate methods fail can be roughly taken as 200 miles at 60 cycles, and 400 miles at 25 cycles. The complex hyperbolic functions in these articles have been calculated to take care of lines up to 435 miles in length at 60 cycles, and 850 miles at 25 cycles, even when using the smallest wire considered. Slightly longer lines can be calculated, when larger wires are employed, though the difference is immaterial.

The knowledge of the hyperbolic functions and of the complex quantity possessed by the majority of engineers, is small, and for this reason a short discussion has been given of these matters, which should prove useful to those who wish to get some insight into these quantities. Their understanding is important if the meaning of the equations and their operation are to be understood. The analogy is traced between the circular and hyperbolic functions, and there can be but little doubt that if the hyperbolic functions were taught in school or college in conjunction with plane trigonometry, very little extra work would be required for appreciating and handling them.

In following issues of the REVIEW, curves will be given illustrating how the electrical characteristics vary along a transmission line 400 miles in length at 60 cycles, with various terminal conditions at the receiving end.

A considerable amount of interest is now being taken in corona effect, and therefore this question is briefly considered, curves being drawn in which the corona loss is separated from the capacity current loss along the line at no load, the example taken being a 200 mile line using No. 1 wire and operating at 25 cycles.

Amongst other points discussed, the following may be mentioned: transmission efficiency, velocity of power propagation, shift of phase, and variation of power-factor along the line, a method being given for discovering under what conditions maximum transmission efficiency can be obtained for a given load at the receiving end. As an interesting case in the use of hyperbolics, the volts and amperes of a 1000 mile telephone line have been calculated at various points of the line, both the maximum and instantaneous values of these quantities being plotted. A short discussion on a few of the theoretical points in connection with telephone lines closes the articles.

The table of the hyperbolic complexes and the constants required for transmission lines have been calculated with the greatest possible care, and,through the greater part of the range, the accuracy is about one-quarter per cent. Greater accuracy is not attempted, not only because it is not generally required in electrical engineering, but also because the labor involved would have been enormously increased, since a slide rule could not have been used. It is hoped that few errors occur in the tables, but in work involving over twelve thousand separate calculations, it is practically impossible to entirely avoid mistakes. There is little doubt, however, that no serious discrepancies can exist.

ELECTRICITY ON THE FARM

The high and ever increasing cost of living, which, it is well recognized, is due in a very large measure to the scarcity and the consequent steady advance in the cost of farm produce, is causing the necessity for greater production to assume vital economic importance.

The need for agricultural commodities is urgent, and the reward for the producer certain, but the problems involved are many and perplexing, the chief one being that of securing efficient labor at a rational, or in fact any, price. This difficulty may be overcome to an extent not generally realized by the utilization of machinery for reducing the manual labor necessary. In pursuance of this course, many modern farms have been equipped with labor-saving machinery and, where this solution has been applied to the problem, the results have far exceeded the expectations and have more than justified the investment; not only by greatly increasing the output, but by doing away with "the discouraging and never ending hard work which in the past has done more than any other thing to drive the boys from the farm."

In the great grain districts of the Northwest, agricultural operations have, of course, long been accomplished by the use of machinery; the harvesting, etc., of these enormous crops would otherwise be an utter impossibility. In Europe also, and especially in Germany, plowing and similar operations have been performed by means of electrically driven machinery. These methods have resulted in material economies, and this although the land is poorer than that in the United States and the cost of labor only about one-sixth of that in this country.

While in the Eastern states, the employment of engine or motor driven machines for the more extensive operations may not fit the present conditions, the uses for power on an average American farm are many and varied. The threshing and grinding of grain, the operation of separators, churns, and pumps (both for regular water supply and for service in case of fire), the driving of washing machines and other household devices, are only a few of the labor saving items.

For the purpose of driving farm machinery, the electric motor is the logical choice; there, if anywhere, it stands pre-eminent. The flexibility of the electric system; the fact that a number of scattered motors used for intermittent service may be supplied from a small generator of very much less than the aggregate capacity of the motors; the availability of the current for lighting purposes and the absolute safety as regards fire risks; are but a few, and not necessarily the most important reasons for the selection of electricity as the motive power. The further fact that with the introduction of electricity come many material comforts, and even luxuries, is another cogent reason for its adoption; and when in addition to the above, it is realized that the power for generating the current can, in very many cases, be obtained from local streams, the energy of which would otherwise be wasted, the superiority of electric power becomes evident.

The article by Mr. Liston, in the present issue, describes a large model farm in which electricity has been utilized extensively and has been found to be reliable, safe, and economical.

THE WESTPORT-STOCKTON COAL COMPANY'S COLLIERY WESTPORT, NEW ZEALAND

By W. A. Reece

With the opening of the Westport-Stockton Coal Company's Colliery on October 6th, 1908, an engineering work was successfully brought to completion which affords not only a striking example of a modern coal mine equipment in its highest perfection, but also offers a most interesting study of how a difficult and complicated haulage problem was overcome, involving as it did, the introduction of electric hoists, gravity inclines, and electric locomotives.

In order to give an intelligent idea of the work, it will perhaps be best to first describe the coal formation, taking up the various other considerations such as power plant equipment, haulage systems, transmission line, braking problem, etc., in order.

The Company holds a Crown lease of two thousand acres of coal bearing land forming part of the Buller coalfield. From the outcroppings and test bores the famous Westport seam of coal—a bituminous coal of high calorific power and great purity—was proved to underlie the greater part of the 2000 acre area. The seam is from eight to twenty feet in thickness and has a fine roof of hard sandstone and in most places a hard bottom of the same material. The lease is situated on the tableland of the steep coastal range, at an elevation of about 2000 feet above sea level.

The Buller coalfield may be described as unique. The coal lies at a moderate inclination on the coastal range plateau, and is underlain by sandstones which repose directly on granite. The thickness of these sandstones rarely exceeds 100 ft. and in some portions of the field the granite intrudes into the coal. The coal formation belongs to the Cretacio-Tertiary, but the coal is truly bituminous in composition and characteristics. Gold is found in the immediate vicinity of the coal measures.

Power Considerations

The coal is brought down from the Company's mines to the Government railway at Ngakawau, which is 19 miles from Westport, the port of shipment. The distance from the Company's tipple at Ngakawau to the siding

Power Station with Tipple and Bins in the Rear

in the mine, from which the coal is hauled by the Company's main haulage system, is four miles. It was decided to install electric power for the whole of the mining operations and to generate it in a central station at Ngakawau; the reasons for locating the plant at this point alongside the government railway being as follows:

(1) Possibility of later augmenting the steam power by available water power.

(2) Saving of difficult transportation and the facilities offered by the Ngakawau site for economical handling and erection.

(3) Proximity to tipple, facilitating the use of screenings from the coal for power plant fuel.

(4) Best location for supervision.

Power House

The power-house is of ferro-concrete construction and is fireproof throughout; it is 174 ft. long by 50 ft. wide, and is divided into three compartments, engine room, condenser room, and boiler room.

There are two main generating units, each consisting of a 300 kw., 6600 volt, 60 cycle, three-phase generator direct connected to and resting on a common bedplate with a 475 b.h.p. Bellis & Morcom triple expansion engine, the set running at 400 revolutions per minute.

In addition there are two exciter sets, each made up of a 14 kw., 88 volt, 600 r.p.m. generator direct connected to and on a common bedplate with a Bellis & Morcom single expansion engine run condensing. For lighting about the plant and for operating a number of d.c. motors on the conveyors and jiggers in the main coal storage bins, a motor-generator set is installed in the power-house. This set consists of a 100 kw., 280 volt flat compound direct current generator direct connected to a 150 h.p., 6300 volt, form K, three-phase motor, the set running at 705 r.p.m.

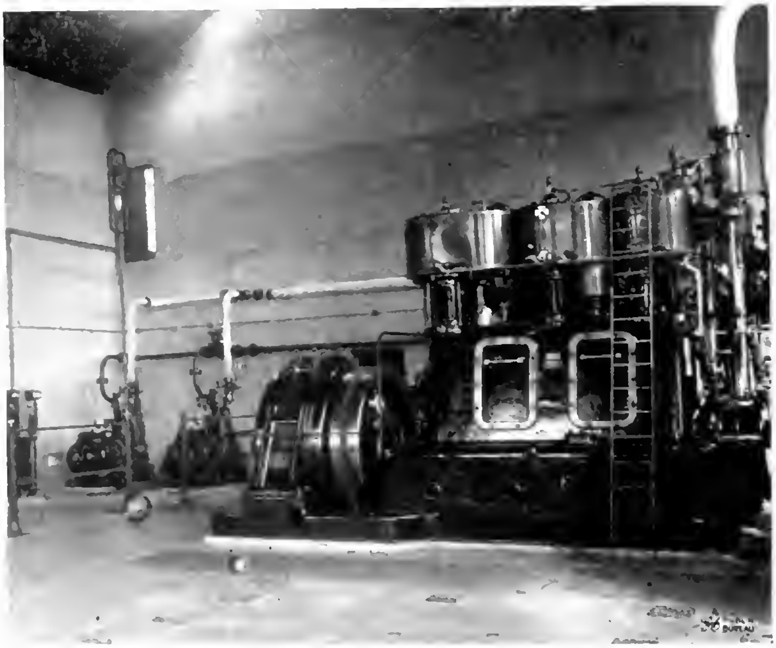
The main switchboard comprises eight panels of blue Vermont marble and three blank panels to provide for future extensions. From left to right the switchboard is made up as follows:

Feeder panel for generator of motor-generator set.
Generator panel of motor-generator set.
Starting panel for motor of motor-generator set.
Two blank panels.
Two main generator panels.
Main high tension feeder panel.
Blank panel.
Two exciter panels.

The direct current voltmeter for the motor-generator set is mounted on the extreme left panel, the synchronizing indicator and exciter voltmeter, together with voltage regulator, being mounted on the extreme right panel.

The engines exhaust into a Worthington surface condenser, which has a capacity of 30,000 lbs. of steam per hour with the circulating water at a temperature of 55 deg. F. A Worthington centrifugal pump draws circulating water from a well near the power house. The air pump, which is of the three-throw "Edwards'" type, is driven by an engine of 25 b.h.p. condensing. A Webster feed water heater which is capable of raising the temperature of 30,000 lbs. of water 30 deg. F. in one hour, is installed and uses the exhaust steam from the two boiler feed pumps and the engine driving the automatic stokers.

There are four Babcock & Willcox boilers, each with a heating surface of 1690 sq. ft. and a fire grate area of 34 sq. ft. and capable of evaporating 5000 lbs. of water per hour at



Generator Units in Power Station

212 deg. F. The boilers are fitted with Babcock superheaters which superheat the steam 150 deg. F., and with automatic stokers of the Babcock chain grate type having four-speed feed gears and driven by a 15 b.h.p. single engine.

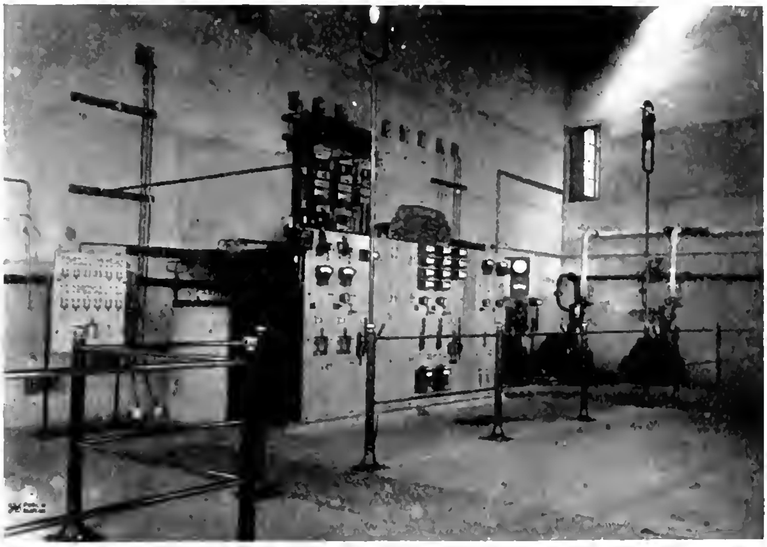
The boiler feed pumps, of which there are two, are of "Tangye's" manufacture and have each a capacity of 75,000 lbs. of water per hour against a pressure of 150 lbs. It will be noted that the condenser plant and the feed pumps are of sufficient capacity to take care of the ultimate engine and boiler capacity of the plant, which will be double that at present installed.

Hoists

Two small auxiliary panels are located near the main switchboard in the power house, one of which is employed for the control of a 40 kw., 6600/230 volt transformer. This transformer supplies current to a 52 b.h.p. motor connected to a Lidgerwood hoist located near the bins, the hoist being used for hauling the government railway coal trucks out of a dip onto an incline. From this incline the trucks are distributed by gravity to the various tracks under the bins for loading; after which they are run by gravity to the main siding and there made up for dispatch to Westport harbour. The second auxiliary panel is for the control of a 75 kw., 6600/230 volt transformer supplying current to a 112 b.h.p. motor connected to a second Lidgerwood hoist. This hoist has two drums with main and tail ropes and brake and friction clutch levers, and is used for hauling the loaded coal tubs from the foot of the lower incline through the Ngakawau tunnel to the bins, and for returning the empties; the method of haulage being main and tail rope. An auxiliary arrangement is also provided so that tubs, stores and miscellaneous material can be hauled up from the shops and stores to the tunnel mouth.

Haulage Way

Ngakawau tunnel. The Ngakawau tunnel is 28 chains long with an average gradient of 1 in 60 in favour of the load. The tunnel commences about 100 yards from the bins and runs through to the foot of No. 1 incline, a single track of 40 lb. per yard rails being laid, with sidings at each end. The method of haulage, as previously mentioned, is by main and tail rope, and the tubs can be run



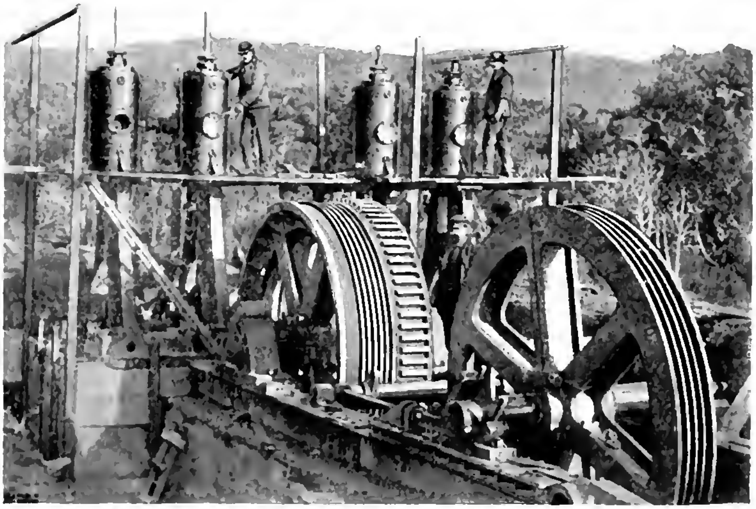
Switchboard in Power Station

in sets of 25 at the rate of four round trips, or 100 tubs per hour.

Gravity Inclines

The lower incline is 33 chains in length and has an average gradient of 1 in 4 and a maximum gradient of 1 in 3. At the top of this incline is located a flat where the mine tubs are changed from the upper incline rope to that of the lower incline. The upper incline is 10 chains in length with an average gradient of 1 in 6.7 and a maximum gradient of 1 in 5. These inclines have been most carefully graded; there are no dishes, and changes of gradient have been effected by long vertical curves. Towards the bottom of the upper incline there is a sandstone tunnel seven chains in length, but on the lower incline there are no tunnels. Heavy cuttings and fillings have had to be constructed on both inclines; filling having been resorted to wherever practicable in preference to bridging, with a view to keeping down cost of maintenance.

A double track of 40 lb. rails is laid on each of these inclines and the cars are operated by gravity, the endless rope system of haulage being used. The tubs are spaced on both the full and empty sides at intervals of 1½ chains, the greater weight on the loaded side causing the motion. The speed of the rope is regulated by powerful four-cylinder hydraulic brakes of the vertical type, which were built by Messrs. Simpson Brothers, of Sidney, Australia. The braking is effected by churning the water from end to end of the cylinders through by-pass valves, a small quantity of water being admitted and a small quantity expelled at each stroke to keep the water cool. These brakes act admirably, imparting a steady motion to the ropes and giving good speed regulation.



Hydraulic Brakes for Gravity Incline

Vertical grooved pulleys 10 ft. in diameter are employed in place of surging drums to eliminate side friction between the coils of rope. The braking pulley has five grooves turned to fit the ropes, and the idler pulley four grooves. The incline ropes are of Shaw's manufacture and are made of the best patent plough steel wire, the lower incline rope being 1½ in. in circumference and the upper incline rope 4 in.

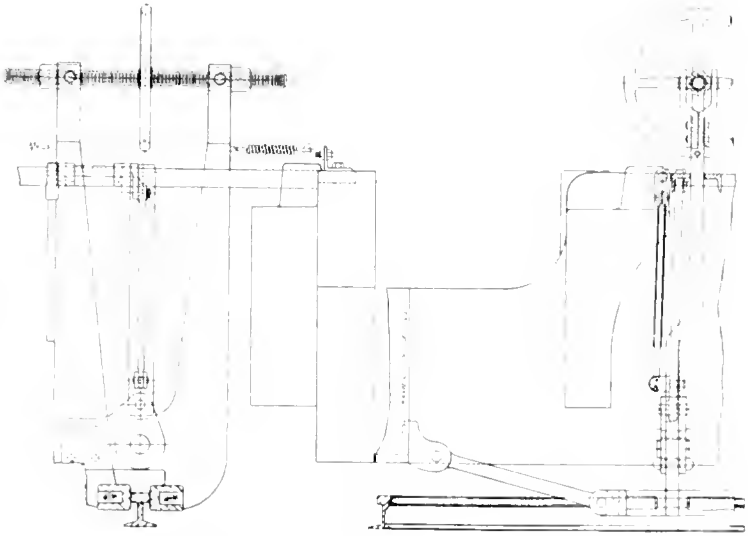
The mine tubs are built of mild steel with wooden buffers and 12 in. diameter cast steel fast wheels of Hadfield's make set for 3 ft. gauge. The tubs weight 12 cwt. empty and have a carrying capacity of 30 cwt., and when spaced every 1½ chains and travelling two miles per hour, have a capacity about 160 tons per hour. With the tubs spaced every chain and travelling at the same speed, their capacity is increased to 240 tons per hour. The rope runs under the tubs and is attached to each by means of chain clips. The tub drawbar is provided with a hook, and the clip chain, which is made with a large link at each end, is wound three times round the rope, one end being then passed through the other and hung onto the tub hook. The lower incline clips are made of ⅝ in. diameter Staffordshire short link chain and the upper incline clips of similar chain ½ in. diameter. These clips hold well on the steep gradients, and so far not the slightest trouble with them nor with the hydraulic brakes has been experienced. It is surprising with what facility boys can handle these clips. Before employing the chain clip, a patent screw clip was tried, in which the rope was held in a sort of vise; but it was found that with this clip the personal factor came too much into play, and one clip insufficiently screwed up might be responsible for a serious wreck. An accident of this kind actually happened on one occasion when a loaded tub got away on the lower incline on the 1 in 3 grade and cleared the rope of all tubs below it, piling up and wrecking about 14 tubs.

Electric Haulage System

At the head of the upper incline, which is termed the brakehead, the trucks run onto a level plat where the main electric locomotives begin their run. These locomotives deliver the loaded tubs from the mine to the head of the upper incline and pull back the empties. At present the Company has three of these main locomotives (an additional one being on order) and two gathering locomotives. The main locomotives weigh 20 tons each and are equipped with Sprague General Electric Type M control to permit them to be worked as separate units or coupled in tandem as required. Each locomotive has a drawbar pull of 7500 lbs. and a speed of 8.2 miles per hour. The length of the tramway from the brakehead to the mouth of "A" tunnel is 2¼ miles, and from the latter point the track runs for half a mile in the mine through a coal tunnel 8 ft. high and 7 ft. wide to the layby, where the loads are at present picked up.

Braking Problem

The vertical rise in this 2¼ miles of track is 710 feet, giving a gradient of 1 in 20.5. There are several curves on the track and the minimum radius is two chains. Up to the present time the locomotives have been used singly, no difficulty having been experienced in hauling the empty tubs up to the mine. The train is made up of twenty empties weighing 12 cwt. (112 lbs. per cwt.) each, and a braking car weighing two tons; making a total train load on the up grade of 14 tons. Braking the loads down has proved a much more difficult problem. In the first place the center rail for the Fell brake was laid only on the steeper gradients and the tubs were all fitted with wheel brakes independently operated. These brakes were set before the train started from the mine and it was impossible to manipulate them for the first half mile of the run as there was insufficient room in the tunnels for a man to get from tub to tub; and even outside it was not practicable to work the brakes in this way owing to the small clearance between line and trolley poles which made it dangerous for the brakeman to pass over the tubs.



Fell Center Rail Brake

Train of Cars Leaving Tunnel

The result was that the brakes were often set so tight as to skid the wheels, or else so light that there was very little braking effected. It was early discovered that the locomotive wheel brakes in conjunction with the tub brakes could not be relied upon for braking the train, even on the flattest grades, and it was necessary to put in the center rail from end to end of the track. It was also found that accidents occurred at points where the center rail had to be picked up by the so-called Fell center rail grip brake, owing to the fact that the brake occasionally struck the end of the rail. After installing the center rail throughout the entire hauling distance, it was found that one Fell brake, although powerful enough to control the speed of the train with the assistance of the tub brakes and wheel brakes could not be depended upon to stand the heating and strain of continuous running.

The loaded tubs weigh 12 cwt. each and the weight of the train load is therefore 12 tons plus the 20 tons weight of the locomotive, or 62 tons. On the Rimutaka incline of the New Zealand Government railway, the train load allowed per Fell brake on a 1 in 14 grade is 20 tons. On one occasion, after the equipment had been in operation a few weeks, the Fell brake gear carried away on a downward trip, fortunately at such a point that the damage caused was not great and the driver escaped injury. Should such an accident occur near the top of any of the steep grades on the road under consideration, which, by the way, is the most likely place for an accident of the kind to occur, it would probably wreck the locomotive and train and kill the driver. It was therefore decided to add a braking car fitted with a second Fell brake, to be used in conjunction with the locomotive Fell brake and sufficiently powerful to brake the whole train load in case of emergency; the most improved braking car being fitted with two Fell brakes. This method has proved satisfactory and the tub brakes have been discarded on account of the difficulty of effectively manipulating them and the heavy cost of upkeep. On the up-trip to the mine with the empty tubs, the braking car is placed at the rear end of the train and is run with the Fell brake down ready for action should a coupling break. On the downward trip, however, better results are obtained by running the car at the front end of the train next to the locomotive, as in this position the brakeman is more in touch with the driver and can apply the brakes as required.

Gravity Incline

In making the down trip with the braking car at the rear end of the train, it was found that on approaching a brow the car brakes were sometimes applied too soon, thus throwing a severe strain on the couplings, or else not soon enough, throwing the whole weight on the locomotive. It is believed that it would not be advisable to run the locomotives in tandem, owing to the excessive amount of current that would be required in ascending steep grades on the up-trip and to the severe strain the buffers would be subjected to on the down-trip unless two braking cars were employed, one next to the locomotive as at present, and one at the rear end of the train.

Motor-Generator in Substation

The wear and tear on brake shoes is very heavy, the wheel brake shoes lasting for only eight hours and making about eight trips. It was found necessary to design the Fell brake shoes with removable wearing strips, mild steel proving most economical for the purpose and giving the best results. Cast iron was found to wear away very quickly and consequently required to be heavier and was considerably more costly. A set of mild steel wearing strips lasts about eight hours, as stated above.

The smaller gathering locomotives weigh 6½ tons each and have a drawbar pull of 2500 pounds and a speed of 7.4 miles per hour. These locomotives are used for the subsidiary haulage from the working places in the mine to the siding from which the main haulage starts. They are equipped with a reel which is mechanically worked from the locomotive axle and which is supplied with 900 feet of flexible twin cable, thus permitting the locomotive a considerable range of operation beyond the point of overhead construction.

Track

The track from the brakehead into the mine is 36 in. gauge and of extremely solid construction. The rails are 40 feet long and weigh 56 lbs. per yard; they are laid on 8 in. by 5 in. ties and are bonded at each joint with two number 00 bonds and cross bonded at every third rail. The distance from the brakehead, where the main locomotives deliver the loaded trains to be conveyed by gravity down the endless rope inclines and thence through the Ngakawau tunnel to the bins at No. 1 substation, is 35 chains, with a minimum curve of 132 ft. radius and the grades varying from 1 in 32 to 1 in 12, or an average of 1 in 25, all in favour of the load.

From No. 1 substation to No. 2 substation at the mouth of A tunnel is 145 chains, the grades all being in favor of the load and varying from 1 in 12 to level, the average being 1 in 21. The minimum radius of curves is 132 ft. From No. 2 substation to No. 3 substation, through A and B tunnels, is 79 chains, the A tunnel being 15 chains long and the B tunnel 64 chains long. The distance to the layby, where the coal is at present lifted, is 40 chains, the track being straight and the minimum grade 1 in 12.

Overhead Construction

The trolley wire is 7 ft. 8 in. above the level of the head of the rails, and is of No. 0000 throughout. In parallel with the trolley for the whole run is a bare stranded cable of 600,000 c.m., the latter being tied to the former at an average of every 150 feet.

Sub-Stations

Three sub-stations, which are identical with regard to electrical equipment, feed the overhead trolley network. In each sub-station is a motor-generator consisting of a 200 kw., 280 volt flat compound direct current generator direct connected to and on a common bedplate with a 300 b.h.p., 6300 volt, form K three-phase motor, the set having three bearings. The switchboard consists of three panels of blue Vermont marble, and from left to right are as follows:

- Starting panel for motor with automatic oil switch.
- Direct current generator panel.
- Direct current feeder panel with voltmeter on swinging bracket.

Transmission Line

The three substations operate in parallel and are supplied with three-phase current at 6600 volts, the transmission wires being No. 0 hard drawn bare copper throughout and the total length of the transmission line six miles. A lightning arrester ground wire consisting of five No. 16 stranded galvanized wires is strung along the high tension line and stapled to the top of each pole. The distance between poles averages 150 feet and the lightning arrester wire is effectively grounded at approximately every fourth pole.

There are nine transpositions in the transmission line.

Telephones

Telephone lines connect the three substations, power house, offices, mine, etc., and are run on the transmission line poles from the power house to the brakehead; thence following the overhead construction to the end of the tramway. Each locomotive carries a portable telephone by means of which communication can at once be established with any of the points on the telephone network.

Mine Working

The mine is worked on the bord and pillar system, with six yard bords and 16 yard pillars. The coal is from 8 to 20 feet in thickness and lies in positions varying from horizontal to a slope of 1 in 8, the grades being all in favour of the haulage. The main drainage of the mine is also free, the haulage tunnel cutting the coal at its lowest point.

The present output is 500 tons and upwards per day of eight hours, half of this quantity being mined by hand and half by machinery. The machine mining is proving the more economical, however, and additional machines will shortly be installed. The Company is at present working two "Sullivan" bord and pillar chain machines with six foot cutting bars, each machine being driven by a 30 h.p. motor. These machines are the first of their class to be used in New Zealand and are giving excellent results.

The machines are cutting from three to four 6 yard bords per shift, each bord producing on an average about 30 tons of coal. The undercut is made in the coal itself at the bottom of the seam.

Tipple and Storage Bins, Showing Hydraulically Operated Doors

Ventilation

The mine is singularly free from explosive gases and the workings are so arranged that the ventilation is a simple proposition. The main workings are at present in the "B" tunnel, which is ¾ of a mile in length and runs out to daylight at each end. An electrically driven Waddel fan is situated at the top of a shaft in the center of the tunnel and draws air through the workings from both ends of the tunnel. At 290 r.p.m., the fan has a capacity of 80,000 cubic feet per minute at 1½ in. water gauge and requires 30 b.h.p. to operate. It is belt driven from a 40 h.p., 500 volt, three-phase motor, the three single-phase transformers for which are situated in No. 3 substation. The object in using 500 volt, three-phase motors for driving the fans in preference to operating them from the 250 volt direct current trolley is that this service will be continuous irrespective of any possible interruptions to the trolley overhead network. In addition to this fan there are six "Sturtevant" blowers direct connected to 5 h.p., 250 volt, direct current motors; these units being located at various points in the workings and used for ventilating the headings through 12 in. pipes which are run into the working places in place of brattice. These blowers are found very convenient and can easily be moved from place to place as required.

Quality of Coal

The coal is a good bituminous variety with a high calorific value and low percentage of ash, swelling on heating and giving a fairly hard coke. On the opposite page an analysis of coal taken from "B," "C," and "D" tunnels is given, which was made by the government analyst:

From an inspection of these figures it will immediately be noted that the ash percentage is unusually low. It should, however, be taken into consideration that the coastal range from which this coal is obtained has other coals which are also very low in ash, though test figures have hardly been comparable with the analysis given here.

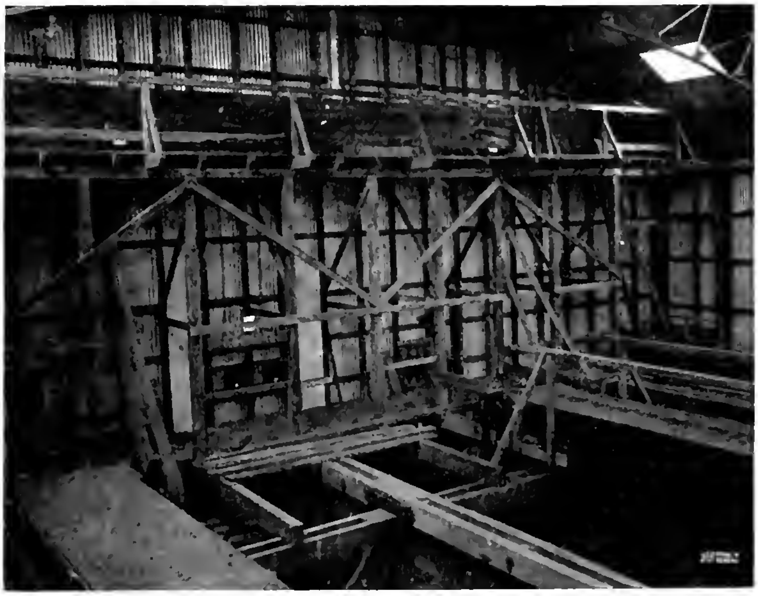
Tipple and Storage Bin

The main bin into which the coal is delivered at Ngakawau has a capacity of 5000 tons and is divided into three compartments, two of 2000 tons each for the storage of unscreened coal and one of 1000 tons for the storage of slack. The loaded tubs run into the bins by gravity and are thrown into any one of the three tipples desired, whence their contents are discharged onto the distributing jiggers or into bins as the case may be. The slack from the screens is elevated and conveyed by a scraper conveyer to the slack bin. Through tipples are employed, the loaded tubs displacing the empties which automatically gravitate to the empty siding to be made up into a train for the trip back to the mine. The main bin is composed entirely of ironbark built on pile foundations and has five loading roads under it, from which the coal is loaded into the eight ton capacity government cars and conveyed to Westport. The loading doors work in a horizontal plane and are opened and closed by hydraulic rams which operate at a pressure of 120 lbs. per square inch. Pressure is obtained from an accumulator operating from a 500 foot head of water derived from a small stream near the top of the lower incline, the object of the accumulator being to maintain a constant pressure when the doors are operated. The scraper conveyer for elevating the slack from the screens, and the picking band for loading the screened coal, are both operated by one 15 h.p. direct current motor. The two unscreened conveyer belts are each operated by a 10 h.p. motor and the distributing and screening jiggers by 5 h.p. motors. The bins are lighted by two arc lamps and in addition by a number of incandescent lamps where required.

Mark	"B" per cent.	"C" per cent	"D" per cent.
Fixed carbon . .	61.75	61.85	66.80
Volatile hydrocarbons	36.80	36.45	31.85
Water . . .	1.25	0.95	1.05
Ash	0.20	0.75	0.30
	100.00	100.00	100.00
Coke (from closed retort) . . .	61.8	61.90	67.10
Calories per gram .	8182	8183	8139
British thermal units per lb. . .	14718	14698	14650
Evaporative power per lb. . . .	15.24	15.3	15.22
Practical evaporative power per lb. (calculated on 60 per cent. efficiency) .	9.19	9.18	9.13

Labour Conditions

The supply of all classes of labour necessary for working the mine is fairly plentiful at the present time. Wages are regulated by the Arbitration Court, and New Zealand has practically been without a strike since the introduction of the "Arbitration and Conciliation Act," although recently there has been some signs of dissatisfaction on the part of the workers.



Distributing Belts

Cost of Production

A royalty of twelve cents per ton to be paid to the State, and the compulsory payment to the "Government Compensation for Accident Fund" of one cent per ton, are factors which must be considered in addition to the actual cost of production.

Markets

Up to the present there has been a full and ever increasing market within the Dominion for the West Coast coal, this section being the only part of the Dominion in which good bituminous coal has been found. For the past ten years, the local consumption has increased at the rate of 100,000 tons per annum. Ten years ago the consumption was, roughly speaking, one million tons, while at the present time it is two millions, rather more than half of which is supplied from the West Coast coal fields. The balance, with the exception of about 200,000 tons imported from New South Wales, is supplied from the Lignite & Brown coal seams which are found in various parts of the colony. Up to the present time, owing to the full home market, the foreign coal trade has not been exploited, but with the extension of coal mining on the West Coast, it may become necessary to look for an oversea trade. The foreign markets commanded through Westport are:

West Coast of South America. This, perhaps, is the most important customer in the Pacific, and a glance at the chart shows that Westport is 1200 miles nearer than Australia. Australia exports about 500,000 tons per annum to South America, and in addition, shipments are frequently made from English ports and latterly from Durban.

Manila, Java, Sumatra, or in other words the East Indies, are perhaps the next in importance. There is a strong demand for good steam and gas coal there. The Indian coal does not by any means satisfy the requirements and from three to four hundred thousand tons are sent annually from Australia.

Mexico, California and the Hawaiian Islands are also, geographically speaking, close to New Zealand, and the West Coast bituminous coal must command an extensive market there.

Entering the Tipple

Harbour

The Westport harbour is the most prosperous bar harbour in the Dominion, about half a million sterling having already been expended in improving the harbour and deepening the water on the bar.

The port may be safely worked by vessels drawing about 18 feet of water.

The expenditure of a new loan of £200,000 is expected to increase the depth of water on the bar and in the fairway to such an extent that ocean going tramp steamers of from 5 to 6 thousand tons will be able to fully load. This will encourage and render possible a much larger foreign trade than can be coped with at the present time.

Electrical Equipment

The entire electrical equipment for this enterprise was furnished by the Australian General Electric Company, and manufactured partly by the General Electric Company, Schenectady, U. S. A., and partly by the British Thomson Houston Company, Rugby, England.

The Tipple

The writer is indebted to the Company's engineer for assistance in securing the photographs and data for this article.

COMMERCIAL ELECTRICAL TESTING

Part VI

By E. F. Collins

Technical Superintendent, General Electric Company

ROTARY CONVERTERS

Preliminary Tests

The cold resistance of the armature of a rotary converter is measured between the collector rings, as follows:

For a three-phase machine, between rings 1–2, 1–3, 2–3

For a two-phase machine, between rings 1–3, 2–4

For a six-phase machine, between rings 1–4, 2–5, 3–6

The resistance of the various phases should be the same and it is immaterial whether the rings are numbered from the inside or from the outside for this measurement.

Running light on a rotary is taken with the machine running from the direct current end. With the brushes set on the neutral point, the direct current voltage is held constant and the shunt field varied until the rated speed of the machine is obtained. The input to both field and armature is then read. Since there is very little armature reaction in a rotary converter, the brushes are set on the neutral point before the machine is started. It often happens, however, that better commutation can be secured by shifting the brushes away from the neutral point very slightly. In case of unsatisfactory commutation, the brushes should be shifted in each direction, since some machines require a forward and some a backward shift from the mechanical neutral.

The determination of the ratio of the alternating current to the direct current voltage is one of the important tests on a rotary, and care should be taken to secure accurate results. The converter may be driven from either the alternating or the direct current end and, in order to check the accuracy of the instruments, two alternating current voltmeters, two potential transformers, and two direct current voltmeters should always be used. During the test the direct current voltage is held constant and the alternating current voltage read between rings 1 and 3 on a two-phase, and 1 and 4 on a six-phase machine.

The ratio is taken at no load and at full load, and should be as follows when the machine is running from the alternating current end:

RATIO A.C. TO D.C. VOLTAGE

	No Load	Full Load
Single-phase	71.5	73
Two-phase (measured on diameter)	71.5	73
Three-phase	61	62.5
Six-phase (measured on diameter)	71.5	73
Six-phase (measured on adjacent ring)	35.8	36.5
Six-phase (measured on alternate rings)	61	62.5

The amount of pole face arc will change the ratio.

An easy and approximately correct method of telling whether a rotary is running with the proper shunt field excitation, is to note the ratio of the alternating current to the direct current, which should be as follows:

Three-phase alternating current and direct current practically the same.

Two-phase alternating current equal to three-quarters of the direct current.

Six-phase alternating current equal to one-half the direct current.

Equalizer Taps

As soon as a rotary is assembled and before any running tests have been started, the spacing of the equalizer taps and the taps to the collector rings must be carefully checked. Occasionally a wrong connection is made and, if it is not corrected before the running tests are started, one or more equalizer leads may become badly overheated or be burned off.

Constant Ratio

The standard shunt wound rotary converter has a very nearly constant ratio of alternating to direct current voltage, so that any fluctuation in the voltage of the alternating current supply will show directly on the direct current voltage delivered. Such machines are unsatisfactory when much variation in load occurs. When the direct current volts have to be varied on a standard machine, the impressed alternating current volts must be altered. This is generally done by using transformers provided with dial switches, by means of which the transformer ratio is changed.

If a series field winding is added to the standard machine, a practically constant voltage can be obtained with sudden changes in load by introducing reactance into the circuit, or in some cases by using the inductance and resistance inherent in the feeder circuit. This is possible, for the reason that an alternating current passing over an inductive circuit will decrease in potential if lagging, and increase in potential if leading.

A rotary converter running as a synchronous motor requires a certain definite field excitation to effect the minimum input current to the armature. Varying the excitation either way changes the input current, so that by using sufficient reactance in the alternating current circuit from which the converter receives its power, the alternating current voltage at the converter terminals may be increased or decreased by increasing or decreasing the field current. By adjusting the shunt excitation of the compound wound machine to give a no load lagging current of about 25 per cent. full load current, and the series field to give a slightly leading current at full load, the impressed voltage at no load will be automatically lowered and that at full load increased. Hence a practically constant direct current voltage will be delivered at all loads.

Variable Ratio Machines

The split pole rotary differs from the ordinary rotary in that the poles consist of two separate and independent parts, each provided with its own field coil. The auxiliary pole may be placed on either the leading or the trailing side of the main field, depending upon the conditions under which the machine is to operate. If it is to operate as a straight rotary, the auxiliary pole is to be placed on the trailing side; while if the machine is to float on the line to take fluctuations of load through a storage battery, and hence run inverted part of the time, the auxiliary pole should be on the leading side. The reason for this is as follows: The auxiliary pole influences commutation when on the leading side, as well as regulates the direct current voltage, and will be of correct polarity for commutation if the machine inverts at a direct current voltage corresponding to no excitation of the auxiliary poles.

In wiring a split pole rotary for test, the transformers used must be exactly alike. The best results are obtained by using transformers with two secondaries excited by one primary. Care should be taken to see that the cables from the transformers to the rings do not differ in length or cross section, and that all switches in these circuits have their contact surfaces well cleaned with sandpaper. These precautions are necessary to prevent any unbalancing of the current in the alternating current circuits outside of the armature.

The testing instructions should specify the manner in which the transformers are to be connected, both primary and secondary; the alternating current volts to be held across corresponding rings; and the range through which the direct current volts are to be varied by means of the auxiliary field. The following no load readings should be taken:

Current per phase. (Must be balanced.)

No load phase characteristic.

Ratio of voltage.

Volts between adjacent collector rings with main field only.

A set of readings of alternating current amperes while varying the direct current volts by means of the auxiliary field through the total voltage range, the main field being held at minimum input value, the alternating current volts constant, and the brushes shifted to give the best commutation over the whole range.

A set of readings while varying the direct current volts through the total range by means of the auxiliary field, the main field being adjusted to give minimum input for each change in direct current voltage.

A full load ratio and the current per phase for minimum input, using main field only.

Phase Characteristics

Three full load phase characteristics should be taken as follows:

1st. Holding the alternating current volts constant and using the main field only.

2nd. At the lowest limit of the direct current volts: holding the alternating current and direct current volts constant and adjusting the direct current line current to that value which gives the rated output for the mid voltage with zero auxiliary field.

3rd. At the highest limit of the direct current volts: holding the alternating current and direct current volts constant and adjusting the direct current line current to that value necessary to give the rated output for the mid voltage with zero auxiliary field.

Core Loss

Three core loss tests are required to cover the various conditions of operation. These are made as follows:

1st. Core loss while varying the direct current volts by means of the main field only, with auxiliary field not excited.

2nd. Core loss while holding the excitation of the main field constant at that value which gives mid direct current voltage, and varying the auxiliary field to change the direct current voltage.

3rd. Core loss while holding the alternating current volts constant and varying the main field each time the auxiliary field is changed to change the direct current volts throughout the range. This gives unity power factor.

All other tests are made as on standard rotaries.

Inverted Rotaries

The speed of a rotary when running from the alternating current side is determined by the line frequency. The same machine running as an inverted rotary and delivering alternating current operates as a direct current motor. Its speed depends upon the field excitation and load, and it will deliver a variable frequency, particularly if compound wound. When run inverted, a compound wound machine should have its series field almost, if not entirely, short circuited when part of its load is inductive, since a lagging current will weaken the field and increase the speed, sometimes causing a runaway. For this reason care must always be taken when running a rotary inverted to see that sufficient shunt field excitation has been obtained to prevent excessive speed, particularly when another machine is operating as a rotary from the inverted machine.

Motor-Converter

A motor-converter consists of a standard rotary converter and an induction motor. The induction motor has a wound rotor with taps brought out to a set of common rings, which take the place of the collector rings for both motor and converter. The voltage of the induction motor rotor is the alternating current voltage of the converter. The advantage of the motor converter is that high tension currents (up to 13000 volts) may be applied to the stator of the induction motor, the rotor delivering low voltage to the converter. Hence the intervening bank of transformers, always necessary with a rotary, is not required. No reduction of power factor is caused by the induction motor, since unity power factor may be maintained with the motor-converter by the proper adjustment of the field of the rotary.

Starting Tests from the Alternating Current End

The rotary should be wired to an alternating current generator of sufficient capacity to start it without overloading. If transformers are needed in order to get the correct voltage, they should be placed between the dynamometer board and the generator.

A rotary, when starting from the alternating current end, is similar in action to a transformer. The armature corresponds to the primary, and the field, which has a large number of terms, to the secondary. Hence the induced volts on the field may be very high, often 3000 or 4000 volts. In all cases, therefore, the field connection must be broken in two or more places to keep this voltage within safe limits. A potential transformer and voltmeter should be connected across one or two spools in series for reading the induced volts field, and a record made as to the number of poles included in the reading.

Starting tests should be made from several different positions of the armature with respect to the field. A scale, corresponding in length to the distance between collector ring taps, should be laid off on the armature and divided into five equal parts. A point of reference is then marked on the field, opposite to which the marked positions of the armature are placed for the successive starts.

Having brought point No. 1 opposite the reference point, the alternating current switches should be closed and the field on the alternator increased until about one-half normal full load current is sent through the rotary, reading volts and amperes in the various phases. As it is impracticable to read all phases at once during the start, the ammeter should be cut into that phase which shows the highest current and the voltmeter across the phase which indicates the highest voltage, in order to get the maximum readings at the instant of starting. The field of the generator should be increased until the armature begins to revolve, when volts and amperes input and induced volts on the field should be read. The voltage across the collector rings should then be held constant until the rotary reaches synchronism, the time required to reach this point from the start being noted.

There are several methods of determining whether the rotary is in synchronism; one, by the fact that the induced volts field will fall to zero; another, that the voltmeter across the armature will read a definite voltage, which will vary from a negative to a positive reading if the rotary is below synchronism. Readings of volts and amperes should be taken on all phases after the rotary has reached synchronism. The machine should then be shut down, the armature brought to position No. 2. and the test repeated. In this manner all five points should be tested. After these tests have been made, the time required to bring the rotary to synchronism should be taken by throwing one-half voltage across the collector rings.

Starting Tests from Direct Current End

When starting from the direct current end, the rotary must be wired to a direct current generator of ample capacity. The rotary should be separately excited with a field current corresponding in value to that for no load at minimum input (unless full field is specified), and the voltage across the armature brought up gradually by increasing the field on the driving generator, until the armature begins to revolve. The voltage should then be steadily increased at that rate which will bring the rotary to normal speed in approximately one minute. This rate can be found by trial, and when once found, the test should be repeated once or twice to make certain that the results are correct.

Phase Characteristics

No Load. If the phase characteristic tests follow a heat run in which an IRT regulator has been used, it must be disconnected. The most satisfactory combination is to run two converters for this test, the one under test running as a rotary and driven by the other running inverted with a direct current loss supply. The speed and the direct current voltage are held constant by varying, respectively, the field of the inverted machine and the voltage of the loss supply. It must be remembered that a lagging current will increase the speed of the inverted rotary, and therefore the inverted machine should be watched constantly so long as the current lags.

With the field excitation of the rotary reduced to the lowest limit permitted by the inverted machine, the alternating current amperes and volts line and the direct current amperes and volts field should be read. As stated above, the speed and the direct current volts are held constant throughout the test. The field current of the rotary is increased by small increments and readings taken as above. The alternating current amperes input will decrease rapidly until the minimum input point is reached, when they will increase again. The field excitation should then be increased until the input current has a value of at least half the full load current of the machine.

Full Load. The full load characteristic is taken in exactly the same way as for no load. The direct current volts are held constant at normal rating and the amperes output constant at full load value. The field excitation is varied through nearly as possible the same range as for no load characteristic. The readings taken are, for the alternating current side, volts and amperes; and for the direct current side, volts armature (held constant), amperes output (held constant), volts field, and amperes field. The speed is held constant.

Compounding Test with Reactance

When a rotary is required to automatically deliver a constant direct current voltage under a load subject to sudden changes, a compound wound machine is used with a definite reactance inserted between the rotary and the line. Such reactances must be tested with the machines for which they are designed. A constant voltage is possible, since an alternating current passing through a reactance will increase the potential if leading, and decrease it if lagging. By adjusting the shunt field so that about 20 per cent. lagging current flows at no load, the strength of the series field can be adjusted to give a slightly leading current at full load and thus maintain a constant direct current voltage. A compound converter operating with reactance in circuit must be compounded like a direct current generator. Unless otherwise specified, the voltage of the alternator driving the rotary should be held constant and the shunt field adjusted to give the correct no load voltage; when, without touching the field rheostats, full load should be applied and the direct current volts read. If the machine over-compounds, the series field is too strong and gives too large a leading current, in which case a shunt must be adjusted across the terminals of the series winding to shunt a portion of the current. In this compounding test all readings are taken and all adjustments made without touching the field rheostat after the no load adjustment is effected, as in the case of a direct current generator.

Pulsation Bridges

Since the torque of a rotary only needs to be great enough to overcome the mechanical losses, the machine is very sensitive to changes in line conditions; *i.e.*, excessive line drop or speed changes of the driving unit. In many cases the line drop alone will start a rotary pulsating, and once started the pulsating generally increases rapidly until the rotary falls out of step or flashes over. To prevent pulsation, copper or brass bridges, which act as short circuited secondaries and prevent sudden changes of the input armature current, are placed between the poles. Rotaries of new design are tested for pulsation by inserting a definite resistance in each phase between the machine itself and the driving alternator. The drop through this resistance corresponds to the line drop which will probably occur in practice. Usually 15 per cent. drop is assumed and the resistance per phase necessary to produce this is determined from the formula $\frac{(\text{A.C. voltage})^2}{\text{Kw.} \times 1000} \times \text{per cent. drop} = \text{resistance}$. If two rotaries are tested together each machine should have 15 per cent. drop between it and the driving alternator, or 30 per cent. between the two rotaries, as shown in Fig. 29.

With the two machines running in synchronism, self-excited, and with the fields adjusted to give minimum input, observe the direct current voltmeters on the two machines. Any slight pulsation will be shown by these instruments at once. The direct current volts should be held constant on one machine throughout the test. Now, with the field current on one machine held at minimum input value, the field current on the other

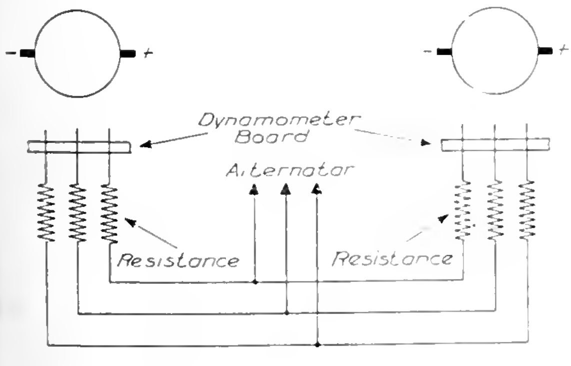


Fig. 29. Connections for Pulsation Test on Rotary Converter

machine should be reduced to about one-half minimum input value. If no pulsation is noted, a full set of readings should be taken on both machines, reducing the field current of the other machine to one-half minimum input value and watching for pulsation on both machines, which now take a heavy lagging current. A full set of readings under these conditions should be taken. The field of the first machine is again adjusted to the minimum input value, readings are taken, and pulsations watched for. With this field held at minimum input, the field of the other machine should be changed from its value of one-half minimum input to twice the minimum input value, readings and observations being made as before. The other field should then be brought up to twice normal value, readings taken, and the effect of the heavy leading current in each machine noted. Leaving one field over-excited, the other field should be weakened to give minimum input, and a full set of readings taken. If no pulsation develops with the high line drop under these extreme conditions, the machines are satisfactory.

Input-Output Efficiency Test

Input-output tests on small machines (300 kw. or less) are made with the machine running as a rotary, dead loaded on a water-rheostat. Larger machines are tested in pairs, one machine pumping back on the other with an electrical loss supply. The machines are wired in a manner exactly similar to that used in a pump back heat run (circulating power heat test), special attention being given to the wiring to see that no unbalancing occurs on either the alternating current or the direct current circuits. With the machine running as a rotary, wattmeters are connected in the alternating current end, between the rotary and the transformers, and preparatoins made for reading direct current armature and field amperes and volts. If current transformers are used with the wattmeters, duplicate transformers must be used in the other phases of the machine to prevent unbalancing caused by the resistance and inductance of the transformers. With the machine running in synchronism at rated speed and zero load, and all meters connected, the alternating current volts impressed on the rotary should be held constant and careful readings taken of all instruments. The currents and volts in each phase should be read as a check on the wiring and balancing of all phases. All instruments should also be carefully checked for stray fields and any instruments affected by these must be protected by iron shields, or their location changed. With full load, the test for stray field should be repeated, since any instrument affected will give misleading and erroneous results. With the no load minimum input field current held constant, the alternating current input, as shown by the wattmeters, should be carefully read as a check on the no load losses.

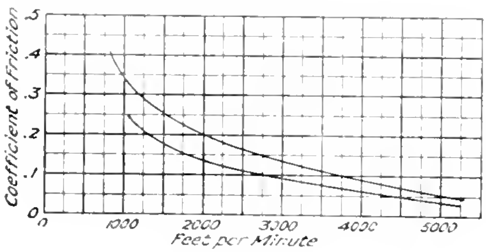


Fig. 30 Coefficient of Friction of A.C. Brushes

As efficiency is usually guaranteed at $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, 1 and $1\frac{1}{4}$ full load, careful readings must be taken at these loads. Each time the load is changed, the rotary field excitation must be changed to the minimum input value for that load, which is shown when the sum of the wattmeter readings is exactly equal to the kv a. input. To obtain this condition for each load, several trials and considerable time is usually required, so that an efficiency test made in this way is more expensive than one made by the separate loss method. The likelihood of error is also greater. This method, therefore, is not satisfactory for rotary efficiencies at other than full load.

The method employed to calculate the efficiency of a standard rotary converter is similar to that used for direct current generators, except for the additional C^2R and friction losses of the alternating current brushes. Because of the neutralizing action of the motor and generator currents it should be noted that only a certain percentage of the current as given by the instruments must be used for calculating the C^2R loss in the armature. This percentage varies for different machines as follows:

Single phase	147%
Two-phase	39%
Three-phase	59%
Six-phase	27%

The calculation of the alternating current brush contact resistance requires a measurement of the alternating current flowing in the armature, which varies in different types of machines. The following are the constants by which the direct current should be multiplied to obtain the alternating current.

For Single-phase	1.00
Two-phase	.72
Three-phase	.943
Six-phase	.472

As with the direct current brush resistance, a curve of the alternating current contact resistance must be referred to and no direct measurement of resistance attempted. In every case the contact resistance per ring should be calculated, the total loss being obtained by multiplying by the number of rings.

Brush contact area per ring = width of brush in inches × arc of contact in inches × the number of brushes.

The brush density per ring =

$$\frac{\text{Alternating current}}{\text{Brush contact area per ring}}$$

The resistance obtained from the curve corresponding to this value, divided by the

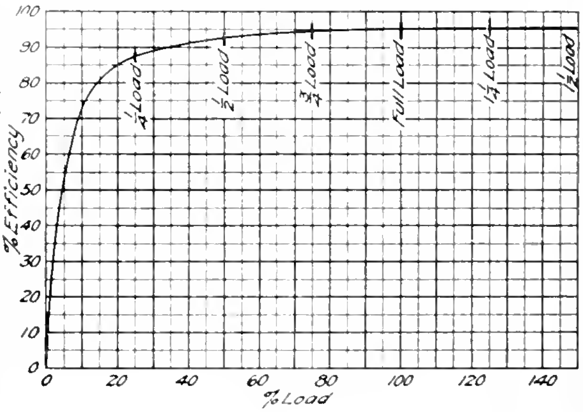


Fig. 31-a

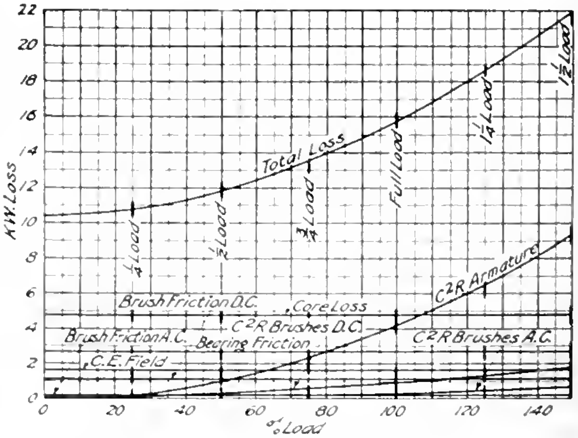


Fig 31. Efficiency and Losses on a 750 Kw., 600 Volt, 750 R.P.M., 25 Cycle, 3-Phase Rotary Converter

TABLE XII

EFF. AND LOSSES OF A 300 KW., 600 V., 4-POLE, 25 CYCLE 3-PHASE ROTARY CONVERTER

% Load	0	25	50	75	100	125	150
Volts Line	600	600	600	600	600	600	600
Amps. Line	0	125	250	375	500	625	750
Amps. Shunt Field	2.65	2.65	2.65	2.65	2.65	2.65	2.65
Amps. Arm. D.C.	2.65	127.6	252.6	377.6	502.6	627.6	752.6
Amps. Arm. A.C.	—	122.5	242.5	362	482	602	722
Core Loss	4760	4760	4760	4760	4760	4760	4760
Brush Friction D.C.	1134	1134	1134	1134	1134	1134	1134
Bearing Friction	2654	2654	2764	2651	2654	2651	2651
C^2R Armature (.585 × D.C. C^2R)	0	267	1046	2340	4140	6450	9300
C^2R Brushes D.C.	0	105	310	641	960	1280	1720
C^2R Shunt Field	900	900	900	900	900	900	900
C^2R Rheostat	690	690	690	690	690	690	690
C^2R A.C. Brushes		17	73	161	286	446	575
C^2R A.C. Brush Fric.	211	211	211	211	211	211	211
Total Losses	10349	10738	11808	13491	15735	18525	21944
Kw. Output	—	75	150	225	300	375	450
Kw. Input	10.3	85.7	161.8	238.5	315.7	393.5	471.9
% Efficiency	0	87.4	92.7	94.3	95.0	95.3	95.4
Brush Density A.C.	—	10.45	19.9	29.8	39.6	49.5	59.3
Brush Density D.C.	—	8.5	16.9	25.2	33.6	41.9	48.2
Brush Contact Resis. A.C.	—	.00123	.00123	.00123	.00123	.00123	.00110
Brush Contact Resis. D.C.	—	.0062	.00534	.00451	.0038	.00326	.00304

Resistance of Armature D.C. End 25° C. .0243 Ohms. Warm .0280 Ohms at 65° C.

Resistance of Shunt Field 25° C. 111.3 Ohms. Warm 128. Ohms at 65° C.

Dimensions of Brushes $1\frac{3}{4} \times 1\frac{3}{4}$ are (A.C.) No. of Studs 4 D.C. 12 A.C. No. per Stud 8 D.C. 1 A.C.
$\frac{3}{4} \times 1\frac{1}{4}$ (D.C.)

Brush Contact Area, One Side 15 A″ D.C.
12.2 (A.C.) Sq. In. Brush Pressure 2 Lbs. per Brush.

Coeff. of Friction = .2 D.C. Coeff. of Friction = .12 A.C.

brush area per ring, is the contact resistance per ring.

The alternating current brush friction should be calculated in the same manner as that for direct current measurements, the coefficient of friction being taken from a curve. (See Fig. 30.)

Table XII and Fig. 31 show the form used in calculating and plotting rotary converter efficiencies.

Normal Load Heat Runs

When loading a rotary converter on a water rheostat, see that all cables from the transformers to dynamometer boards and to the alternating current rings of the machine are of the same length and capacity, and that all contacts are cleaned and brightened before connection. Equal resistance per phase will thus be obtained and unbalancing in the alternating current circuits external to the armature prevented. In wiring the direct current circuit, the series field and its shunt are disconnected.

When wiring rotaries, as in the case of all other high current direct current machines, both sides of the circuit should be laid close together. No iron, such as a bearing pedestal or a section of the frame, must lie within the loop of the circuit, since it will become magnetized and materially affect the operation of the machine and instruments. Divide the shunt field into at least four sections by a "break up switch," which must always be open while starting from the alternating current end; since, due to transformer action and the relative number of turns of the field and armature, a high voltage is induced in the field at starting.

Always wire the positive ring of the rotary through a breaker to the blade of the water box, and the negative ring to the box itself. Connect enough boxes in multiple to limit the current per box to about 400 amperes maximum. Make provision for reading alternating current amperes and volts armature, direct current amperes and volts armature, amperes and volts field, and the speed of the alternator.

To start the machine, close the alternating current line switches and the field switch of the driving alternator, increasing the excitation of the alternator and keeping close watch on the current in the alternating current lines. If this current reaches 150 per cent.

normal before the rotary starts, check over the wiring. If the machine starts rotating in the wrong direction, reverse two of the leads on the primary side of the transformers. After starting, as soon as the alternating current drops to the minimum value (showing that the machine is in synchronism), and the alternating current volts become normal, close the field "break up switch." If, after closing the shunt field switch, the brushes begin to spark, the residual magnetism left in the poles by the induced voltage at starting is of the wrong polarity.

Two methods can be used to correct this; First, reverse the field with respect to the armature; or second, reverse the residual polarity by opening the alternator field circuit and then closing this circuit and bringing the rotary back to synchronism, repeating the operation if necessary until the field builds up in the right direction. This second method is the more satisfactory since no change of wiring is required.

Before proceeding further, read the current in each phase to make sure that there is no unbalancing. These currents should not vary over 1 per cent. from the average; any greater variation due to wiring must be remedied at once. After balance is established, the no load and full load phase characteristics are taken.

These operations complete the preliminary tests and the full load heat run may now be made, care being taken to set the brushes for the best commutation. For the load run, hold full load direct current amperes and volts constant with minimum input field current. The load should be kept on at least one hour after all temperatures are constant. At the end of the run, temperatures must be taken on all parts of the machine and the resistance measured on the armature (alternating current end) and field. If the rotary is a six-phase machine, the armature resistance is measured between rings 1-4, 2-5, 3-6, counting outwards from the armature.

If an overload run is required, take a few points on the overload phase characteristic to determine the field current required for minimum input; then hold this current and the direct current volts and amperes constant, as on the normal load run.

After the heat runs, the tests should be finished by taking a phase rotation, hot drop on spools, direct current running light at normal voltage, and direct current starting tests.

(To be continued)

ELECTRICITY ON THE FARM

By John Liston

For the economical application of power to the various farm operations that are now to a very large extent carried on by mechanical means, electricity offers so many advantages for this particular service as compared with other sources of power that it stands pre-eminent. Its unqualified success on those farms where it has been adopted indicates that it has become a factor of such importance that it must now be seriously considered as affecting both the cost and quality of the products of the modern farm. If we compare electricity with other forms of applied power we find that its chief advantages are reliability, safety, cleanliness and flexibility in application.

Owing to the necessarily scattered location of the buildings on the average farm, the cost of power when applied by means of separate engines (except in isolated cases which can properly be considered as special) is practically prohibitive. At the same time, the use of such engines would add appreciably to the fire risk, which is a consideration of more vital importance in farming than in any other industry owing to the absolute dependence, as a rule, upon relatively limited local fire fighting facilities. When electricity is used for power and lighting the fire risk is reduced to a minimum.

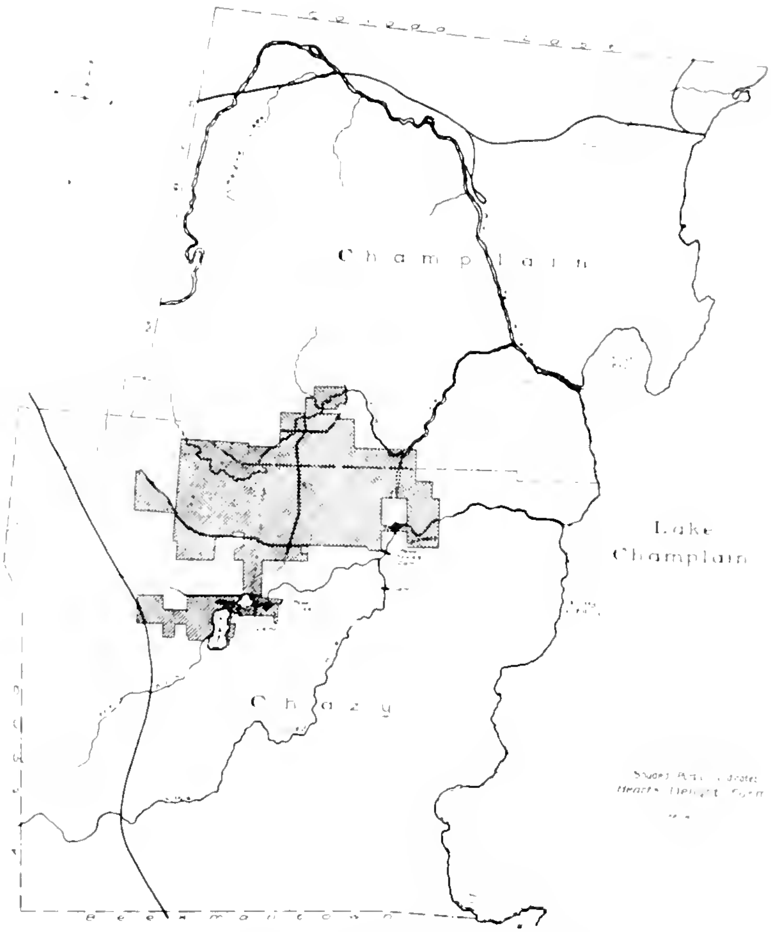
In the application of electric power the relative location of the buildings is immaterial, as motors can be installed in each building or group of buildings and the current transmitted by means of wires from a central generating plant, which may be erected either on the farm or at a distance from it.

When planning the electrification of a farm, it should be remembered that as the service required of motors for farm work is in nearly every case intermittent, the periods for operating the various units can be so arranged that at no time will all of the motors or even a large proportion of them be in operation simultaneously.

This condition will in most cases allow the installation to be so designed that a small generator can supply ample current for a relatively large number of motors, having an aggregate capacity greatly in excess of that of the generating plant. As a consequence the cost of generating current for a given capacity in motors for farm work is usually much lower than that involved in other industries.

The use of electric motors does not involve the necessity of employing skilled men to operate them, for, owing to the simplicity of the controlling devices, the average farm hand can start and stop them and control their speed without danger of injury to himself or the apparatus.

Local conditions must always affect the selection of a prime mover for the electric generators, and compact generating sets for utilizing steam, gas, gasoline or water power can now be readily procured. Where streams of sufficient head and volume exist in the vicinity of the farm, they may easily be converted into economical producers of electrical energy by the construction of dams and the installation of automatically governed water turbines. Many streams have in recent years been utilized in this way with entire success, both as to cost and service rendered, even on comparatively small farms.



Map Showing Location of Heart's Delight Farm and Streams from which it Derives its Hydraulic Power

As an interesting demonstration of the value of electricity on the farm, the following description will appeal to every practical farm manager.

At Chazy, N. Y., near the western shore of Lake Champlain and at a point about 15 miles north of the city of Plattsburg, there is located a modern stock and dairy farm which, in its operation, exemplifies the manifold advantages to be derived from the use of electricity for lighting and for the various power requirements of the farm.

This farm, which is owned by Mr. W. H. Miner and is called "Heart's Delight", is centrally located across the border line of Champlain and Chazy townships, in Clinton County, as shown in Fig. 1, and covers an area of 5160 acres. The nucleus of the present farm consisted of the old Miner homestead of 150 acres, which is now entirely surrounded by the land subsequently acquired.

Of the total farm area, about 1200 acres are under cultivation, another 1200 acres are used for pasturage, and the remainder is woodland. The output consists of live stock and dairy products; all crops grown on the farm being fed to the stock and only finished products shipped out.

The live stock includes registered Percheron and Belgian horses and pure bred short horn Durham and Guernsey cattle, special attention being given to the raising of "Dorset" sheep for breeders and hot-house lambs, and hogs for breeders and the production of sausage, hams and bacon. There is a considerable number of poultry and squabs, and a well equipped fish hatchery is devoted to the propagation of trout. The

View of Tracy Brook Power House and Beginning of Direct Current Transmission Line

quality of the materials shipped is indicated by the fact that practically the entire output of the farm goes directly to the Waldorf-Astoria and to other high-grade hotels and clubs in New York, Washington and Chicago.

About three years ago it was decided to provide the farm with electricity for light and power, and the results have been so uniformly satisfactory that the equipment has been increased from time to time, some novel applications having resulted owing to the energy and initiative of those charged with the management of the farm.

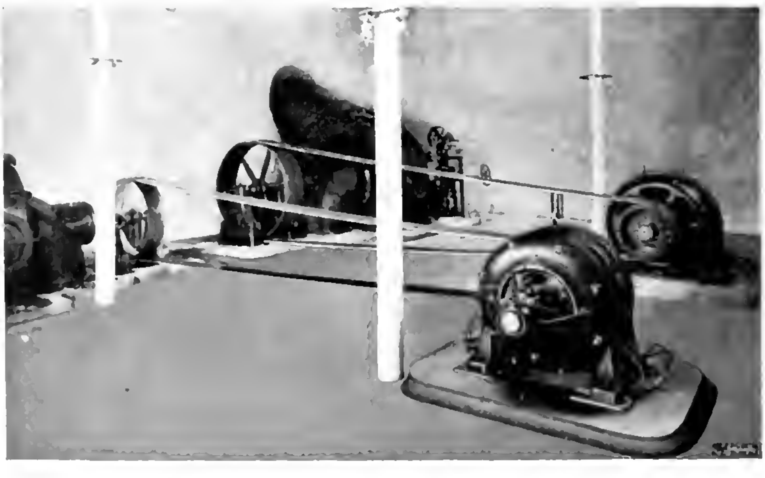
Sufficient water power was found on the farm itself to provide a cheap and reliable source of electric energy. Two streams pass through the southern portion of the farm, as shown in Fig. 1; the smaller one being known as Tracy Brook and the larger one as the Chazy river. It was found that these streams were both fed by numerous active springs which, together with the drainage area afforded by the Adirondack foot hills, insured a dependable flow of water that could readily be conserved by the construction of dams.

Across Tracy Brook three small concrete dams were built, thereby forming three ponds and giving a total reservoir area of about 170 acres. A concrete penstock 44 in. inside diameter and 670 feet long carries the water from the reservoir to a power house compactly constructed of concrete, and so located as to obtain an effective head of 19 feet.

The power house equipment consists of two reaction water turbines, automatically governed and direct connected respectively to one 30 kw. and one 12½ kw., 220 volt direct current generator. The current is transmitted over a pole line 1¼ miles long to a central station located in the main group of farm buildings.

About a mile below the power house Tracy Brook joins the Chazy river, and the tail race water from the Tracy brook station adds to the volume of water in the Chazy river reservoir, which is formed by a dam across the river a short distance below the point of confluence of the two streams.

The Chazy river is about 30 miles long and empties into Lake Champlain; it has a considerably greater volume than Tracy Brook, and it was found that by building dams ample storage water and an effective head of 30 ft. could be obtained.



Interior View of Chazy River Power Station, Showing General Electric Alternating Current Generator Belts Connected to Water Turbines

It was therefore decided to construct two concrete dams and a second and larger power house to supplement the Tracy Brook station, to provide current for the rapidly extending electric power applications at the farm.

After passing through screens at the intake gate-house (which forms part of the lower dam), the water is carried to the Little Chazy power house through a concrete penstock 18 by 60 inches inside diameter and 630 ft. length. At the power house, it enters a concrete flume provided with controlling gates and is led directly to the water turbine wheels by short steel pipes.

There are two turbine belts connected respectively to one 50 kw. and one 100 kw., 2300 volt, 60 cycle, three-phase General Electric alternating current generators. The current is transmitted at the generator voltage over a single circuit pole line $2\frac{3}{4}$ miles long, to the power station at the farm.

In the hydro-electric development the work has been carefully and thoroughly done, so that the danger of interrupted service has been reduced to a minimum. The concrete penstocks are reinforced with steel bars, both horizontally and vertically, and are covered with earth embankments. The tail water from the Chazy river power house is carried by a canal to some distance below the station before being returned to the river, in order to secure the full benefit of the available head. The turbine governors are arranged for both hand and automatic control, and in addition, the governors at this station are also provided with emergency motor-operated mechanisms, controlled from the switchboard. Telephone wires are carried on the transmission pole lines, establishing communication between the power houses and the central station on the farm.

The transmission line poles are of cedar with fir cross-arms, and are fitted with pin insulators; they are from 35 to 40 feet high and are spaced at an average of about 120 feet. The conductors are bare copper wire, No. 00 B.&S. being used for the Tracy Brook line and No. 2 B.&S. for the Chazy river line.

An auxiliary of the hydraulic equipment consists of two hydraulic rams receiving head from the Tracy Brook reservoir and pumping water to a 60,000 gallon tank located 100 ft. above the ground on a steel tower erected at the farm for fire protection.

As stated above, both the direct current Tracy Brook power house and the alternating current Chazy river power house

View of the Alternating Current Transmission Pole Line

feed into a power station at the farm, where the equipment includes a six-panel switchboard and two motor-generator sets of General Electric manufacture, and a storage battery.

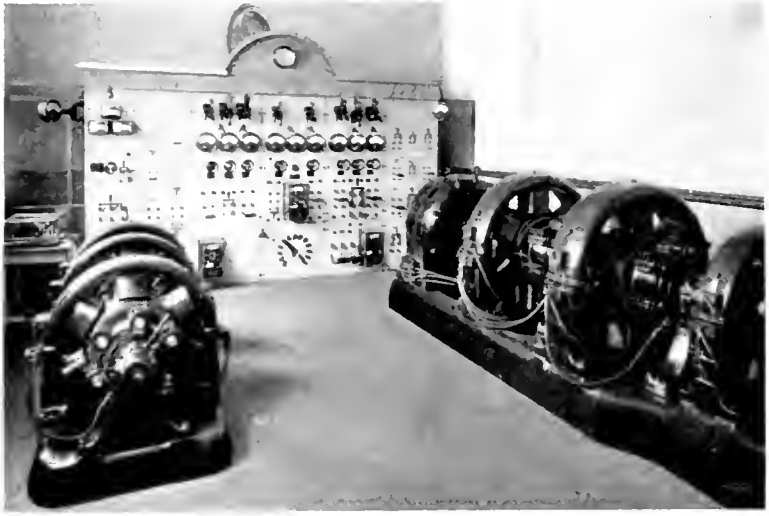
Nearly all the motors used on the farm at present are direct current machines, operating on 110 and 220 volt circuits, and in order to supply the 110 volt motors and the lighting circuits, and to charge the storage battery, the current which is received from the Tracy Brook power house at 220 volts direct current is stepped down by means of a three-unit, 1100 r.p.m., direct current motor generator set, consisting of:

- One 25 kw., 220 volt, direct current motor, compound wound
- One 25 kw., 110 volt, direct current generator, compound wound
- One 12 kw., 110-150 volt, direct current generator, shunt wound

The alternating current from the Chazy river power house is received at 2300 volts, three-phase, 60 cycles, and stepped down to 220 volts through three 40 kw. type H transformers. It is then converted to direct current by means of a four-unit, 900 r.p.m., motor generator set, consisting of:

One 100 h.p. synchronous motor

One 75 kw., 220 volt direct current generator, compound wound



Interior of Power Station at the Farm, Showing Switchboard and Motor Generator Sets

One 75 kw., 110 volt direct current generator, compound wound

One 12 kw., 110-150 volt generator, shunt wound

These two sets are interconnected by means of switches in order to insure continuity of service in the event of a shut down of either of the hydro-electric stations. If the incoming direct current supply is interrupted, the alternating current—direct current motor generator set can replace it. Vice versa, if the incoming alternating current supply fails, the 220 volt direct current unit of the alternating current—direct current set is operated as a motor, and the synchronous motor is then utilized as an alternating current generator.

On both of the motor generator sets the 12 kw. units are used for charging the storage battery, which consists of 52 main and 13 end cells, and has a capacity of 600 ampere hours. The battery is used as a balancer, and for lighting and power after 9:30 p.m., at which time the hydro-electric plants are shut down.

An interesting feature of the farm power station is an electrically operated instrument which is connected with a weather station located on one of the fire tank towers and automatically records on a cylindrical chart a continuous record of the speed and direction of the wind, the amount of moisture in the air, and the precipitation.

MOTOR DISTRIBUTION

No.	H.P.	R.P.M.	Department	Service
1	10	850	Dairy Barn	Hay Hoist
1	2	1100	Dairy Barn	Root Cutter
1	1½	1350	Dairy Barn	Vacuum Pump
1	1½	2000	Dairy Barn	Cream Separator
1	3	1440	Butter Making	Butter Churn
2	20	650	Refrigerating	Ammonia Pumps
2	3	500-1000	Refrigerating	Brine Circulating Pumps
1	7½	1500	Refrigerating	Centrifugal Water Pump
1	25	600	Grist Mill	Milling Machinery
1	4	650	Sausage	Meat Grinder Mixer and Bone Cutter
1	2	1100	Sheep Barn	Root Cutter
1	1½	1350	Sheep Barn	Root Cutter
1	2	750	Fish Hatchery	Fish Food Grinder
1	7½	500	Woodworking	30 in. Band Saw
1	7½	825	Woodworking	Wood Surfacer
1	5	1650	Woodworking	Circular Saw and Boring Machine
1	5	1650	Woodworking	Wood Planer
1	3	500-1500	Machine Shop	Engine Lathe
1	2	1100	Machine Shop	30 in. Drill
1	5	900	Water Supply	Triplex Water Pump
1	3	685	Laundry	Washing Machine
1	2	1100	Laundry	Centrifugal Dryer
1	½	535	Laundry	Mangle

The steam boiler capacity at the farm station is 120 h.p. Steam is used in the various farm buildings for heating, for cooking food for the animals, and for the operation of air and circulation pumps. There is also a vertical engine direct connected to a 22½ kw., 110-150 volt direct current generator, this set being ordinarily held as a reserve.

It will be seen from the foregoing that, in planning the farm equipment, every effort has been made to insure the continued maintenance of the electric service. That the precautions are fully justified by the benefits derived from the electric service in the saving of time and labor, and the possibility of carrying on all indoor work under safe, well lighted and sanitary conditions, will be fully appreciated from the following description of the varied motor applications.

The motors are distributed among the different buildings as shown in Fig. 2, and in most cases no special foundations have been required, since one of the advantages of motor drive for farm machinery is the fact that the motors usually required for this service are relatively light in weight and may be mounted either on the machine itself or on the floor, wall or ceiling.

Plan of the Main Group of Farm Buildings. Black Dots Indicate Location of Motors

In the main dairy barn a motor driven hay hoist is installed, to which is geared direct a 10 h.p. motor, a simple drum controller being used to regulate the hoisting speed. The load of hay is driven in onto the main floor of the barn and stopped under an opening to the loft, located in the center of the building Two U-shaped forks are inserted in the hay by the driver and the hoist is started by a man in the loft and the entire load elevated thereto, the motor controller being so placed near the loft opening as to give the operator an uninterrupted view. The hoist pulley is then automatically tripped, and the load of hay thereby transferred to an overhead rail, along which it is pulled by the hoist to the position selected for it in the loft. The forks are next released by pulling two light tripping ropes and the hay is deposited on the loft floor, the hoist tackle returning for the next load. The entire operation is carried on by two men and a ton of hay can be lifted from the wagon and stored at either end of the 280 ft. loft in less than five minutes.

On the main floor of this barn is a root cutting machine for preparing feed for the cattle. This machine is operated by a 2 h.p. motor mounted on the ceiling and belt connected to the machine, the controller being mounted on the wall beside the machine.

Motor Operated Hay Hoist and Controller

obtained, with the added assurance of absolute cleanliness, since the machines are totally enclosed. The milk as it is withdrawn from the cow passes through a short glass tube in the top of the machine and is in this way made visible to the operator, who is thus enabled to stop the process at the proper time. The milk is then carried to a room located on the same floor and provided with a motor driven separator. After being tested it is passed through the separator, the cream being thence taken to the butter making section of the dairy building.

A $1\frac{1}{2}$ h.p. vertical shaft motor having an initial speed of 2000 revolutions per minute runs the separator. Upon its arrival in the dairy building the cream is deposited in a covered tank and is ripened before being piped to the churn. The churn is driven by a 3 h.p. motor, which is mounted directly on the churn frame and drives it and its auxiliaries through gears which are enclosed in a sheet iron casing to insure safety and cleaniness.

The motor starting rheostat is mounted on the wall back of the churn, the solenoid of the rheostat being arranged that it can be short circuiting from the front of the churn, thus permitting the operator to stop the churn instantly, at a distance from the rheostat, by simply pressing a button.

In the dairy section is a vacuum pump operated by a $1\frac{1}{2}$ h.p. motor and supplying power for milking machines. A metallic vacuum pipe leading from the pump is permanently located around the outside of a double row of cow stanchions, with an outlet for each pair of stalls controlled by a single valve. When ready for milking, the motor is started and flexible tubes from the milking machines are connected to the vacuum pipe outlets; soft rubber cups at the ends of other flexible tubes connecting with the milking machine are then placed on the nipples of the cows, where they are securely held by the uniform pressure created by the vacuum.

There are five of these machines used at Heart's Delight farm, each machine milking two cows simultaneously. The suction is applied intermittently by an automatic valve on the milking machine; and thus by alternate pressure and relaxation the effect of hand milking is

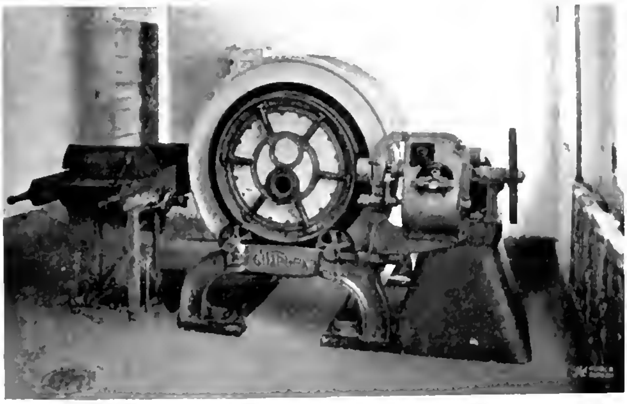
All the milking and butter making processes are carried on by, or under the direct supervision of experts; this arrangement together with the high grade cattle and scientific feeding insuring the best quality of dairy products and a correspondingly good market.

Near the dairy building is an ice making plant with a capacity of twenty tons every twenty-four hours. Motors are utilized for driving the pumps, although there is also a steam equipment for the purpose; this, however, is held only as a reserve. Two ammonia pumps are driven through chain drive by two 20 h.p. motors, and the brine circulation pumps by two 3 h.p. motors, also through chain belts.

This plant uses only spring water and furnishes ice for drinking purposes, for cold storage, and for the shipment of products affected by changes in temperature.

A small centrifugal lift pump direct connected to a $7\frac{1}{2}$ h.p. motor is located in the ice machine building and elevates water to a nearby tower tank. This motor runs at 1500 revolutions per minute, and as both the centrifugal type of pump and the electric motor operate best at relatively high speeds, this unit is a particularly good example of a compact, high efficiency pumping set. If necessary, it can be equipped with device, which will automatically maintain a predetermined water level in the tank.

A substantial grist mill is included among the farm buildings and the machinery in this is driven through counter shafting by means of a 25 h.p. motor, housed in a separate building to eliminate the fire risk due to the presence of inflammable grain dust in the mill. Many modern grist mills, however, use motors which are installed in the mill buildings, and the polyphase induction motor is peculiarly adapted for this service owing to the absence of a commutator; thus eliminating the potential danger from sparking brushes.



Butter Churn Operated by Direct Geared Motor

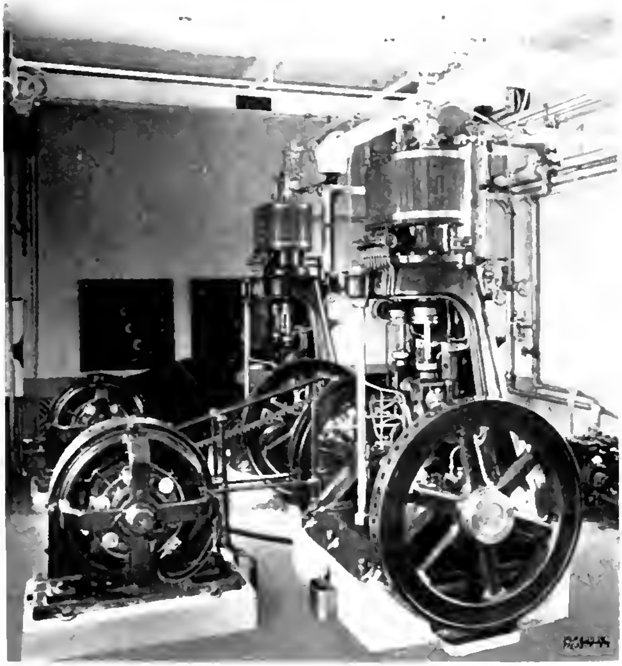
The grist mill motor is not set on permanent foundations, but is mounted on a truck and can therefore be readily transported to other buildings for temporary or emergency service. It is taken out in the field in this way and used to drive a threshing machine, the necessary conductors being laid along the ground to supply the current.

Milking with Vacuum Operated Milking Machines

The use of portable motors for field work on farms is becoming of increasing importance wherever electric current is available. A notable example of its possibilities was recently given in Germany, where two motors were used to pull plows across a field by means of steel cables actuated by motor driven drums. Two portable motor driven outfits were located on opposite sides of the field and moved forward as the plowing progressed. Of course, this method of plowing would only be practicable under certain conditions; but it illustrates the all-round adapability of the electric motor for farm work.

An item of growing importance at Heart's Delight farm is the production of sausage, the meat chopping and mixing machines, for which are driven by a single 4 h.p. motor utilizing an overhead countershaft. The sausage casings are filled by a machine operated by hydraulic pressure and compressed air, and in this way two men can maintain continuous production up to the capacity of the sausage making equipment.

The two sheep barns are supplied with root cutting machines driven through belting by



Two 20 H. P. Motors Driving Ammonia Pumps in Ice-Making Plant

motors of 1½ and 2 h.p. capacity. The motors are mounted on shelves and therefore occupy no space which could be otherwise utilized.

One of the farm auxiliaries is a thoroughly equipped fish hatchery used for the propagation of trout. A number of concrete fish ponds, located at slightly different levels in order to maintain the necessary water motion, have been constructed, and the fish food is prepared by a grinding machine, belt connected to a 2 h.p. motor.

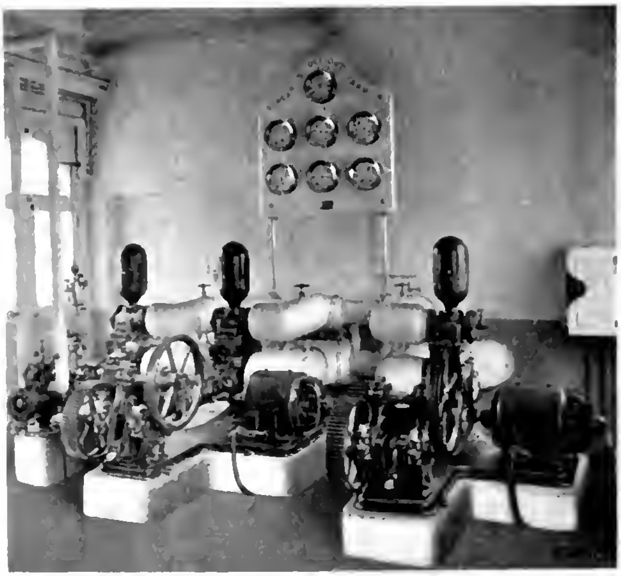
Every farm occasionally requires carpentry work, and the use of up-to-date wood-working machinery will always expedite such work and lessen the labor cost. The serviceability and economy of motor drive for wood working machinery has led to its extended adoption in sawmills and other wood-working plants, and one of the largest plants of the kind in the world that of the Great Southern Lumber Company at Bogalusa, La. is equipped with General Electric motors throughout.

The utility fo the electric motor in the operation of woodworking machinery on the farm, for farm building construction and repairs, and for repairing wagons, etc., is well demonstrated here, where the wood-working building contains a 30 in. band saw and a wood surfacer, each driven by a 7½ h.p. motor. The band saw is directly connected to the driving shaft of its motor, while the wood surfacer is driven from a countershaft. There is in addition a wood planer, which is driven by a 5 h.p. motor, and a circular saw and a wood boring machine, also driven by a 5 h.p. motor.

In connection with this woodworking shop, there is a machine shop having a 30 in. drill driven by a 2 h.p. motor and an engine lathe driven by a 3 h.p. motor; both motors being mounted directly on the machines and driving them through gearing.

The blacksmith shop has not as yet been electrically equipped, but a motor driven centrifugal forge blower and a motor operated trip hammer will be installed there at an early date.

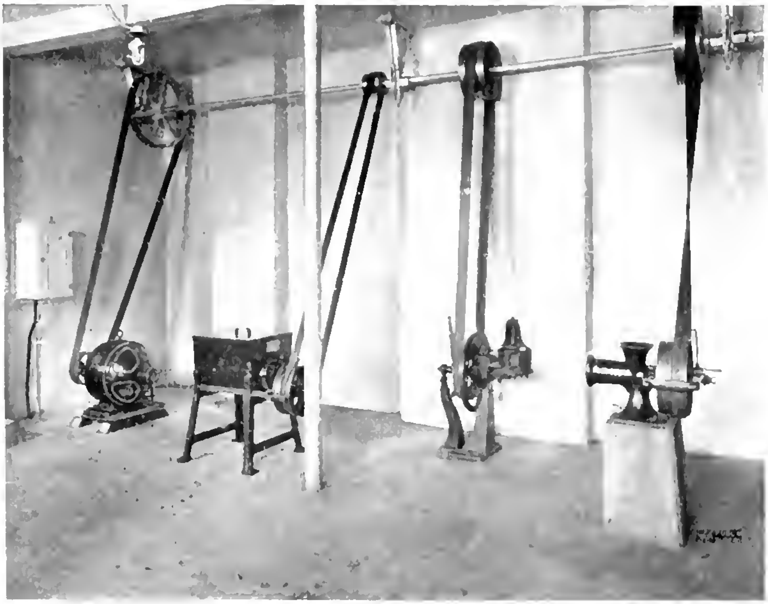
While windmills are used for pumping the water for some of the outlying buildings on the farm, there is also a 5 h.p. induction motor installed in a pump house and direct connected to a triplex reciprocating water pump. This is the only alternating current motor installed on the farm at present, but the further adoption



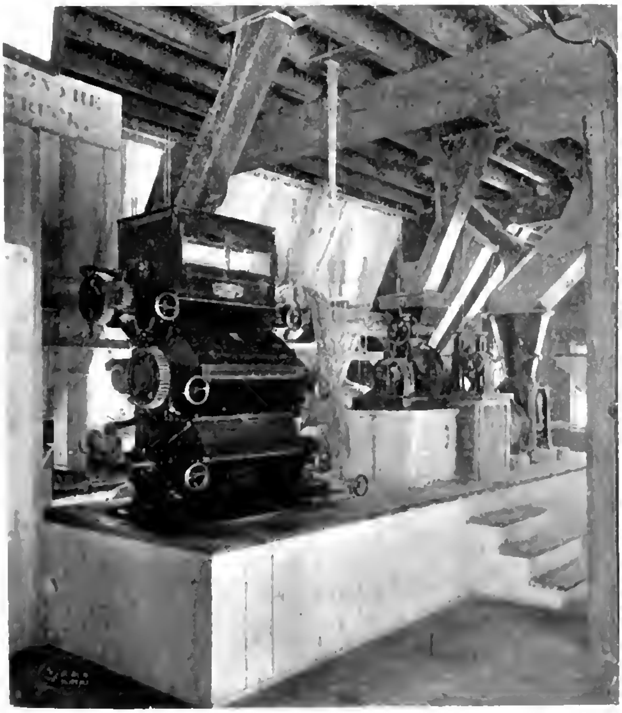
Motor Driven Brine Circulation Pumps in Ice-Making Plant of this type of motor is being considered in providing for the future extension of the electrical service, as it is the best form of motor for operations requiring a constant speed.

In addition to the present equipment, motors will hereafter be utilized on this farm for shearing sheep, clipping horses and other similar work.

Motor drive has been extended to the housework, and there are installed in the laundry of the main house on the farm, known as "Heart's Delight Cottage", a clothes washing machine driven by a 3 h.p. motor a centrifugal dryer operated by a 2 h.p. vertical shaft motor, and a mangle driven by a 2.5 h.p. motor direct connected.



View in Sausage Making Department, Showing Meat Cutting, Mixing and Bone Grinding Machines



Grist Mill Machinery which is Driven by a 25 H. P. Motor Housed in a Separate Building

Among the auxiliary electrical devices at the cottage are an electric piano, heating and cooking devices, and a motor driven ice cream freezer. Fan motors are also liberally provided.

Electricity on the farm not only permits the ready application of power to machinery located in widely separated buildings, but insures the safe and most efficient lighting for both buildings and farm yards.

At Heart's Delight Farm the buildings are all lighted with incandescent lamps, and in order to insure absolute safety they are enclosed in vaper-proof enclosing globes which fit into porcelain bases, the wiring being all run through iron conduit. In the yards the high efficiency of the flaming arc lamp for the lighting of large areas has resulted in its adoption for the purpose, and four lamps of this type are used, one of them being installed on the top of the 131 ft. steel tank tower. At an early date, the lighting system will be extended to the roadways on the farm, and either luminous arc or incandescent lamps will be used.

View in Laundry, Showing Motor-Driven Washing Machine and Centrifugual Dryer

In accomplishing the electrification of this farm, every effort has been made to preserve the natural beauties of the farm lands. The concrete dams are smoothly finished and the penstocks covered by earth embankments which have been carefully sodded. The wiring to the various farm buildings is carried underground in conduits, and as a consequence there are no unsightly effects produced by the various conductors which radiate from the farm power station.

It is obvious from the foregoing that the adoption of electricity on the farm effects a marked saving in the labor cost of a great variety of operations and renders possible those economies in production which result from the elimination, either wholly or in part, of manual labor and the substitution of mechanical devices which are highly efficient and easily operated and controlled by the average farm worker.

It renders possible the adherence to a definite schedule of work and therefore enables the modern farm to emulate the successes obtained in other industries by the most economical use of that expensive commodity, modern labor.

Heart's Delight Farm has had electric service for a period of about three years during which time it has been definitely proven that the electric motor can be applied with unqualified success to the operation of all machinery used in farm buildings. It constitutes a potent argument for the general adoption of electricity on the farm.

General View of Heart's Delight Farm

HYPERBOLIC FUNCTIONS AND THEIR APPLICATION TO TRANSMISSION LINE PROBLEMS

Part I

By W. E. Miller

Introduction

The discussion of transmission lines has not, as a rule, considered lines much above 200 miles in length. This being the case, approximate methods have generally been used, as these possess all needful accuracy for lines not over 200 miles long operating at 60 cycles, or not more than nearly double this distance at 25 cycles. When applied to greater distances, however, these methods are not reliable,* and the following discussion of long distance lines has therefore been prepared. These methods are equally applicable to short distances, and in general are as simple to handle as those usually employed. The results are obtained from the exact solution of the general equations which solve the problem of transmission lines with distributed capacity and self induction and leakage, of which the last can appear either due to corona effect, † or to leakage at the insulators. The various constants required for the complete computation of any transmission line likely to be used for some time to come have been calculated, as well as the mathematical tables necessary for the work. The solution employed is that used by Kennelly and involves the use of hyperbolic functions of the complex quantity. The use of the complex quantity was first introduced into this problem by Steinmetz, with a resulting simplification of the formulæ and operations required for obtaining results.

Applications of Formulæ and Conditions Necessary for Determining Problem

The determination of the power factor, voltage and current can be as readily made at any point of the line by this method as at the line terminals, a matter of considerable importance where another line is connected at some intermediate point. Further, except for changes in sign, the same formulæ apply whether the terminal conditions are given for the generator or receiving end, so that it is a matter of indifference so far as the calculations are concerned at which end the volts, current or power factor are given.

The calculations can easily be adapted to take care of cases where two of the terminal conditions are given for, say, the receiving end, and the other condition for the generator end. Actually, the method is not limited in any way and can be used, if necessary, to solve cases where three electrical conditions, such as volts, current, and power factor are given at any point or points along the line, or where two power factors and a voltage or current are given, or any combinations of these factors, provided that none of them is used more than twice and that only three are given.

Tables and Constants Calculated

One of the reasons why the hyperbolic functions are not commonly known is due to he absence of complete and readily available tables of their values. In transmission line problems, where hyperbolic functions of the complex quantity are used, the tables so far published do not give the values of the functions at sufficiently close intervals to allow of either ready or accurate interpolation. A sufficiently complete set of tables has therefore been computed which give the values of these functions at intervals which allow interpolation to be made by inspection for any value of the function which lies between those tabulated. The tables have been very carefully calculated and through the greater part of their range can be relied upon for an accuracy of one-half to one-quarter per cent. They will be published in the next issue of the Review, together with a table of the constants required for calculating transmission line problems involving their geometrical properties, i.e., capacity and self induction, at frequencies of 25 and 60 cycles.

The latter constants are calculated for three-phase transmission with the three wires placed at the corners of an equilateral triangle, and for the wires equally spaced and lying in a plane, provided a sufficient number of transpositions has been made in the latter case to obtain a balanced system. The constants include lines using wires from No. 2 B.&S. to 250,000 circ. mills, and are calculated for the following spacings, 6 ft., 8 ft., 10 ft., and 12 ft. As the values of the constants do not change quickly with the spacing, the proper constant can be at once determined by inspection for any spacing lying between those determined. The capacity and self induction involved in these constants are taken between line and neutral, so that the voltage relating to them is that between line and neutral and must be multiplied by $\sqrt{3}$ to obtain the line voltage.

* See Steinmetz "Transient Phenomena" pages 294 and 295.
† Only true if voltage is practically constant along the line.

Operations Required and Speed of Calculations Possible

By the aid of these tables and constants, the calculation of the power factor, amperes and volts at the generator end of the transmission line of any length up to nearly 500 miles long for 60 cycles, and nearly 900 miles long for 25 cycles, can be performed with a little practice in about a quarter of an hour, when volts, amperes and power factor are given at the receiving end, or vice versa. From these results, the transmission efficiency can be at once obtained for the given load, and the line regulation can be determined by a calculation for no-load conditions by means of a simple multiplication. The electrical conditions at any point of the transmission line can also be as easily and quickly computed. In fact, after looking up the proper constants to employ and the values of the hyperbolic functions, as given in the tables, the whole problem, so far as results are concerned, resolves itself into two multiplications and one addition for obtaining either volts or amperes at any point, and two divisions for obtaining the power factor, although a table of cosines is necessary for the latter.

Curves Illustrating Electrical Conditions Along the Line

To show how the electrical characteristics vary from point to point in a long transmission line, curves have been plotted for a transmission line 400 miles long, using three 0000 stranded hard drawn copper wires, with a spacing of ten feet between wires, operating at a frequency of 60 cycles. These curves and the ones mentioned below, will be published in the next issue of the REVIEW, where this side of the matter will be more fully discussed. They include curves showing the variations of volts, amperes, and power factor along the line, under various conditions at the receiving end as to power factor and load, the volts at this end being assumed constant and 60,000 volts, or 104,000 volts between wires. Curves illustrating a method for determining what power factor at the receiving end gives maximum transmission efficiency at any given load delivered. Curves illustrating the corona effect along a line 200 miles in length operating at 25 cycles, using No. 1 wire with a spacing of 8 ft. and a voltage of 110,000 volts between wires. The power wasted in capacity current and owing to corona are separately plotted for each point of the line. The corona constant used in these calculations was computed from results obtained on a 50 mile line, operating at a line voltage of 110,000 volts. This line is, electrically similar to the one taken for illustration, so that it is believed that the corona effect calculated cannot be far from the true value.

Lastly, the hyperbolic method has been applied to a telephone line consisting of two No. 6 B.&S. wires twelve inches apart and 1000 miles in length, the frequency being taken as 1000 cycles per second, and the power factor of the receiving apparatus being assumed to be .5 lagging. The voltage required for the receiving instrument has been taken as .2 volts, and the current as .5 milli-amperes. The hyperbolic functions in this case had to be specially calculated, since the tables do not cover the range necessary. Curves have been plotted giving the variation of the maximum value, as well as the instantaneous values of the current and volts at every point of the line. This problem illustrates the shift of phase of current and volts along the line and the finite velocity of electric wave propagation much more forcibly than any problem relating to commercial transmission lines, and it was chosen for this reason.

Introduction to Mathematical Portion

The majority of engineers, unfortunately, are not familiar with hyperbolic functions, and the complex quantity has not received the attention it has deserved of the electrical fraternity. The hyperbolic functions are extremely simple and are as easily understood as the circular functions, sine, cosine, etc.; while the complex quantity is one of the greatest labor and thinking saving methods of treatment devised, and carries its physical meaning through all the mathematical operations to which it may be subjected. As the understanding of the following treatment depends on these matters being appreciated, the following short discussion is given, which may help to elucidate the meanings of these quantities and the laws governing them.

Hyperbolic Functions

The hyperbolic functions, as their name implies, can be derived from the hyperbola in a manner similar to that employed in the derivation of the circular functions, sine, cosine, etc. The following discussion illustrates the close analogy existing between the two methods.*

* See Osborne's "Integral Calculus, page 278.

Consider the circle $x^2 + y^2 = a^2$

Let the angle $POA = \theta$ and let the sectorial area $POA = u$

Then $x = a \cos \theta$ and $y = a \sin \theta$

While $u = \frac{a^2\theta}{2}$ or $\theta = \frac{2u}{a^2}$

Hence, $OM = x = a \cos \frac{2u}{a^2}$ (1)

and $PM = y = a \sin \frac{2u}{a^2}$ (2)

That is to say, the length OM, or x, divided by the radius or distance from the center of the circle to the circular boundary, is equal to the cosine of the ratio of twice the sectorial area to the constant area of the square erected on the radius. The length $\frac{PM}{a}$ is equal to a similar function involving the sine in place of the cosine.

If the above definition is applied to the rectangular hyperbola, the values of the hyperbolic sines and cosines, or sinh and cosh, as they are usually denoted, can be as readily obtained as follows:

Let O be the center of a rectangular hyperbola, of which the arc is PA.

Then the equation of this hyperbola referred to its center is $x^2 - y^2 = a^2$.

The sectorial area u is equal to the shaded area of Fig. 2, and equal to the area of the triangle POM − area PAM, which is equal to

$$\frac{xy}{2} - \int_a^x y\,dx = \tfrac{1}{2}xy - \tfrac{1}{2}xy + \frac{a^2}{2} \log \frac{x+y}{a}$$

$$= \frac{a^2}{2} \log \frac{x+y}{a} \qquad (3)$$

Whence $\frac{x+y}{a} = e^{\frac{2u}{a^2}}$ (4)

and $\frac{x-y}{a} = e^{-\frac{2u}{a^2}}$ (5)

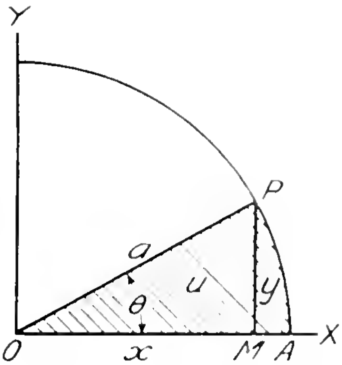


Fig. 1

Hence by definition similar to that given for the circular functions in the case of the circle.

$$\frac{x}{a} = \frac{e^{\frac{2u}{a^2}} + e^{-\frac{2u}{a^2}}}{2} = \cosh \frac{2u}{a^2} \qquad (6)$$

and $$\frac{y}{a} = \frac{e^{\frac{2u}{a^2}} - e^{-\frac{2u}{a^2}}}{2} = \sinh \frac{2u}{a^2} \qquad (7)$$

Hence, $OM = x = a \cosh \frac{2u}{a^2}$

and $PM = y = a \sinh \frac{2u}{a^2}$ which are exactly similar

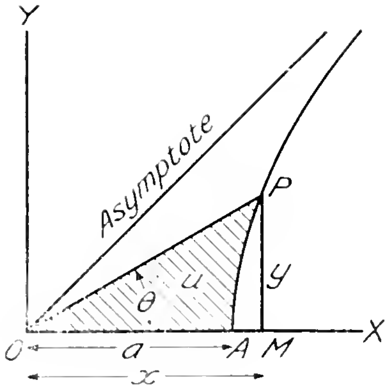


Fig. 2

expressions as those obtained for the circular functions. If θ = angle POA then $\tan \theta = \frac{y}{x} = \tanh \frac{2u}{a^2}$

The values of $\sinh x$ and $\cosh x$ can thus be obtained in terms of the exponential expressions, i.e.

$\sinh x = \frac{e^x - e^{-x}}{2}$ and $\cosh x = \frac{e^x + e^{-x}}{2}$ (8) and (9)

It will be observed that for large values of x, the two expressions are equal, and that therefore $\sinh x$ is equal to $\cosh x$ when x is large, when $\tanh x = 1$.

The analogous expressions $\sin x$ and $\cos x$ are as follows:

$\cos x = \frac{e^{jx} + e^{-jx}}{2}$ and $\sin x = \frac{e^{jx} - e^{-jx}}{2j}$ (10) and (11)

where j is imaginary and equal to $\sqrt{-1}$, whereas the expressions for $\sinh x$ and $\cosh x$ do not involve imaginaries. The presence of imaginaries in the exponential expressions for $\sin$ and $\cos$ render them periodic in value; the absence of these imaginaries in the straight hyperbolic functions make them non-periodic. The complex hyperbolics have, however, a period $2\pi j$ as will be seen later.

By adding or subtracting (8) and (9) the following series are obtained.

$$\sinh x = x + \frac{x^3}{3!} + \frac{x^5}{5!} + \ldots \qquad (12)$$

and $$\cosh x = 1 + \frac{x^2}{2!} + \frac{x^4}{4!} + \ldots \qquad (13)$$

from which the value of these functions can be calculated.

The addition and subtraction formulæ of $\sin(x \pm y)$ and $\cos(x \pm y)$ are $\sin x \cos y \pm \cos x \sin y$ and $\cos x \cos y \mp \sin x \sin y$ respectively, these formulæ being readily obtained geometrically from the properties of the circle. The following formulæ can be deduced for the hyperbolic functions from the geometrical properties of the hyperbola in a similar manner.

$$\sinh(x \pm y) = \sinh x \cosh y \pm \cosh x \sinh y \quad (14)$$
$$\cosh(x \pm y) = \cosh x \cosh y \pm \sinh x \sinh y \quad (15)$$

By changing x into $-x$ in 8 and 9, it follows that $\cosh x = \cosh(-x)$ and $\sinh x = -\sinh(-x)$

also $\cosh o = 1$, $\sinh o = o$, $\cosh \infty = \infty$, $\sinh \infty = \infty$ hence, $\tanh \infty = 1$ and $\tanh o = o$

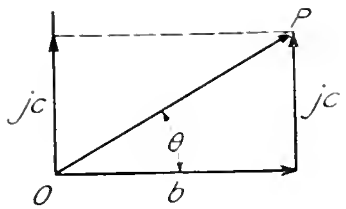


Fig. 3

By the addition and subtraction formulæ, 14 and 15, the following relations are seen to exist:

$\sinh 2x = 2\sinh x \cosh x$
$\cosh 2x = \cosh^2 x + \sinh^2 x$
$\cosh^2 x - \sinh^2 x = 1$, etc.
Compare $\sin 2x = 2\sin x \cos x$
$\cos 2x = \cos^2 x - \sin^2 x$
$\cos^2 x + \sin^2 x = 1$

From 8 and 9, we have also

$$\frac{d \sinh x}{dx} = \frac{e^x + e^{-x}}{2} = \cosh x$$

and $$\frac{d \cosh x}{dx} = \frac{e^x - e^{-x}}{2} = \sinh x$$

Therefore

$$\frac{d^2 \sinh x}{dx^2} = \sinh x$$

and $$\frac{d^2 \cosh x}{dx^2} = \cosh x$$

That is to say, the hyperbolic functions repeat themselves in two differentiations, which may be regarded as the mathematical reason why they appear in the solution of the equations relating to transmission lines.

It is apparent from the above how closely the formulæ of the hyperbolic functions follow those of the circular, and how readily they are obtained. For further information on these functions and on the hyperbolic complex, see McMahon "Hyperbolic Functions."

Complex Quantity

As is well known, all directed physical quantities can be represented vectorially, the scalar part or length of the vector representing the magnitude of the quantity, and the direction of the vector representing the direction of the quantity. Such a vector can be resolved into two vectors, at right angles to one another. The simplest notation to employ in such cases, to differentiate between the horizontal and vertical component, is to prefix a symbol in front of the vertical component. This symbol, in electrical science is usually called j, and means that the vector in front of which it stands must be added vectorially to the horizontal component and not algebraically.

Thus if b represents a horizontal force, and c a vertical force acting at the same point on a body, the resultant of the force will be denoted by $b+jc$, the magnitude of the resultant being by the parallelogram of forces $\sqrt{b^2+c^2}$, making an angle with the horizontal component $\theta = \tan^{-1}\left(\frac{c}{b}\right)$. This at once shows that in order to get the magnitude of the vector, of which the two rectangular components are given in the form of $b+jc$, the square of b must be added to the square of c, and the square root extracted of their sum, and that the angle the horizontal component makes with the vector is given by the equation $\tan \theta = \frac{c}{b}$. Vectors thus resolved into comp-ponont vectors at right angles to one another are very easily operated, when the meaning of j is appreciated, and the sum of the component vectors is called the complex quantity.

In order to discover the meaning which should be assigned to the symbol j the following case is taken, let P represent a force acting along a constant direction OP through a length l lying in the direction of OP (see Figs. 3 and 4). Then the work done by the force is equal to Pl. Now suppose that the force P is resolved into two

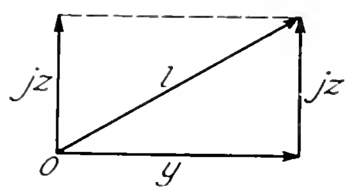


Fig. 4

components, $b+jc$, and the length similarly into two components $y+jz$, then the product so far as magnitude is concerned

$$(b+jc)(y+jz)$$

must equal lp. This product equals $(by+j^2zc)+j(bz+yc)$. If j is equal to $\sqrt{-1}$, the above expression becomes $(by-zc)+j(bz+yc)$, and the magnitude of this vector is given by $\sqrt{(by-zc)^2+(bz+yc)^2} = \sqrt{b^2+c^2}\sqrt{y^2+z^2}$ which is equal to lP. Hence, the value given for j yields a correct result.

Better illustrations perhaps could be obtained from electrical engineering, because work is not a directioned quantity, but the idea is so familiar that the foregoing illustration was chosen.

Currents and volts can be resolved into two components at right angles to one another in a similar manner. And, since inductive reactance and dielectric susceptance are proportional to the rate of change of current and volts with time respectively, they can be regarded as at right angles to the resistance and conductance in the functions impedance and admittance. Thus, the impedance and admittance can be represented as $r+jx$ and $g+jK$ respectively where r is resistance, x the reactance, g the conductance, and K the susceptance. These quantities are, of course, scalars, but the method applies to any quantities which can be resolved into two directions at right angles to one another.

(To be Continued)

THE ELEMENTS OF TRANSFORMER CONSTRUCTION

Part I

By W. A. Hall

In electrical work, the term "transformer" is used to denote a certain class of apparatus which embraces a great variety of devices, each possessing a certain given inherent characteristic of marked simplicity.

Probably the simplest geometrical conception of a transformer is that suggested by three links of a chain, in which the middle one represents the magnetic and the other two the electric circuits. In constructing this device, however, the designer is immediately confronted with certain conditions which materially modify his elementary figure.

The best materials commercially available for these circuits (steel and copper, respectively), are far from the theoretically perfect in that their highest efficiency is much below 100 per cent.; or, in other words, each offers a certain resistance to the transmission of electrical forces that results in an energy loss, operating against the efficiency of the transformer. The resistance in the copper circuit varies directly with the length and inversely with the cross section of the conductor, while the loss varies directly with the resistance and as the square of the current carried by the conductor. The resistance to the passage of magnetic force through the iron circuit usually termed "reluctance," also varies directly with the length and inversely with the cross section of the core. The relation of loss to reluctance, however, is somewhat more complicated, owing to the fact that while the specific resistance of commercial copper wire is practically uniform, the specific reluctance of commercial steel varies widely. Eliminating this variable, we still find that any grade of steel of given dimensions has a different reluctance for each value of magnetic force, that is, the reluctance varies in a fixed relation with what is termed the magnetic density. Therefore, while it is not convenient, generally speaking, to express the loss in a magnetic circuit ("core loss") in terms of reluctance, it may be safely taken as somewhat greater than the first power relation, or the relation which exists between copper loss and resistance in the copper members of the transformer.

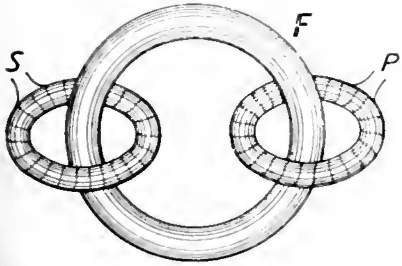


Fig. 1

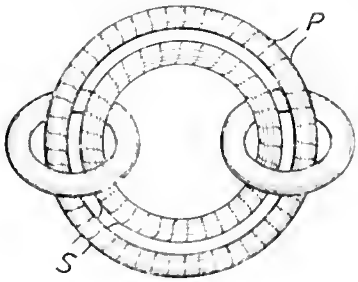


Fig. 2

From the foregoing it is evident that a minimum loss in each member results from that circuit which has minimum length and maximum cross-section. It is equally obvious that these conditions are conflicting in the primitive linkage, which fact renders this arrangement open to improvement, while other considerations make it in exact form practically prohibitive. It is further observed that space lost in one of the elements by reason of the greater length imposed upon the others, causes therein both loss of electrical efficiency and material, representing a double waste. It is essential, therefore, that the space factor; i.e., the ratio of net effective material to total space occupied, be a maximum in both iron and copper circuits.

Opposed to this are considerations of equal or greater importance. In order to increase the resistance in the path of the wasteful eddy currents within the core, this member is built up of laminations or punchings of sheet steel, varying in thickness in commercial

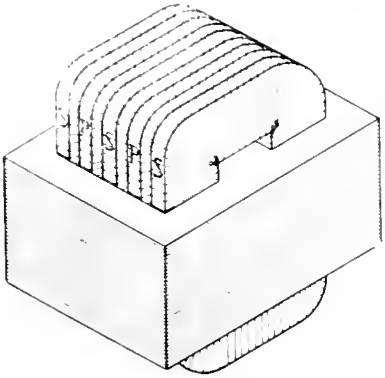


Fig 3

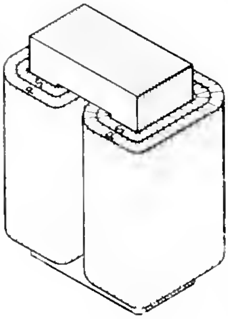


Fig 4

transformers from 14 to 25 mils., to which is added on each side a coating of some insulating material that increases the thickness of the sheet by approximately another mil. This insulation, together with the loss of space incident to building up into a core, causes a loss of from 5 to 20 per cent., or in other words produces a space factor varying from 95 to 80 per cent.

In the copper circuit it is necessary to insulate each turn from all other turns thereof, and from all other parts of the transformer. Since the potential accumulates along the conductor, it follows that the amount of insulation required between adjacent turns of a coil is relatively small, that between sections of a coil being somewhat greater, while that between other parts and the coil is considerable. The entire amount of space given up to this most essential feature is even more than that occupied by the copper, and therefore the space factor of the copper circuits in the average transformer is lowered to a figure well under 50 per cent. Thus far, the discussion aims to show the value of the space encompassed by both the magnetic and current elements of the transformer.

The engineer is next confronted with the problem of conserving this space by designing in the form of regular geometrical figures, which will best accomplish the result in a manner consistent with economical manufacture. For reasons already referred to cores must be laminated, and moreover, in such a manner that they can be readily linked with the copper circuits. The prevention of waste of material during manufacture, which requires straight line punchings that interlock, at once determines the rectangle as the form of the magnetic circuit for nearly all commercial transformers; a conclusion which is strengthened by the fact that this figure is also best adapted to the formation of the coil sections which it encloses. These and other considerations have led to the development of three general types, upon one of which nearly every commercial transformer of any considerable capacity is constructed. These types are shown in Figs. 2, 3 and 4, numbered respectively in the order of their commercial origin.

The design in Fig. 3 was employed exclusively from the beginning of transformer manufacture in this country in 1885, until 1895. It consists essentially of rectangular coils, wound upon a rectangular form. The core, instead of being a single link as in our elementary conception of the transformer, has a double magnetic circuit. The portion within the coil was considered the core proper, and at a very early date came to be known as such. The remainder of the iron circuit was in a similar manner identified as the "shell." Since the coil is principally within the iron, it follows that one characteristic of this type is a relatively large amount of iron and a small amount of copper, and consequently, a small cross-section of the latter. For a given voltage then, this necessarily means few turns, which fact, for a given core loss, demands a large cross-section of the magnetic circuit. This in turn results in a long mean length of copper and short mean length of magnetic circuit.

The design shown in Fig. 4 was introduced commercially in this country about 1895. Fundamentally, it is directly the reverse of that of Fig. 3, in that the coils are, in general, disposed externally.

These two types of transformers have been named according to the arrangment of the iron with respect to the winding. Since that portion of the core which is called the shell is a prominent feature of the design shown in Fig. 1, this type has become known as the shell type. In contradistinction, the design shown in Fig. 2, in which the greater part of the iron forms the core proper, is called the core type.

The core type has relatively a lighter core of less cross-section and greater mean length, while the copper is relatively heavier and of larger cross-section and is composed of a greater number of turns of less mean length. Since the introduction of the core type approximately 15 years ago, the designing engineer, manufacturer, salesman and operator have engaged in an endless and verbose struggle to demonstrate the superiority of that particular type in which each was interested. If, in the face of this controversy, the author may venture an opinion, it is to say that each type has its comparative advantages and disadvantages, depending upon the particular use for which it is intended. In fact, some manufacturers make both types for the same or different service, and in this manner have done much to eliminate artificial differences and make the two more nearly alike.

The shell type, having a large ratio of cross-section of core to coil, is at once superior to the core-type with its opposite characteristics, when the service demands high duty from core and moderate requirements from coils. The core-type, with its large ratio of coil cross-section to length, likewise possesses an advantage in those instances where conditions are exacting with regard to windings. Hence we find the shell type particularly adapted to transformers of moderate voltage, requiring few turns and little insulation, large currents (easily provided for by heavy conductor in its few turns), low frequency and consequently heavy flux; while the core-type, with its ample winding space, lends itself more readily to the higher potentials which require many turns and much space for insulation, smaller currents and lighter wires for the many turns, and higher frequencies with low magnetic densities. Hence it follows that the former is essentially a high capacity and the latter a low capacity transformer, which fact accounts for the practice of the manufacturer who builds a core-type for his small transformers and those of exceptionally high voltage, and his large power transformers upon "shell-type" lines.

Now as we compare without prejudice the two types before us, we will in general conclude that, because of the shorter mean length of the core of the shell-type and the coils of the core-type, these elements possess advantages over corresponding elements of the opposite type; suggesting immediately the possibility of a marked gain could any means be devised whereby these points of advantage might be combined. To assist in the solution of this problem, let us briefly return to our first conception of the transformer; *viz*: the three links. In Fig. 1 we have a single magnetic circuit and double copper circuit, hence a core-type transformer. In Fig. 2 we have a double magnetic circuit linking a single copper circuit, or a form of the shell-type transformer. Now, if the several links represent coils or cores of substantial magnitude of cross-section, the mean length of the external member may be materially lessened by distributing them about the periphery of the enclosed member.

This development will result respectively in Figs. 5 and 6, which may be considered to fairly well represent the ideal transformer of highest efficiency, where each element is in

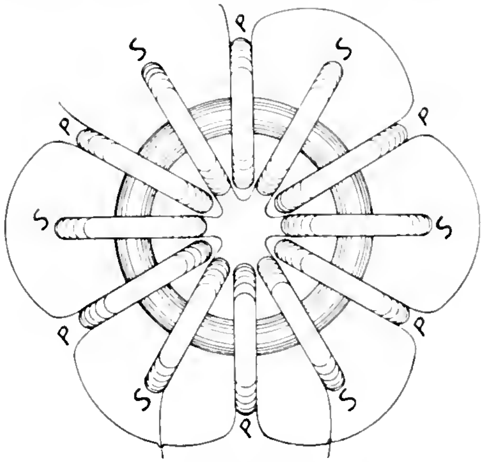


Fig. 5

the form of a circle, and hence has a minimum length for unit area enclosed. There are many obstacles between this design and its commercial use, such as lack of good mechanical characteristics, difficulty of insulation, inability to properly dissipate heat generated within the inner member, and excessive cost of manufacture.

The problem then narrows down to that of combining the advantageous points of the two types and extending the development as far as possible toward the design of the theoretically best. To that end there was placed upon the market in 1905 the design shown in Fig. 7, which, by subsequent adoption as the standard type for small transformers of the two largest manufacturers in this country, represents probably the majority of all transformers at present made therein.

That we may derive a proper conception of this transformer, let us first consider Fig. 3 as modified by placing all of its windings on one leg (Fig. 8). Obviously, for equal efficiency, this step has been attended by an addition in cost of material, because of the larger mean length of the copper circuit.

Now divide the iron circuit into two equal parts and rotate one through 180 degrees when we have Fig. 3, in which it should be noted that the width of laminations outside the coil has been reduced by one-half while the full cross-section has been maintained and the mean length materially reduced, thus

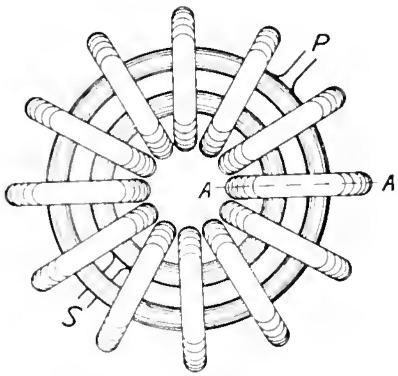


Fig. 6

gaining simultaneously in cost of material and iron energy loss. Consequently, to restore the original efficiency, the whole transformer may be reduced, making a double saving in cost.

Consider now a second division whereby the iron in each of the two branches is split and one-half rotated 90 degrees, thus developing Fig. 7, in which the width of iron is now one-half of that in Fig. 3, or one-fourth of that in Fig. 8, and the mean length of the magnetic circuit so far shortened that there results a very great saving in the cost of material for a given efficiency, or conversely, a greatly improved transformer for the same cost. Obviously, this process of division might be extended indefinitely until we arrived at an approximation to the ideal transformer. However, a little thought will disclose the fact that there is a problem involved in thus dividing the center leg without loss of space factors, maintaining at the same time a practical manufacturing proposition. In consideration of these facts, together with a number of others, such as coil radiating surface, oil channels, leads, cost of labor, etc., it appears that this type as shown approaches as nearly as practicable to the ideal transformer.

It is at once apparent that this new type, which is called the distributed core type, combines certain characteristics of the other two. As we have seen, the efficiency of the shell type demands small coil space and low mean length of magnetic circuit. Hence the opening in the core, or the window as it is frequently termed, is relatively short and broad; that is, it approaches a square. Consequently, it has been found profitable to make the coils narrow and deep, or of the so-called "pan-cake" type. On the other hand, for obvious reasons, the coils of the core type have become long and thin, or of the cylindrical type. Thus these features of construction have become to be regarded as characteristic of the respective types.

It is the marked increase in the mean length of the magnetic circuit of Fig. 7 that enables the designer to lengthen the core of Fig. 3 so as to employ the cylindrical coils of short mean length—an advantage which is increased by the special construction of the core and which has become to be characteristic of this new type. Recognizing the fact that but approximately a third of the mean length of the magnetic circuit is within the winding, this portion has been deliberately shrunk in cross-section and the loss increased therein, while the cross-section of that portion of the magnetic circuit outside of the coils, having twice the length, is correspondingly enlarged to compensate therefor. There thus results the design which combines with the advantages of the core-type coil construction those of the shell-type core, though much improved.

Let us now consider the practical application of these types. The commercial

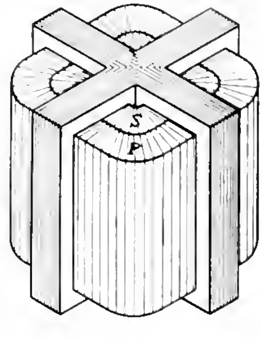


Fig. 7

transformer is susceptible of division into four principal classes, each comprising a greater or less number of components, as follows:

I. Multiple or Constant Potential: Receiving an impressed electromotive force of fixed value and delivering upon the secondary lines regardless of load, a voltage bearing a fixed ratio to that of the primary.

II. Series Transformer: Connected in series with the line, as the name implies, and hence receiving a current of a value depending upon the load therein; possessing the function of delivering to the secondary a current the value of which bears a fixed ratio to that impressed upon the primary.

III. Constant Current: In effect, a combination of I and II, designed to receive a constant voltage and to deliver a fixed and constant current to the secondary.

IV. Variable Ratio: Receiving a constant voltage and delivering a voltage varied at will, or receiving a varying primary voltage and converting it into a fixed predetermined secondary voltage.

By far the greatest in importance is group I, in that it comprises the standard lines of lighting transformers, testing transformers, all transmission and power transformers, as well as a host of miscellaneous modifications for an almost infinite variety of

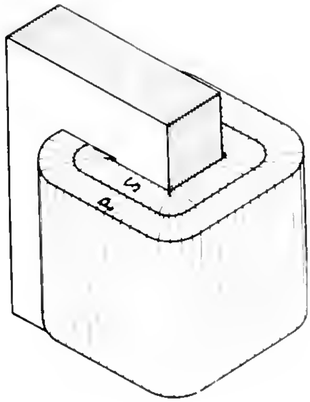


Fig. 8

purposes. Of these, undoubtedly the most familiar is the so-called lighting transformer, generally hung upon the cross-arms of a pole in the street and receiving a voltage of from 1100 to 2400, 40 to 60 cycles, and delivering from 110 to 240 volts on secondary lines carried into the buildings. More than half the value of the entire transformer output in this country consists of this type. Because of the fact that the primary voltage is dangerous to life, and the secondary circuit comes into almost actual contact with multitudes of people, it is obviously of paramount importance that the secondary should be thoroughly and carefully insulated, while the large number of these transformers employed demands that attention be given to the important question of efficiency; both, together with other characteristics, giving the design, manufacture and sale of this device great prominence.

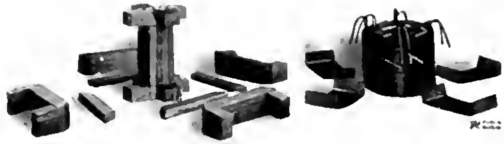


Fig. 9

Reference has been made to the fact that all three types described have been employed for this service and that the distributed core type has practically superseded the other two, although the latter is still manufactured by some companies. The most convenient form of punchings devised for this core are "L" shaped, and are readily cut from the sheet steel by shearing dies in such a manner as to result in a comparatively small waste, at the same time permitting the dies to be operated at very high speed. As this shape of punching is particularly well adapted to the construction of the transformer, it is fairly economical.

The punchings are built up by pairs into four sections which, when locked together, form a square center of solid iron with four branches at each end containing half the amount of iron in the central core (Fig. 9 standing). This arrangement provides a natural spool-shaped design, around the middle leg of which the coils are wound when it is placed in a winding lathe designed to properly hold it. This done, the magnetic circuit is completed by interweaving the laminations of the four outside legs with those of the end branches. The laminations of the core are secured by steel clamps placed at top and bottom, which in turn are retained by straps of the same material extending somewhat above the top clamp and supporting the connection-board to which are carried the coil leads. The transformer is then subjected to a vacuum and filling process, after which the construction is finished by attaching flexible insulated cables to the connectors and assembling the transformer within its case.

(To be continued)

KEY FOR THE COMPLETE CALCULATION OF A TRANSMISSION LINE

PART VII

By Milton W. Franklin

Given:

- (a) Kilowatts load
- (b) Length of line
- (c) Power factor of load
- (d) Frequency
- (e) Number of phases
- (f) Estimated cost of power per kw. year
- (g) Cost of conductor per lb.
- (h) Interest rate on line investment.

To Be Determined:

- (1) Voltage (see page 447, Vol. XII No. 10)
- (2) Choice of conductor (see page 276, Vol. XII No. 6)
- (3) Most economic loss (see page 139, Vol. XIII No. 3)
- (4) Cross-sectional area of conductor (equations *c, e, g, i*, page 140, Vol. XIII No. 3)
- (5) a Pounds of conductor (equation 3, page 139, Vol. XIII No. 3)
  - b Total cost of conductor
  - c Interest on line investment
- (6) Resistance of line (equation 6, page 139, Vol. XIII No. 3)
  - a Skin effect (see page 450, Vol. XII No. 10)
  - b Recalculation of loss for cable selected (equation *l*, page 141, Vol. XIII No. 3)
- (7) a Kilowatts loss on line
  - b Kilowatts delivered (generated)
  - c Kilovolt amperes delivered (generated)
- (8) Line spacing of conductors (see table, page 449, Vol. XII No. 10)
  - a Capacity (see table)
  - b Charging current (see table)
  - c Self induction (see table)
  - d Inductive reactance (see table)
- (9) Natural period of line (see page 417, Vol. XII No. 10)
- (10) Voltage and current at generating end (under full load conditions)
- (11) Regulation of line (unity power factor)
- (12) Summary of results

The use of the key may best be illustrated by means of a worked example.

EXAMPLE:

Proposition:

To transmit 40,000 kw. (power at generator end)
Length of line, 100 miles
Frequency, 60 cycles
Number of phases, 3
Power factor of load .85

Given:

- a. Kilowatts load, 40,000
- b. Length of line, 100 miles
- c. Power factor of load .85
- d. Frequency, 60 cycles
- e. Three-phase
- f. Estimated cost of power per kw. year $10.00
- g. Cost of conductor per lb.—copper $.15
  —aluminum $.38
- h. Interest rate on line investment 5 per cent.

Since 20,000 kw. is the maximum load that can be economically transmitted over a single line we shall assume two parallel lines of 20,000 kw. capacity, and consider each individually.

The order of solution as outlined on page 139, Vol. XIII No. 3, will be followed:

1. Voltage receiver end 100,000 volts.
2. Choice of conductor: Aluminum $.38 per lb. Copper $.15 per lb.

From curve (see page 276, Vol. XII No. 6) it can be seen that copper will prove the cheaper conductor, aluminum will cost 18 per cent. more for the same percentage power loss on the line.

Hard drawn copper wire is chosen for the conductor

3. Most economic loss: See page 140, Vol. XIII No. 3, Equations (*f*) and (*a*).

$$x = \sqrt{\frac{3K}{4\ cE_R^2 + 3\ K}}$$

$$K = \frac{4000\ pc_1K_1K_2L^2}{\cos^2\theta}$$

The values of the constants for this particular case are given below:

P = power at generating end, 20,000 kw.
c = estimated cost of power per kw. year, $10.00
E_R = receiver voltage, 100,000
L = length of line in miles, 100
$\cos\ \theta$ = power factor of load, .85
c_1 = cost of conductor per lb. $.15
p = interest rate .05
K_1 = resistance of conductor per mil mile, 56,700
K_2 = weight of conductor per mil mile, lbs., .0161

From formula (4) page 450, Vol. XII No. 10, we have

$R_t = R_{os}\ y$

R_{os} = 55,810 (table 6) y = 1.016 (curve, page 449, Vol. XII No. 10

$R_t = 55{,}810 \times 1.016 = 56{,}700 = K_1$

Substituting the values of the various constants in the equation for K we have

$$K = \frac{4000 \times .05 \times .15 \times 56{,}700 \times .0161 \times 100^2}{.85^2}$$

$K = 379{,}040{,}000$

and

$$x = \frac{3 \times 37904 \times 10^4}{\sqrt{4 \times 10 \times 10^{10} + 3 \times 37904 \times 10^4}} = .053$$

Thus we derive a value of 5.3 per cent. for the most economic loss, and hence can calculate the size of conductor $= S$.

4. Cross sectional area of conductor [equation (g) page 140, Vol. XIII No. 3].

$$S = \frac{1000(1-x)^2 P K_1 L}{E_R^2 \cos^2\theta \; x}$$

$$S = \frac{1000(1-.053)^2 \times 20\,000 \times 56700 \times 100}{10^{10} \times .85^2 \times .053}$$

$S = 265{,}500$ circular mils.

But the nearest size standard cable is 250,000 circular mils. This size cable (stranded cable) is adopted, and all the following computations based upon that size. This will alter our value of x as found under economic loss, hence a new value x_1 must be calculated, as given under (6 b of this problem).

5-*a*. Pounds of conductor [equation (3) page 139, Vol. XIII No. 3]
Pounds of conductor $= 3LK_2S$
$Lbs = 3 \times 100 \times .0161 \times 250{,}000 = 1{,}207{,}500$

b. Cost of conductor ($.15 per lb.) $.15 × 1,207,500 = $181,125.

This cost is for one line transmitting 20,000 kw.

c. Interest on line investment (conductor only) per annum $181,125 × .05 = $9,056.25

6. Resistance of line (single wire). Eq. (6) page 139, Vol. XIII No. 3

$$R = \frac{K_1 L}{S} = \frac{56700 \times 100}{250{,}000} = 22.68 \text{ ohms.}$$

The per cent. increase in resistance for 60 cycles (see Skin Effect page 451, Vol. XII No. 10) equals 0.8 per cent. for the size cable adopted.

This is an increase of 0.8 per cent. in the resistance hence the resistance per wire will be $22.68 \times 1.008 = 22.86$ ohms.

b. Having the resistance of our cable we are now in position to recalculate the loss for 250,000 circular mil cable, this being slightly different from the economic loss x as calculated under (3) due to the fact of choosing a 250,000 circular mil cable as opposed to a 265,500 circular mil cable as given by formula. See page 140, Vol. XIII No. 3

$$\frac{1000\, R_1 P}{E_R^2 \cos^2\theta} = \frac{x_1}{(1-x_1)^2} \qquad \frac{1000\, R_1}{E_R^2 \cos^2\theta} \quad a$$

$$x_1 = \frac{(2a+1) \pm \sqrt{4a+1}}{2a}$$

In this case $R_1 = 22.86$

$$a = \frac{22.86 \times 20{,}000 \times 1000}{10^{10} \times .85^2} = .0633$$

$$x_1 = \frac{(1.1266) \pm \sqrt{1.2532}}{.1266} = .0561$$

The economic loss for this particular case is hence 5.61 per cent.

7-*a*. Kilowatts loss on line (RI^2 loss)
Kilowatts loss on line $= Px_1$
$20{,}000 \times .0561 = 1122$ kw.

b. Kilowatts delivered at 100,000 volts, $\cos\theta = .85$
$20{,}000 - 1122 = 18{,}878$ kw.

c. Kilovolt amps. delivered receiving end

$$\frac{18878}{\cos\theta} = \frac{18878}{.85} = 22{,}209 \text{ k.v.a}$$

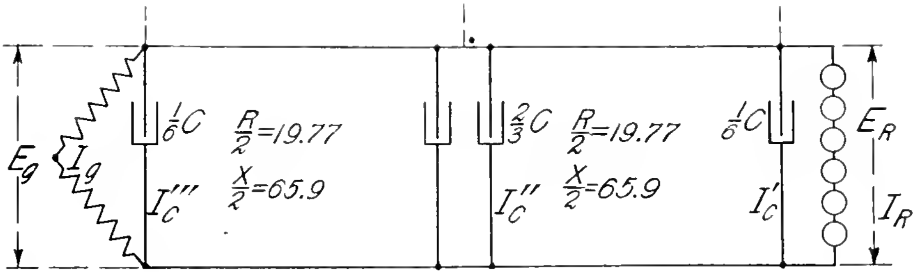


Fig. 15

d. Receiver current $\dfrac{k.v.a.}{\sqrt{3}\, E_R} = \dfrac{22{,}209}{\sqrt{3} \times 100{,}000}$

128.2 amps.

8. *Line spacing* of conductors. (Table) page 449, Vol. XII No. 10. 114 in. line spacing.

a. *Capacity*. (Table)

For 114 in. (by interpolation between 108 in. and 120 in.) capacity per 1000 feet of line (2 conductors) $= .001415$ *m.f.* For 100 miles $= 100 \times 5.28 \times .001415 = .7471$ *m.f.*

b. *Charging current*. (Table)

For 114 in. (by interpolation between 108 in. and 120 in. we get $.06165 \times 10^{-2}$ amp. per 1000 feet per 1000 volts.

Approximation of charging current per wire for the line:

$$.0615 \times 10^{-2} \times 100 \times 5.28 \times 100 = 32.5 \text{ amps}$$

c. *Self induction*. (Table)

For 114 in. (by interpolation between 108 in. and 120 in.) we get .3847 milli-henries per 1000 feet.

Self induction (single wire) for line $= .3847 \times 100 \times 5.28 = 203.12$ milli-henries.

d. *Inductive reactance* (ohms). (Table

Values as given in table $= \sqrt{3} \times x$. x = reactance for a single wire. These values multiplied by the current per wire give the reactance drop per phase.

Reactance for 114 in. (by interpolation between 108 in. and 120 in.) we get .2512 ohms per 1000 feet.

For total line (per phase) $= .2512 \times 100 \times 5.28 = 131.8$ ohms.

9. Natural period of line.

$$P = \frac{7900}{\sqrt{LC}}$$

$L = 203.12$ milli-henries.

$C = .7471$ microfarads.

$$P = \frac{7900}{\sqrt{203.12 \times .7471 \times 2}} = 454$$

From this we conclude that 60 cycles is a safe frequency.

10. *Voltage and current at generating end under full load conditions.*

Under this heading we shall make certain assumptions which will greatly facilitate the calculations, and while they introduce approximations, still the results attained are very close to the true state of affairs, and do not seriously affect the accuracy of the problem.

Consider the capacity of the line as concentrated at points as shown in figure below.

The calculations are based on a single-phase of the line as shown in Fig. 15

Reactance per phase calculated 8d) $X = 131.8$ ohms.

Resistance per phase $= \sqrt{3} \times 22.86 = R = 39.55$ ohms.

$$\frac{X}{2} = 65.9 \qquad \frac{R}{2} = 19.77$$

Values of X and R just calculated are not the true values of reactance and resistance per phase, but are thus designated to avoid the continual multiplying by the factor $\sqrt{3}$. Thus the drop in any phase can be found by taking these values and multiplying by the current per leg.

Consider the current along the line as separated into its components, power and wattless, and calculate the drop due to each.

Assume the following notation:

E_R = receiver voltage.

E^1 = voltage across center of line.

E_g = voltage at generating end.

I_R = current in receiving circuit.

$I_P = I_R \cos\theta$ = power component of current, I_R.

$I_W = I_R \sin\theta$ = wattless component of current, I_R.

I_c' = charging current per wire for condenser at receiver end.

I_c'' = charging current per wire for condenser at middle of line.

I_c''' = charging current per wire for condenser at generator end.

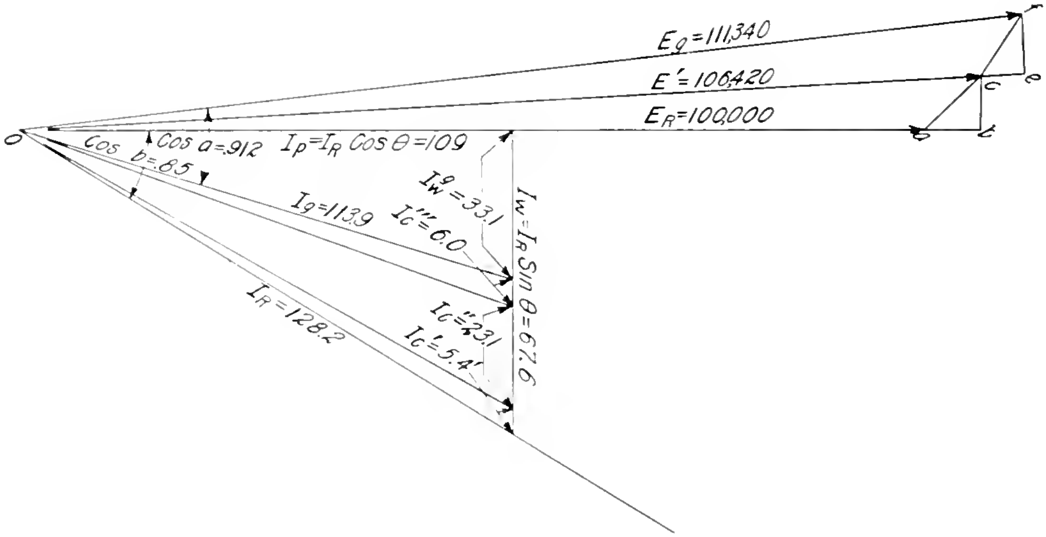


Fig. 16

I_w' = wattless component current in section 1 of line.

I_w'' = wattless component current in section 2 of line.

I_w^g = wattless component current in generator.

I_g = total generator current.

The quantities together with their values for this particular problem are clearly shown in the vector diagram (Fig. 16).

$E_R = 100{,}000$

$I_R = 128.2$

$I_P = I_R \cos\theta = 128.2 \times .85 = 109$ amps.

$I_W = I_R \sin\theta = 128.2 \times .527 = 67.6$ amps.

$\cos\theta = .85$

Charging current I_c' for condenser at receiving end.

$$I_c' = \frac{2}{\sqrt{3}}\left(\frac{1}{6}\omega C E_R\right) \quad \omega = 2\pi f = 377$$

$$C = \frac{.7471}{10^6}$$

$$E_R = 10^5$$

$$I_c' = \frac{2 \times 377 \times .7471 \times 10^5}{\sqrt{3} \times 6 \times 10^6} = 5.4 \text{ amps.}$$

This is shown plotted in Fig. 16.

$I_{II}' = 67.6 - 5.4 = 62.2$ amps

Drop section 1 of line.

In phase	$\frac{R}{2} I_P = 19.77 \times 109$	=	2155
	$\frac{X}{2} I'_{II} = 65.9 \times 62.2$	=	4100
	ab	=	6255
In quadrature	$\frac{R}{2} I'_{II} = 19.77 \times 62.2$	=	−1230
	$\frac{X}{2} I_P = 65.9 \times 109$	=	7183
	bc	=	5953

Generator voltage full load 111,340.

Charging current I_c''' for condenser at generating end of line.

$$I_c''' = \sqrt{\frac{2}{3}} \left[\frac{\omega C E_g}{6} \right]$$

$$I_c''' = \sqrt{\frac{2}{3}} \left[\frac{1 \times 377 \times .7471 \times 111{,}340}{6 \times 10^6} \right] = 6.0$$

amps.

Current at generating end:

$$I_g = \sqrt{I_P^2 + I_{g}'^2}$$

$I_g' = 67.6 - 34.5 \qquad = 33.1$

$I_P = \qquad\qquad = 109$

$I_g = \sqrt{109^2 + 33.1^2} = 113.9$ amps.

K.v.a. at Generating End

$k.v.a. = \sqrt{3} E_g I_g = \sqrt{3} \times 111{,}340 \times 113.9 = 21.965$

Power factor generator end $= \frac{20000}{21930} = .912.$

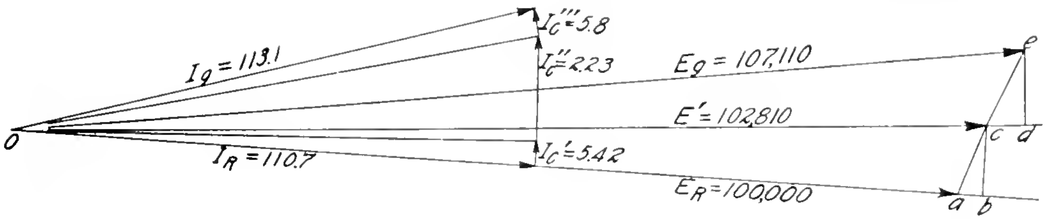


Fig. 17

Add on the drop in Fig. 16 as shown.

$E' = \sqrt{Ob^2 + bc^2}$

$Ob = Oa + ab = 100{,}000 + 6255 = 106{,}255$

$bc = \qquad 5{,}953$

$E' = \sqrt{106{,}255^2 + 5{,}953^2} = \qquad 106{,}420$

Charging current for condensers at middle of line.

$$I_c'' = \sqrt{\frac{2}{3}} \left[\frac{4\,\omega C E'}{6} \right]$$

$$I_c'' = \sqrt{\frac{2}{3}} \left[\frac{4 \times 377 \times .7471 \times 106{,}420}{6 \times 10^6} \right] = 23.1$$

amps.

$I''_{II} = I'_{II} - I''_c = 62.2 - 23.1 = 39.1$ amps.

Drop Section (2):

In phase	$\frac{R}{2} I_P = 19.77 \times 109$	=	2155
	$\frac{X}{2} = 65.9 \times 39.1$	=	2577
	ce	=	4732
In quadrature	$\frac{R}{2} I''_{II} = 19.77 \times 39.1$	=	− 773
	$\frac{X}{2} I_P = 65.9 \times 109$	=	7183
	ef	=	6410

$E_g = \sqrt{Oe^2 + ef^2}$

$Oe = Oc + ce = 106{,}420 + 4{,}732 = 111{,}152$

$ef = \qquad 6{,}410$

$E_g = \sqrt{111{,}152^2 + 6{,}410^2} = \qquad 111{,}340$

Full load conditions.

	Generating end.	Receiving end
Load	20,000 kw.	18,878 kw.
Voltage	111,340	100,000
Power factor	.91	.85
K.v.a	21,965	22,209

Loss on line 1122 kw.

Per cent. total drop 11.1 per cent.

11. Regulation of line ($\cos\theta = 1.00$). See page 141, Vol. XIII No. 3

Kilowatts generating end	20,000
Voltage receiving end E_R	100 000
Resistance per wire, R_1	22.86

From formula page141. Vol. XIII No. 3, we have

$$\frac{R_1 P}{E_r^2 \cos^2\theta} = \frac{x_1}{(1 - x_1)^2}$$

In this case $\cos\theta = 1$

$$\frac{R_1 P}{E_r^2 \cos^2\theta} = a = \frac{22.86 \times 20{,}000 \times 10^3}{10^{10}} = .0457$$

$$x_1 = \frac{(2a + 1) \pm \sqrt{4a + 1}}{2a}$$

$$= \frac{1.0914 \pm \sqrt{1.1828}}{.0914} = .0415$$

x_1 per cent. loss = 4.15 per cent.

Loss in kw. = 20,000 × .0415 = 830

Kw. delivered at receiving end, 20,000 − 830 = 19,170

$$I_R = \text{Amperes at receiving end} = \frac{19{,}170{,}000}{\sqrt{3} \times 100{,}000} = 110.7$$

Charging current I_c' for condenser at receiving end = 5.42 (calculated in 10)

See Fig. 17 for graphic outline of problem.

Drop Section (1).

$\frac{R}{2}\times I_R = 19.77\times 110.7 \qquad = 2189$

$\frac{X}{2}\times I_c' = 65.9\times 5.42 \qquad = 357$

$ab = 2546$

$\frac{R}{2}\times I_c' = 19.77\times 5.42 \qquad = 107$

$\frac{X}{2}\times I = 65.9\times 110.7 \qquad = 7295$

$bc = 7402$

Add these drops in Fig. as shown.

Voltage at middle of line = E'.

$E' = \sqrt{\overline{Ob}^2+\overline{bc}^2}$

$Ob = Oa + ab = 100{,}000 + 2{,}546 = 102{,}546$

$bc = \qquad\qquad = 7{,}402$

$E' = \sqrt{102{,}546^2+7402^2} \qquad = 102{,}810$

Rise of Voltage at No Load.

Consider the voltage at generating end as held constant between full load ($cos\ \theta = 1$) and no load. At no load the voltage will rise in value from the receiving end of line toward the generating end.

It will be sufficiently accurate to calculate the charging current using the value E_g (generator voltage) in each case since the variation in voltage along the line will not be so great as to seriously affect the results.

See Fig. 18.

$E_g = 107{,}110$

$I_c'' = \frac{2}{\sqrt{3}}\left[\frac{4\times 377\times .7471\times 107{,}110}{6\times 10^6}\right] = 23.2$ amps.

$I_c' = \frac{1}{4}\times 23.2 = 5.8$ amps.

Voltage Rise Section 2.

$\frac{R}{2}(I_c''+I_c') = \frac{R}{2}(23.2+5.8) = 19.77\times 29 =$

$(bc) = 573$

$\frac{X}{2}(I_c''+I_c') = 65.9\times 29 \qquad = (ab) = 1911$

$E' = \sqrt{\overline{Ob}^2+\overline{bc}^2}$

$Ob = 107{,}110 + 1911 \qquad = 109{,}021$

$bc = \qquad 573$

$E' = \sqrt{109{,}021^2+573^2} \qquad = 109{,}022$

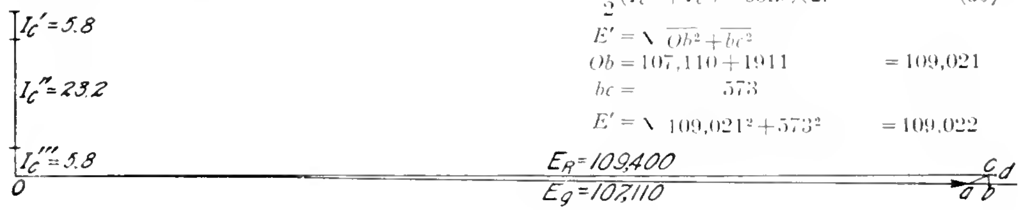


Fig. 18

$I_c'' = \frac{2}{\sqrt{3}}\left[\frac{4\times 377\times .7471\times 102{,}810}{6\times 10^6}\right] = 22.3$ amps.

Drop section (2).

$\frac{R}{2}\times I = 19.77\times 110.7 \qquad = 2189$

$\frac{X}{2}\times (I_c'+I_c'') = 65.9\times 27.72 \qquad = 1827$

$cd = 4016$

$\frac{R}{2}\times (I_c'+I_c'') = 19.77\times 27.72 \qquad = 548$

$\frac{X}{2}\times I = 65.9\times 110.7 \qquad = 7295$

$de = 7843$

$E_g = \sqrt{\overline{Od}^2+\overline{de}^2}$

$Od = 102{,}810 + 4{,}016 \qquad = 106{,}826$

$de = \qquad\qquad = 7{,}843$

$E_g = \sqrt{106{,}826^2+7{,}843^2} = 107{,}110$ volts.

Charging Current Generator End I_c'''.

$I_c''' = \frac{2}{\sqrt{3}}\left[\frac{377\times .7471\times 107\ 110}{6\times 10^6}\right] = 5.8$ amps.

Generator current $= I_g$

$I' = \sqrt{110.7^2+5.42^2} = 110.8$

$I'' = \sqrt{110.8^2+22.3^2} = 113.$

$I_g = \sqrt{113^2+5.8^2} = 113.1$ amps.

Rise Section 1.

$\frac{R}{2}\times I_c' = 19.77\times 5.8 \qquad = 115$

$\frac{X}{2}\times I_c' = 65.9\times 5.8 \qquad cd = 382$

$\left[\frac{R}{2}\times I_c'\right]$ is negligible.

$\therefore E_g = 109\ 022 + 382 = 109{,}404$

Regulation.

109,400
100,000

9,400 rise from full load to no load

$\frac{9400\times 100}{100{,}000} = 9.4$ per cent.

SUMMARY

		Generating End	Receiving End
1	Load	40,000 kw.	37,756 kw.
	Voltage full load	111,340 volts	100,000 volts
	Power factor	.91	.85
	K.v.a.	43,930	44,418
	Loss on line		2244 kw.
	Total drop full loaf		11.1 per cent.
	Regulation ($cos\ \theta = 1$)		9.4 per cent.
2	Pounds of conductor (copper)		2,415,000
	Total cost of conductor (both lines)		$362,250
	Annual interest on investment		$18,112.50
	Cost of lost power		$22 440.00

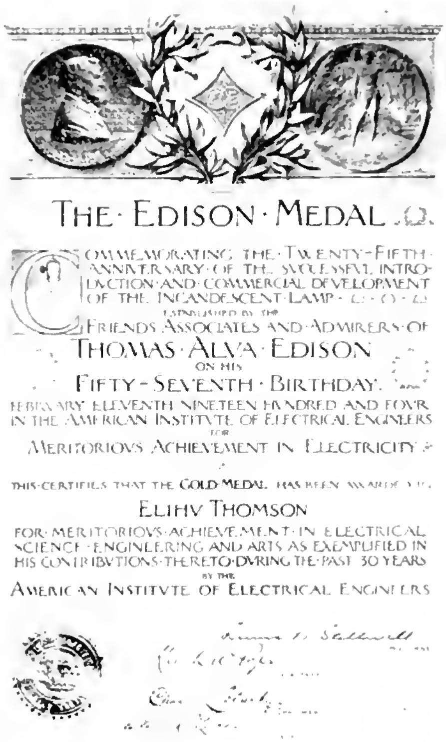
(To be Continued)

PRESENTATION OF EDISON MEDAL

The Edison Medal was instituted by the American Institute of Electrical Engineers in commemoration of the twenty-fifth anniversary of the commercial introduction of the Edison incandescent lamp, and for the first time was awarded to Prof. Elihu Thomson for meritorious achivement in electrical science, engineering, and the arts. The presentation was made at the annual dinner of the A.I.E.E., New York City, February 24, 1910. In acceptance, Prof. Thomson spoke as follow.

Anything which I might say on this occasion could only express in small measure my appreciation of the honor done me in the award of the first Edison medal. To be selected by such a representative body of men, as distinguished in the electrical profession as the Edison Medal Committee, is itself a sufficient recognition; one to be prized most highly. I most heartily thank the Committee.

It is a source of great satisfaction that the award bears the name of the chief of pioneers in the field of large electrical application, the name of one to whose energy and courage, to whose ingenuity and resourcefulness the art owes so much. I know that all present will agree that the name of Edison is peculiarly fitting to characterize an award given for electrical achievement. While the period of invention and technical advancement through which we have been recently passing has affected all fields, with none has the influence upon our conditions of life been more profound than with the applicaitons of electricity.



Certificate of Award

When we look back to the early beginnings, we can realize the privilege of having lived at such a time so as to take some part in all that wonderful progress which has filled the succeeding years.

Who can enumerate the many conquests of man over nature's forces; the unlocking of the treasure house of knowledge of the universe around us? Through it man at last acquires the ability to navigate the air itself; an achievement which the most sanquine of us could scarcely have thought would come so soon. Let us hope that all this is the beginning of an age of still greater advances, in which man will build more and more upon the foundations already laid.

I have sometimes been asked whether I did not like to read what may be called scientific fiction; in which an author tried to picture future scientific progress. I have usually answered "No," for "Truth is stranger than fiction." It is the unexpected which happens. A speaking tube might suggest a telephone, but what writer of fiction was there to predict that such an inexpressibly simple arrangement of wire and iron could transmit speech before Bell did it. Who of them told us of the wireless telegraph, and that an ordinary simple induction coil could stir the ether and transmit signals over hundreds of miles? What fiction writer had imagination so penetrating as to tell us that we could some day see our bones, and that surgery would be helped thereby? Who knew of the wonderful properties of radium, or ever imagined them possible? To come nearer home, who could picture as the many triumphs of electrical engineering– a dozen or more different kinds of electric lights; transmission of thousands of horsepower of energy over hundreds of miles; the electric railroad, and the other developments which in so short a time have far outstripped our most extravagant expectations?

As an instance of what was in the minds of people at the early inception of our art, I will read a little extract which I happened to find in one of the issues of the Gas Light

Journal of 1878, when a discussion of the forthcoming Edison light, then the platinum wire lamp, was had. The following colloquy took place:

Mr. D.—The gas we are now burning comes from Birchington, a distance of four and a quarter miles. Would it be possible for me, if I wished to do so, to send electricity from here to Birchington to give light there?

Mr. G. It would be possible, but not economical.

Mr. D.—Then how am I to light Birchington?

Mr. G.—I should say, decidedly, take your machines to Birchington.

Mr. D.—What am I to do for light along the road between here and Birchington?

Mr. G.—Place machines at convenient distances.

Mr. D.—In other words, several stations in such a short distance!

That was the view of a gas man and actually occurred at a meeting of gas engineers at the time reported, and will be found in the Gas Light Journal.

I could go on and multiply instances of that kind, but that is merely a statement of conditions as they existed, and we have not time to go so far into ancient history.

I have but little more to say in response. I did not intend to make a speech of any length.

I shall always value very highly the distinction which has been accorded me. But however much one may be rewarded for doing that which his tastes and inclinations have led him to do, there is, indeed, another and more immediate reward, the hope of attaining, which is after all the strongest stimulus; I have sometimes referred to it as the "joy of accomplishment." It is the sense of satisfaction which accompanies the doing of a thing, the surmounting of an obstacle, the attainment of a goal. It is the pleasure of having tried, and in spite of difficulties, succeeded. Those who have done this can understand what it meant. I confess that where a result is brought about by compelling taste or aptitude, in whole or part, the question of how much credit is to be accorded is not easy to determine. I am not arguing for the view of the ascetics that there belongs the greatest credit to those who make themselves most miserable.

It is sometimes the case that a difficult thing is a sort of challenge, appealing to the imagination. After all, to the artist, the inventor, the scientific investigator, the engineer and the broad man of business, imagination is often the chief mainspring of action. It enables him mentally to picture a thing as done or accomplished before the doing, and so to seek out the plan to be followed or the measure to be taken. Imagination furnishes the dreams that may come true; they are carried into practice, and if the things done are worth while, success and its accompanying "joy of accomplishment" follow.

What matters it that there are many and unlooked for hardships, setbacks, and struggles, against adverse circumstances, if the end in view is at last attained? There will always be need of energy, self denial and persistence, if we would follow out our plans. Too often success is measured by financial outcome and this we must guard against. We need the broader view which causes us to sympathize with all progress and assist in it.

I wish now to add that in honoring me you should not forget that there were faithful co-workers—some of whom I see now here—without whose help at times when it was most needed much less could have been accomplished. I mean also to include in this those through whose wisdom and business sagacity the means were provided for doing such things as seemed needful at the time. To them a high tribute is due, for they contributed in large measure to render possible that for which the Edison medal has been so graciously accorded.

Ladies and gentlemen, members of the Institute: I thank you all with the utmost sincerity for the honor you do me in being present on this occasion.

GENERAL ELECTRIC REVIEW

VOL. XIII, NO. 5

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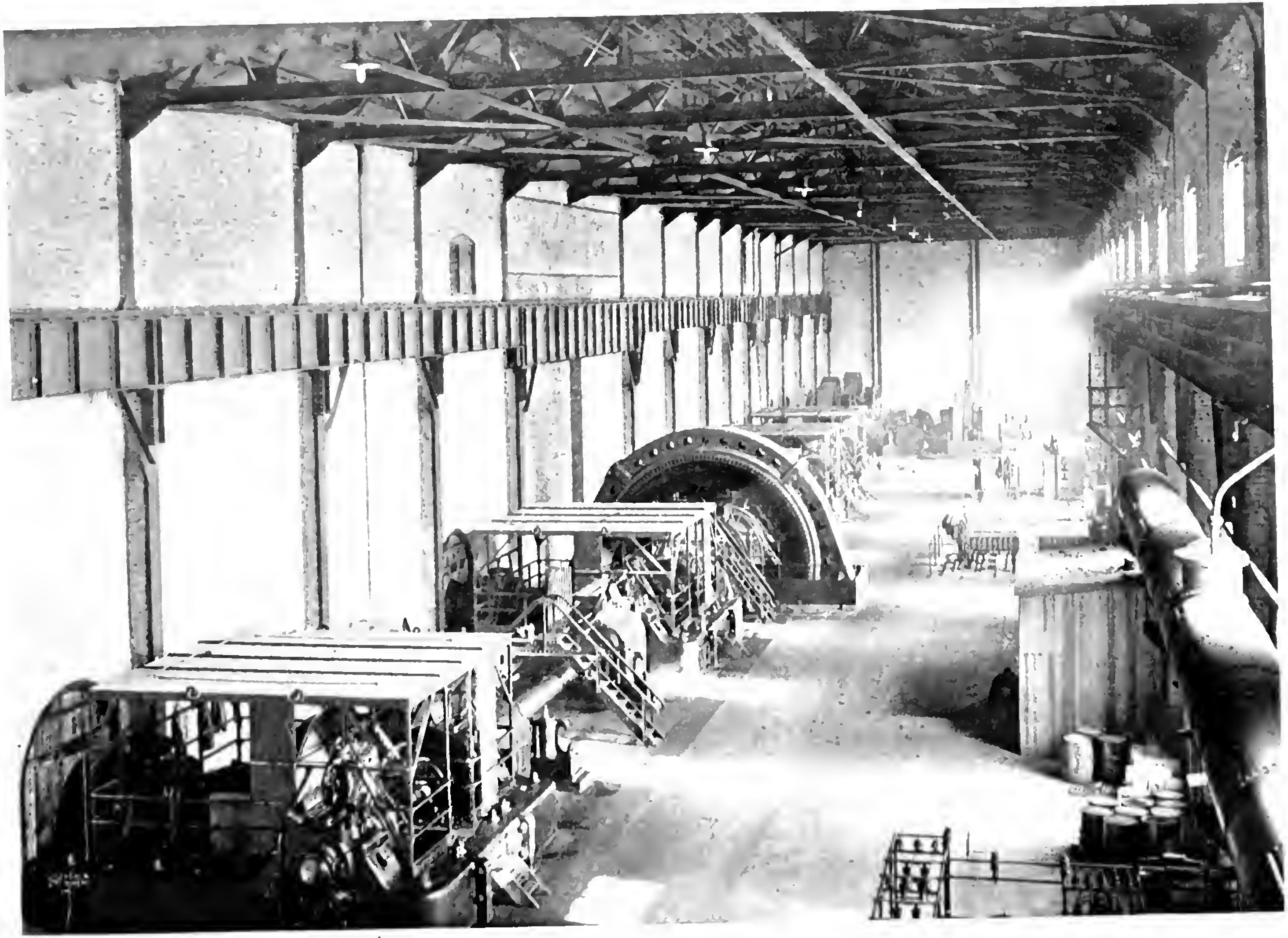


Section of Motor Room in Billet Mill, Indiana Steel Company, Gary, Ind.

(See page 210)

GENERAL ELECTRIC REVIEW

REVIEW SUPPLEMENT AND TRANSMISSION LINE CALCULATIONS

The REVIEW this month publishes a supplement in which the method of calculating transmission line problems by the use of hyperbolic functions is explained; two numerical examples being given to illustrate the method of working; *i.e.*, a 300 mile line operating at 60 cycles, using three No. 000 wires triangularly spaced 10 ft. apart; and a line 100 miles long operating at 25 cycles, using three No. 0 wires equally spaced in a plane with 8 ft. between centers. In the latter case, approximate formulæ are used which have been derived from the hyperbolic equations. The formulæ are given in the supplement with explanatory notes as to their use. The constants and hyperbolic functions necessary for the evaluation of numerical results are also tabulated. No references need therefore be made to other publications or tables, and the supplement is complete and self-contained.

As noted in the first part of Mr. W. E. Miller's article, the method followed is Kennelly's, as given in McMahon's Hyperbolic Functions. The work was undertaken in consequence of the discussion on Mr. Thomas's paper, at Frontenac, reported in the A.I.E.E. Proceedings for November, 1909, where more than one speaker referred to the hyperbolic method as that best adapted to transmission calculations, though there was considerable divergence of opinion on this question. Reference to the supplement ought to remove any doubt as to the simplicity of the hyperbolic method, and to convince engineers of its ready application to the solution of transmission problems when the constants and hyperbolic functions are properly tabulated.

The second part of the article discusses at some length the physical aspect of corona viewed in accordance with one of the modern theories of electricity the contrast between corona and capacity current being emphasized. The law connecting the no load loss with the length of short transmission lines is also given.

It must be understood that the formulæ and constants given can be directly applied to transmission line problems only if the generator current and voltage follow a simple harmonic law; that is to say, only if harmonics of considerable magnitude are absent. The latter is generally the case, but occasionally the capacity or even the load current introduces harmonics into the generator waves. From oscillograph records these waves can be analyzed into their harmonics, and the formulæ can then be applied to the fundamental wave and each harmonic separately. The constants, of course, apply only to the fundamental wave, and new constants must be calculated for each harmonic.

In the present state of knowledge, it is impossible to include corona effect in the equations. Where the corona current is considerable, the no load loss cannot be obtained from the equations, but they are sufficiently reliable in such cases for calculating the electrical conditions along lines under load.

The equations and discussions refer to the electrical characteristics of transmission lines after the normal state has been reached, and the transient phenomena which occur when the electrical conditions are suddenly changed are ignored. The method for calculating these is given in Steinmetz's "Transient Phenomena." These phenomena are under certain circumstances extremely important and it would be well worth while if numerical results were computed for, say, two cases as examples; *i.e.*, a long line on open circuit operating at 60 cycles when the generator is connected to the line at maximum voltage, and when it is connected at zero voltage. The volts and current should be plotted for each case for different points along the line at the moment of closing the switch and after successive time intervals, until the normal state is reached. The advance of the voltage and current waves and their reflection when they reach the end of the line would then be graphically shown.

If the calculations were made at many points along the line and at sufficiently close intervals of time, and each curve were photographed, the series so obtained could be run through a cinematograph machine and show a continuous record of the phenomena by projection on a screen. This would be extremely valuable from an educational point of view, since such visual presentations help towards a physical understanding of the chief phenomena underlying the problem. Were more of the abstruse, and for that matter the simpler, problems which enter into electrical engineering treated in this manner, much clearer ideas would be formed than can be obtained from discussions of or calculations from formulae. The labor and expense involved in the preparation of these curves and their photographic reproduction are far from prohibitive, so that there is no reason why such methods should not be used occasionally as an auxiliary for college training or lecture work.

THE SINGLE-PHASE INDUCTION MOTOR

The REVIEW is fortunate in being able to present with the present issue the first part of an article on the single-phase motor, by Professors Morecroft and Arendt of Columbia University. This article, which the authors have kindly given us permission to print, was written to form part of a treatise on the subject of electrical motors. The book, which will appear later, will include the articles on the synchronous a.c. motor and the d.c. series motor that were published respectively in the May and June issues and the August and September issues of last year.

Coming from this source, the editors have not presumed to pass upon the accuracy of the statements in the article, which, considering the high authority of the authors, has been left entirely with them.

As with the articles on the synchronous a.c. and the d.c. series motor, our readers will find this discussion of the single-phase motor of much interest and value. While the mathematics employed is not difficult, the authors have also presented their conclusions and much of the reasoning in simple non-mathematical language.

The article begins with a description of the interaction between the impressed and induced magnetic fluxes, which is followed by a lucid explanation of how the revolving field is developed and the torque produced.

The first part of the article closes with the torque equations and a clear statement of the conclusions to be deduced from their analysis.

The second part, which will be published in the next issue, opens with the subject of the characteristic curves. A circle diagram for plotting the curves is described and the results in a specific case are tabulated and discussed. The various methods of starting are then taken up and concisely but amply treated. This second portion of the article is wholly free from mathematics.

UNDERGROUND ELECTRICAL SYSTEMS

Under the title Underground Electrical Systems, Mr. W. E. Hazeltine has contributed a remarkably succinct article covering the choice of conduits and cables for various classes of work; the subject being treated in an entirely practical way, without theoretical discussion.

The conditions to be met in underground systems are described; the material used for conduits are then given, and the advantages and disadvantages briefly stated.

The relative utility of single and double ducts, of single and double manhole covers, the construction of manholes and the methods of supporting the cables within them, are given briefly as are also the size of cables and the several kinds of insulation employed in different cases. The essentials to be considered in drawing in the cables and otherwise installing the systems are also treated.

In short, the article forms a very complete and practical summary of the subject of underground electric systems.

THE SINGLE-PHASE INDUCTION MOTOR*

PART I

By Profs. J. H. Morecroft and M. Arendt
Columbia University

In small single-phase alternating current plants, the constant speed motor that is most extensively used is of the induction type. Structurally it is very similar to the corresponding polyphase machine;† in fact any polyphase induction motor will operate as a single-phase machine of somewhat smaller capacity and lower power factor, if it is at first caused to rotate at nearly synchronous speed by some starting arrangement. The necessity of providing some such auxiliary device arises from the fact that the single-phase motor, *per se*, has no starting torque. That such is the case may be readily seen without the introduction of mathematical proof.

Absence of Starting Torque

Consider a bi-polar single-phase motor, provided with a squirrel-cage rotor. The distribution of current in the secondary at standstill is as indicated in Fig. 1. The current in bars aa' is zero, because these are equivalent to a closed loop the plane of

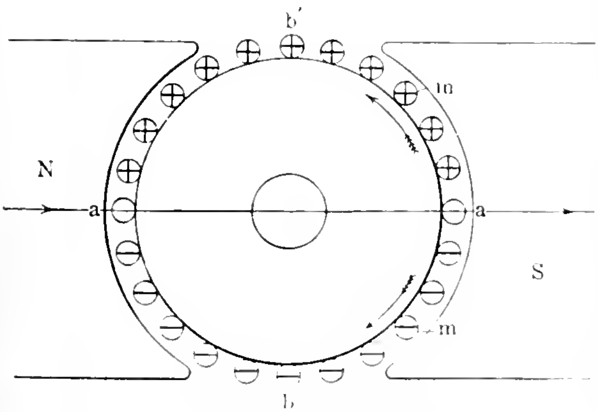


Fig. 1. Distribution of Current in Stationary Rotor of Single-Phase Induction Motor

which is located parallel to the flux. The maximum current is set up in bars bb'. However, this equivalent loop, if it moves at all, must move parallel to the direction of the lines of force; hence it exerts no turning effort. The bar m, carrying current as indicated, will exert a torque upon the rotor, as shown by the arrow alongside it. However, owing to the symmetry of the secondary winding, for every bar m there is another m' having a current of equal amplitude but of opposite

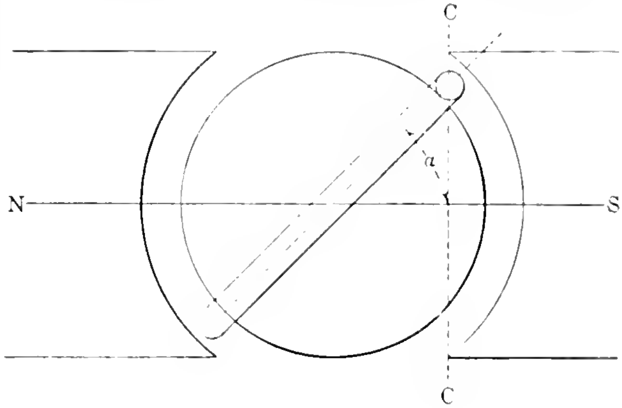


Fig. 2. Short Circuited Coil Inclined to Axis of Oscillating Field

sign. This latter bar being in a field of the same strength and direction as that in which m is located, will exert a torque equal to that developed by m, but in the reverse direction, as indicated by the corresponding arrow. In the same way the effort exerted due to the current in any bar of the winding will be neutralized by that of another bar symmetrically located with respect to the axis of the primary field; consequently at standstill no turning effort is developed and the motor fails to accelerate.

The above fact may be proved as follows: Assume the rotor winding as composed of symmetrically placed short-circuited coils, and consider one having its plane at any angle α to the axis of the field NS, as illustrated in Fig. 2. Further suppose the flux distribution to be a cosine function of α; this is approximately the case with actual motors provided with distributed stator windings; then let

B represent the maximum flux density at $\alpha_1 = 0°$,

$B \cos pt$ is the instantaneous flux density at $\alpha_1 = 0°$,

$B \cos pt \cos \alpha$ is the corresponding value at the inductors selected, and with A as the area

*To appear later as part of a book

†The first successful motor of this type was built by C. E. L. Brown. See London *Electrician*, Vol. XXX, pages 358, 1893.

of the coil the flux passing through it becomes

$$\Phi = \int_0^{\alpha} AB \cos pt \cos \alpha \, d\alpha = BA \cos pt \sin \alpha. \tag{1}$$

The e.m.f. induced in the selected coil is

$$e = -\frac{d\Phi}{dt} = BA\ p \sin pt \sin \alpha. \tag{2}$$

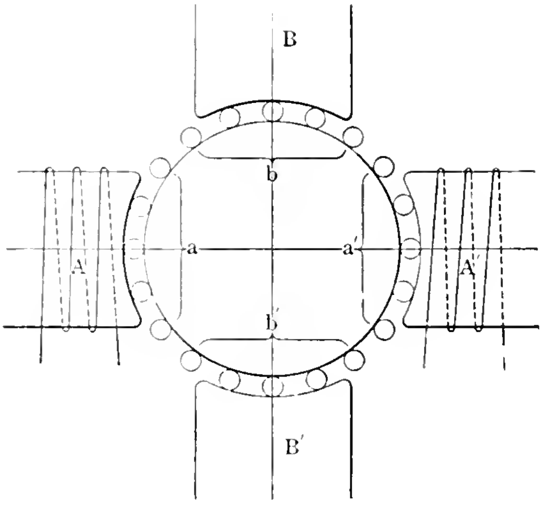


Fig. 3. Main and Quadrature Fields, Single-Phase Induction Motor

The instantaneous value of the corresponding current is

$$i = BA\ p \sin(pt-\theta) \sin \alpha \div Z'. \tag{3}$$

Naturally in the case of a single coil this current will react upon the stator field and produce flux distortion; but as we are going to sum up the effects of all the rotor coils the individual reactions balance and the field distortion becomes negligible. It is to be noted that the impedance of a coil will be modified by the action of the neighboring coils, consequently Z' in equation 16 represents the effective impedance. The angle $\theta = \cos^{-1}(r' \div Z')$, wherein r' is the effective resistance of the coil and Z' the impedance as above defined.

If there are n coils on the rotor equally spaced from one another, the effort of the Kth coil will be

$$t_k = lB^2 A p[\sin(2\ pt-\theta)+\sin\ \theta] \times \sin \frac{2\ K}{n} \pi \div 2\ Z', \tag{4}$$

wherein l is the length of one coil.

The instantaneous torque exerted by the whole rotor is

$$T = \Sigma t = lB^2 A p[\sin(2\ pt-\theta)+\sin\ \theta] \times \Sigma_1^n \sin \frac{2\ K}{n} \pi \div 2\ Z' = 0.* \tag{5}$$

Development of Revolving Field

We have just shown that when we have an oscillating magnetic field the rotor placed therein fails to exert any starting torque. Therefore, if a single-phase induction motor does develop a turning effort after it is caused to revolve, it must be because it has, by some reactions of the rotor currents upon the stator flux, provided for itself a rotating magnetic field. That such is the case may be shown non-mathematically. Assume a two-pole motor (Fig. 3) the stator winding of which is supplied with a single-phase alternating current, producing an oscillating field between the poles AA'. The rotor currents produce a field at right angles to the main field, and for convenience we will assume this to be represented by the poles BB'. In commercial machines no such empty pole spaces exist, as practically all of the stator is covered with coils.

The inductors of the revolving rotor have e.m.f's., induced in them due to two actions; namely, by motion through the field and by the time rate of change of the flux threading the coils. The first we shall designate as a *rotational* e.m.f. and the second as a *transformer* e.m.f.

The inductors aa' will always have a rotational e.m.f. set up in them except when the stator field passes through zero value. The amplitude of this e.m.f. for any given speed will be proportional to the instantaneous value of the stator flux. Conductors aa' may be considered equivalent to closed coils, and the current flowing in them will produce a field in direction BB'. Neglecting temporarily the IR drop in the rotor, the e.m.f. induced in aa' may be placed equal to $\frac{d\Phi_r}{dt}$, where Φ_r denotes the cross field developed by the currents due to the motion of the rotor in the main field. The rotational e.m.f. is in time phase with the main field, hence the cross field Φ_r will be in time quadrature with it. The direction of the main field and the motion of the rotor inductors are such that the e.m.f. generated in aa' is positive.† The rotor currents are in such direction that when pole A is of north polarity and decreasing, pole B will be of like sign but increasing,

*This same result is obtained from analysis of equa. 16.

†Currents flowing away from the reader into the plane of the paper are called positive.

reaching its maximum strength one quarter of a period later. The strength of pole B decreases after a similar lapse of time, the main field reverses and a north pole begins to build up at A'. *That is, the main field and quadrature field so combine that a north pole travels around the stator in the direction $ABA'B'$ at synchronous speed.* Hence, there exists a rotating field produced by the combined action of stator and rotor currents. This simple explanation gives an idea of the production of the rotating field in the single-phase induction motor, but it does not consider all the reactions which occur.

The inductors bb' moving in the quadrature field have a rotational e.m.f. induced in them, in the same manner as those passing through the main field, and this is of maximum positive value when the north pole at B attains its highest value. In addition to these *two rotational* e.m.fs., the varying fields AA' and BB' set up *transformer* e.m.fs., in coil groups bb' and aa' respectively. Consequently, there are *four* e.m.fs., to be considered before the actual rotor currents which produce the quadrature field can be determined.

The rotational e.m.f. induced in inductors aa' is of maximum positive value when the pole A is at its greatest north polarity, but the transformer e.m.f. set up in these bars by the quadrature field is at the same moment of maximum negative value. Hence the actual e.m.f. (Ea) existing in AA' is the algebraic sum of these two voltages. The rotational e.m.f. due to the main field must be greater than the transformer e.m.f. of the quadrature field; in fact the latter is of such strength that the actual e.m.f., Ea, will be just enough to establish the current which produces the field BB'. Since this quadrature field is at right angles to the main field, its m.m.f. cannot be furnished directly by the stator magnetizing current, so we must investigate further to see how it is taken, as it must be, from the line. It must be remembered that the impedance of the rotor coils is here assumed to be such that the IZ drop is negligible; if this is not the case, the rotational and transformer e.m.fs. will not be in time opposition and their *vector sum* instead of algebraic sum, must be considered.

The main field, by transformer action, induces an e.m.f. in bars bb', and this is opposed to the e.m.f. developed in the same inductors by their motion through the quadrature field. The resultant e.m.f. Eb in these conductors sets up a current affecting the main field and, consequently, the current drawn from the line. The current flowing in inductors bb' due to Eb is equal to that existing in bars aa', which is that producing the cross m.m.f. Moreover, the

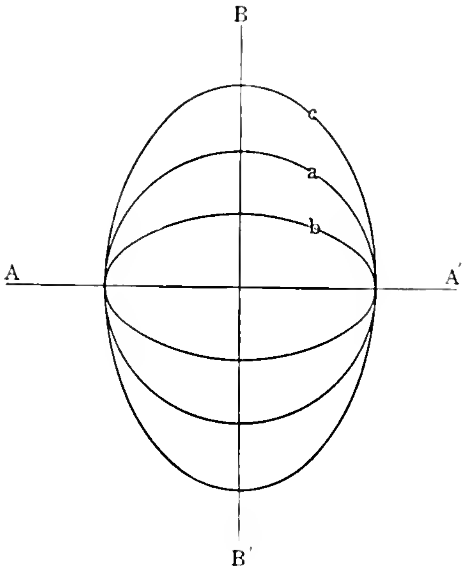


Fig. 4. Forms of Rotating Field at Various Rotor Speeds

current bb' is in such direction that it increases the magnetizing current taken from the line, the increment being that which would be necessary to directly magnetize the quadrature field. The reluctance of the cross field's magnetic circuit is substantially the same as that of the main field, consequently the m.m.f. required for both will be the same, and obviously, therefore, a two-phase motor run on one phase will draw twice its normal magnetizing current. This conclusion is borne out by actual practice, tests showing that *the magnetizing current of a single-phase motor is double that taken per phase by a two-phase and three times that required by a three-phase machine, the potential difference, frequency and turns per phase winding being the same.*

At synchronous speeds the two component fields are of equal strength; accordingly they combine to give a circularly rotating field. Below synchronous speed the rotating e.m.f. in the bars aa' is reduced in inverse proportion to the slip, and thus the quadrature field diminishes, while the main field remains constant. Consequently the rotating field developed below synchronous speed is of an elliptical form, the shorter axis being in the direction of the quadrature field BB'. When driven above synchronous speed the field is also of elliptical form, the major axis, however, being in the direction of the cross field. The field forms for different speeds are as illustrated in Fig. 4, a, b, c, respectively, corresponding to synchronous, sub-synchronous and super-synchronous speeds.

The maximum torque which a motor is capable of exerting, other things being equal, depends upon the average value of the magnetic field in which the rotor moves. This mean value, neglecting IR drop and leakage, is in the polyphase induction motor independent of the slip, while for the corresponding single-phase machine the average value of the field decreases as the slip increases; thus the pull-out torque of a polyphase machine connected single-phase will be less than when normally operated.

Many interesting facts concerning the rotor currents as well as the development of the rotating field may be derived through a simple mathematical analysis. Let us consider the elementary bipolar single-phase induction motor represented in Fig. 5 with a coil at an angle α to the main polar axis. Assume as before that the flux distribution is a cosine function of time, and adopt the following notation:

A = area of coil.

ω = angular velocity of the coil, or $\alpha = \omega t$.

$A \sin \alpha = \sin \omega t$ = projected area of coil on plane CC' perpendicular to the flux NS.

B = maximum flux density, its instantaneous value being $B \cos pt$.

Instantaneous flux interlinking coil α is

$$\Phi = AB \cos pt \sin \omega t$$

$$= \tfrac{1}{2} AB\Big(\sin(p+\omega)t - \sin(p-\omega)t\Big); \quad (6)$$

the e.m.f. induced in coil α is

$$e = -\frac{d\Phi}{dt} = \tfrac{1}{2} AB\Big((p-\omega)\cos(p-\omega)t - (p+\omega)\cos(p+\omega)t.\Big) \quad (7)$$

Let r_1 and L_1 represent respectively the effective resistance and inductance of the coils; the values of these constants being based not only upon the character of an individual coil but also to some extent upon the action of neighboring coils. With this notation the current in any secondary coil can be considered as resulting from the e.m.f. of equation 57, or

$$I = 0.5\, AB\Bigg(\frac{p-\omega}{(r_1^2+(p-\omega)^2L_1^2)^{\frac{1}{2}}} \times \cos[(p-\omega)t-\theta_1] - \frac{p+\omega}{(r_1^2+(p+\omega)^2L_1^2)^{\frac{1}{2}}} \times \cos[(p+\omega)t-\theta_2]\Bigg). \quad (8)$$

wherein

$$\theta_1 = \cos^{-1}\frac{r_1}{(r_1^2+(p-\omega)^2L_1^2)^{\frac{1}{2}}}$$

and

$$\theta_2 = \cos^{-1}\frac{r_1}{(r_1^2+(p+\omega)^2L_1^2)^{\frac{1}{2}}}.$$

The flux produced by one rotor coil and the main field will so react upon each other that the value of the secondary current, if but a single coil be considered, can only be expressed by an infinite series. It has been experimentally shown, however, that the flux-distorting reactions between primary and secondary do not exist with a rotor winding composed of a number of coils which are divisible into pairs, the members of which are placed at 90 degrees (electrical) to each other. The rotor winding of a commercial machine substantially satisfies this condition; consequently the higher harmonics of the rotor current disappear and the current is correctly represented by equa. given above. This equation indicates that the rotor current consists of two parts having different frequencies and amplitudes.

At standstill, any coil spaced an angle y from the axis of the magnetic field will have a current of the following form:

$$I\,(\text{standstill}) = \frac{ABp\cos(pt+y-\theta_{ss})}{(r_1^2+pL_1^2)^{\frac{1}{2}}}, \quad (9)$$

which shows that the secondary current at standstill is of line frequency. The current component with frequency $(p-\omega)$ decreases in value as the rotor speed rises toward synchronism, being zero at that limit, and the secondary current then becomes

$$I\,(\text{syn}) = \frac{ABp\cos(2\,pt+y-\theta\,\text{syn})}{(r^2+2\,pL_1^2)^{\frac{1}{2}}}, \quad (10)$$

which is of double-line frequency.

These variations of rotor current frequencies as well as the presence of the differential $(p-\omega)$ and additive $(p+\omega)$ components may be conveniently observed by the application of a reed frequency meter. Connect such an instrument across the slip rings of the wound rotor of a polyphase motor, excite the stator with single-phase current and then start the machine. As the speed of the rotor increases the frequency meter will indicate the presence of two currents, one increasing and the other diminishing from the line frequency.

Let us now select a coil on the rotor displaced any angle β from the loop α we have just considered, Fig. 5. The flux through this new coil at *synchronous speed* $(\alpha = \omega t = pt)$ will be, from equa. 6,

$$\Phi = AB \cos pt \sin (pt+\beta),$$

$$= \frac{AB}{2}\left\{\sin(2\,pt+\beta)+\sin\beta\right\}, \qquad (11)$$

$$\text{e.m.f. coil } \beta = e = -\frac{d\Phi}{dt} = -ABp(\cos 2\,pt+\beta), \qquad (12)$$

$$\text{current coil } \beta = i = -\frac{ABp}{\sqrt{r^2+(2pL)^2}} \cos(2\,pt+\beta-\theta), \qquad (13)$$

$$= K_1 \cos(2\,pt+\beta-\theta). \qquad (14)$$

The total magneto-motive force of all the coils on the rotor may be expressed as $K_1 \Sigma i$. The maximum m.m.f. exists in the plane of the coil in which the current is equal to zero, and hence the poles of the rotor will be in the same plane. Let β' be the angle of that particular coil; then

$$i = K_1 \cos(2\,pt+\beta'-\theta).$$

But since i is equal to zero,

$$K_1 \cos(2\,pt+\beta'-\theta) = 0,$$

whence

$$2\,pt+\beta'-\theta = \frac{\pi}{2}$$

and

$$\beta' = \left(\frac{\pi}{2}+\theta\right) - 2\,pt.$$

This means that the angle between the reference coil and the magnetic pole of the rotor changes at the rate of $-2\,pt$. It also indicates that the pole rotates backwards on the rotor. The latter, however, is turning forward at a rate pt, consequently the rotor poles revolve backward in space at a rate pt, and the equation of this pole in space is

$$\beta' = \left(\frac{\pi}{2}+\theta\right) - pt.$$

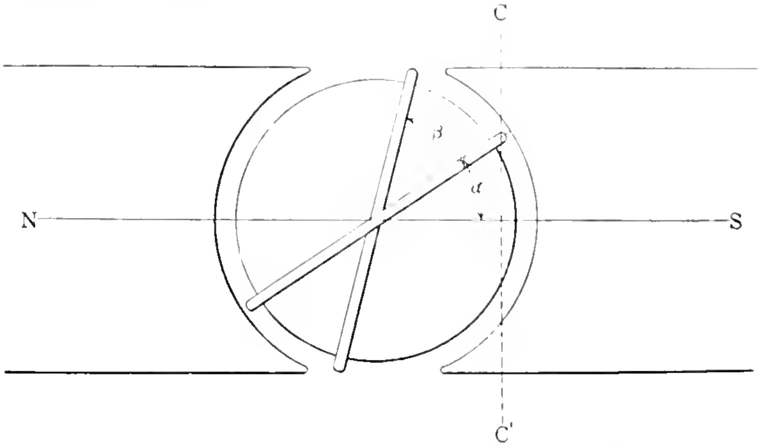


Fig. 5. Coils Inclined to Axis of Oscillating Field

If the equation for the current in the general coil is referred to the magnetic axis instead of to the reference coil, we have

$$i = K_1 \cos\left\{(2\,pt+\beta-\theta)+\left(\frac{\pi}{2}+\theta-2\,pt\right)\right\}$$

$$= K \cos\left(\beta+\frac{\pi}{2}\right).$$

That is, referred to the magnetic axis of the rotor the current distribution is constant; hence the m.m.f. of these currents is constant and rotates backward at synchronous speed, as above proved.

The relative value of the stator and rotor m.m.fs. may be derived as follows: Assume the rotor stationary; this corresponds to considering it as the short-circuited secondary of a transformer. Thus the relations existing between primary and secondary m.m.f's. of a transformer apply or, neglecting resistance and leakage, the secondary m.m.f. is equal and opposite to that of the primary. The current distribution in the bars on the rotor on the basis of the above assumption is expressed by equation (3) as

$$i_a = \frac{ABp}{\sqrt{r^2+p^2L^2}} \sin(pt-\theta)\sin\beta,$$

which upon neglecting r makes $\theta = \frac{\pi}{2}$ and reduces to

$$i_a = -\frac{ABp}{pL} \cos pt \sin\beta;$$

This, if $t=0$, becomes

$$i_0 = -\frac{AB}{L} \sin \beta. \qquad (15)$$

It is to be noticed that when $t=0$, the equation of the rotor currents at synchronous speed equation (13) reduces to

$$i_r = -\frac{ABp}{\sqrt{r^2+(2pL)^2}} \cos(\beta - \theta)$$

which can be still further simplified, if r is negligibly small with respect to pL, to the following form

$$i_r = -\frac{AB}{2L} \sin \beta. \qquad (16)$$

Comparing these values of i_0 and i_r we see that these currents have the same distribution in the rotor, but that amplitude of the latter is only one half that of the former. Consequently, since the m.m.f's. of the stationary rotor and of the stator are equal, the m.m.f. of the synchronously revolving rotor is one-half that of the stator winding.

The magneto-motive force effective in developing the flux $B \cos pt$. *when the two fields coincide*, may be expressed as $Y - X$, wherein Y represents the maximum m.m.f. developed by the stator and X that due to the rotor. But, as above shown, $X = Y \div 2$, hence the excitation necessary to produce the flux $B \cos pt$ throughout the magnetic circuit of the machine is $\frac{Y}{2}$, or X.

The two magneto-motive forces *acting at any instant* in this type of machine are:

$Y \cos pt$, stationary in space,

X, constant in value, but rotating backward at synchronous speed. Since X rotates backwards it may be written $X = X \cos pt - X \sin pt$, and consequently $Y - X$, the total magneto-motive force acting at any instant, becomes

$$Y \cos pt - X \cos pt + X \sin pt = X \cos pt + X \sin pt.$$

This means that *the total m.m.f. acting at any instant is of constant value and rotates forward at synchronous speed.*

The magnetic reluctance of commercial single-phase motors, due to the use of uniformly distributed windings, is practically the same, whatever the axis of the field; consequently the reactions existing between stator and rotor currents produce at or near synchronous speed a circular rotating field, and the formulæ which apply to polyphase motors may be utilized. The effect of leakage and rotor resistance will modify this rotating field somewhat, changing it from circular to elliptical form.

Torque Equations

It has been shown in the derivation of equa. 8 that, when the secondary of a single-phase induction motor is caused to rotate at any rate ω, its current may be expressed as

$$I = \frac{AB}{2}\left(\frac{(p-\omega)}{\sqrt{r_1^2+(p-\omega)^2L_1^2}} \times \cos[(p-\omega)t-\theta_1] - \frac{(p+\omega)}{\sqrt{r_1^2+(p+\omega)^2L_1^2}} \times \cos[(p+\omega)t-\theta_2]\right).$$

Inspection of this equation shows that the rotor current is composed of two parts, one of a lower and the other of a higher frequency than the rotating field. We may consequently consider that this current is set up through the action of two synchronously rotating fields, one revolving in the same direction as the rotor and the other oppositely.* The frequency of the rotor current component, due to the suppositional field revolving in the same direction as the rotor, is naturally less (by the velocity of the rotor) than synchronous value or it is $(p-\omega)$. The component due to the oppositely rotating field has a frequency higher than that of the line, its value being $(p+\omega)$.

The per cent. slip of the rotor with respect to the field first is $\left(\frac{p-\omega}{p}\right)100$, and referred to the second field it is $\left(\frac{p+\omega}{p}\right)100$.

The effective turning effort of the motor is the resultant of the interaction between the rotor current and two oppositely rotating fields. But, since the rotor and one field turn in the same direction, the torque due to this latter field must be greater than that set up by the other. The torque developed by a polyphase induction motor may be expressed by the following equation:

$$T = \frac{X_2^2 e^2 s r_2}{\omega_1 (r_2^2 + s^2 x_2^2)},$$

wherein s is the per cent. slip between rotating field and rotor core; X, inductors in series per phase of the rotor; e, volts per turn; r_2, resistance; x_2, reactance at standstill per motor phase, and $\omega_1 = p$, the angular velocity of the revolving field. We may accordingly

*G. Ferraris. Mem. Reale Accad. di Scienze Torino, Series II, Vol. XLIV, December, 1893. *Electrician*, Vol. 33, pages 110, 129, 152, 184. London, 1894.

write the two component torques existing in the single-phase motor as

$$T_1 = \frac{N_2^2 e^2 s_1 r_2}{\omega_1(r_2^2 + s_1^2\, x_2^2)},$$

$$T_2 = -\frac{N_2^2 e^2 s_2 r_2}{\omega_1(r_2^2 + s_2^2\, x_2^2)}, \text{ wherein}$$

$$s_1 = \frac{p - \omega}{p} = \frac{\omega_1 - \omega}{\omega_1} \text{ and}$$

$$s_2 = \frac{p + \omega}{p} = \frac{\omega_1 + \omega}{\omega_1}.$$

The total effective torque is

$$T = T_1 + T_2 = \frac{N_2^2 e^2 r_2 (s_2 - s_1)(s_1 s_2\, x_2^2 - r_2^2)}{\omega_1(r_2^2 + s_1^2\, x_2^2)\,(r_2^2 + s_2^2\, x_2^2)}, \qquad (17)$$

wherein $s_2 - s_1$ is positive for speeds below synchronism, while $s_1 s_2$ is variable but never greater than unity.

Analysis of this equation brings out the following facts:

1. That the torque of the single-phase machine varies as the square of the impressed voltage, this being the same relation as obtains in polyphase induction motors.

2. That the motor exerts no torque at standstill because $s_2 - s_1$ then equals zero, which fact makes the numerator of the same value.*

3. The motor cannot operate at synchronous speed, because this makes s_1 zero, in which case the torque developed is of negative value ($s_1 s_2\, x_2^2 - p_2^2$ reducing to $-r_2^2$), and the machine tends to act as a generator. Consequently the single-phase induction motor must rotate at less than synchronous speed.

4. The fact that the maximum value of $s_1 s_2$ is unity indicates that the single-phase induction motor cannot operate unless the reactance of its rotor winding at standstill is greater than its resistance. Unless such is the case $s_1 s_2\, x_2^2 - r_2^2$ will have a negative value, which means that the machine would tend to develop a negative torque or act as a generator. Fig. 6 indicates how the speed-torque curves of a single-phase induction motor are affected by change in the value of rotor resistances. Curves *A* and *B* may be considered as representative of standard machines. Curves *C* and *D* indicate the effects produced by inserting relatively large resistances into the rotor winding. It is apparent from these curves that the introduction of resistance into the rotor circuit for purposes of speed regulation is attended by a marked reduction of the overload capacity of the motor, and cannot be used as conveniently or advantageously as with polyphase motors. It is, however, employed to limit the starting current.

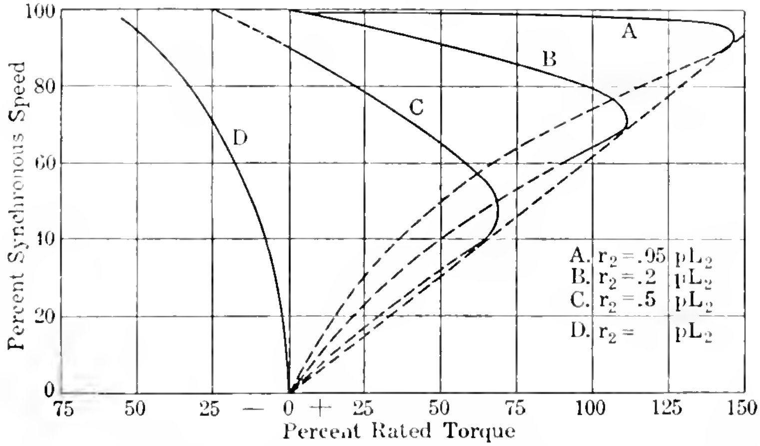


Fig. 6. Speed-Torque Curves of Single-Phase Induction Motor, with Different Values of Rotor Resistance

5. The torque developed by a polyphase motor operated as a single-phase machine is less than that produced when normally connected, because of the presence of the counter torque T_2.

6. If we take the first differential coefficient of equation (17) with respect to r_2 and place it equal to zero, we find that the maximum torque developed for any rotor speed ω exists when

$$r_2 = (x_2 s_1 s_2)^{\frac{3}{2}} \div ((s_1 s_2)^{\frac{1}{2}} + 2),$$

and that the maximum torque

$$T_{max} = N_2^2 e^2 s_1 s_2 (s_2' - s_1') \div \omega_1 r_2. \qquad (18)$$

This equation shows that the torque at any selected speed is greater the less the value of r_2.

* See equations (5) and (6).

(To be continued)

COMMERCIAL ELECTRICAL TESTING

Part VII

By E. F. Collins

ROTARY CONVERTER (Cont'd)

D.C. Circulating Current

Fig. 32 shows the connections for two three-phase converters wired for a pump back heat run without a potential regulator to control the load. The core losses and C^2R losses are supplied from the direct current end. The diagram shows, also, the standard starting panel, which should always be used when two converters are tested together.

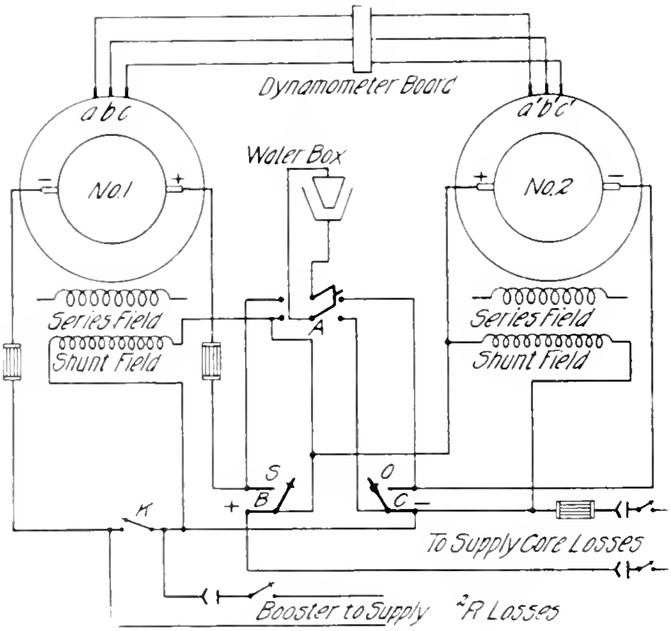


Fig. 32 Connections for Pumping Back Rotary Converters Without the Use of a Regulator

To start the rotaries, for instance No. 1, close the shunt field switch and the switch K, the latter short circuiting the armature of the loss supply. Note that the shunt fields are wired across the core loss supply, which in turn is wired to buses B and C of the starting panel, and that the series fields are left open. Throw switch A to the left and slowly reduce the resistance of the water rheostat until it is practically short circuited, when the switch S may be closed. The blade of the water rheostat is now drawn out of the water and the switch A thrown to the right. Machine No. 2 is then started in a similar manner.

The field strength of each machine is then reduced until both machines run at normal speed. Next connect a number of incandescent lamps in series, the rated voltage of which is equal to the sum of the machine voltages across rings AA; *i.e.*, across switches located on the dynamometer board. Two sets of lamps should be provided, one being connected across one of the switches while the other is stepped across each of the other switches in turn. Should one set show a rise and fall in voltage displaced in time with relation to that of the other, the two phases are reversed and must be corrected. When all phases show a simultaneous rise and fall, the machines may be phased together and their speeds brought to the same value by changing the field on one of them. When the time between rise and fall of voltage, as shown by the lamps, decreases to a period of five seconds or longer, all switches are closed simultaneously and the lamps become dark.

During the period of starting and phasing the machines together, the fields of the booster should be opened and the armature short circuited. When the rotaries are synchronized, the switches across the armatures of the boosters are opened and a weak field applied, the line meter on machine No. 1 being watched. The reading of this meter should reverse from that given on motor load, if machine No. 1 is taking load as a rotary. By reversing the booster field either machine can be made to run as a rotary.

After balancing the current in each phase, full load phase characteristics may be taken by holding the speed constant by means of the field of the inverted machine, and the load constant by means of the booster, the shunt field of the rotary being varied throughout its range and the current input read. Full load voltage ratio should next be taken, after which the heat runs may be made.

A line shunt must be used in each side of the direct current circuit, otherwise one line will have more resistance than the other and the currents flowing through them will have unequal values, the unbalanced current returning through the alternating current ends of the machines. The currents in these lines can be balanced by decreasing the resistance in the low reading line. The direct currents should be balanced before attempting to balance the alternating current.

In running a pump back test there will be a slight difference in the direct current voltages of the two machines, equal to the CR drop of the set. The field of the inverted machine will be less than that required for minimum input and will carry the additional current necessary for supplying the core losses.

This method of supplying the C^2R losses from a booster requires such a large low voltage booster that it is not often used, except for small rotaries.

With a Booster in the A.C. Side

A second method of pumping back rotaries on full load heat runs is to use an induction voltage regulator in the alternating current side of the machines, as shown in Figs. 33 and 34. The regulator is connected with its secondaries in series with the alternating current lines and its primaries across the alternating current terminals of the inverted machine. It is always preferable to connect the regulator between the inverted rotary and the dynamometer board. The regulator takes the place of the booster used in the previous method, and is very satisfactory for supplying the C^2R losses.

Starting the machines, checking the phase rotation, phasing in, and other operations already described, are repeated with this method. Always see that the regulator is set at the no boost point before phasing in, otherwise load will be thrown on when the switches are closed.

Load is increased by turning the core of the regulator in the direction of boost, the ammeter of machine No. 1 being watched at the same time. If the reading reverses from motor load, then No. 1 is running as a rotary; if, however, No. 1 does not reverse, the regulator should be turned in the opposite direction. This shows that the regulator is wrongly connected in reference to its markings; there is no necessity, however, to change connections.

Using A.C. Loss Suppy

If, instead of supplying the losses from a direct current source of power, an alternator is connected across the alternating current lines, between the inverted rotary and the

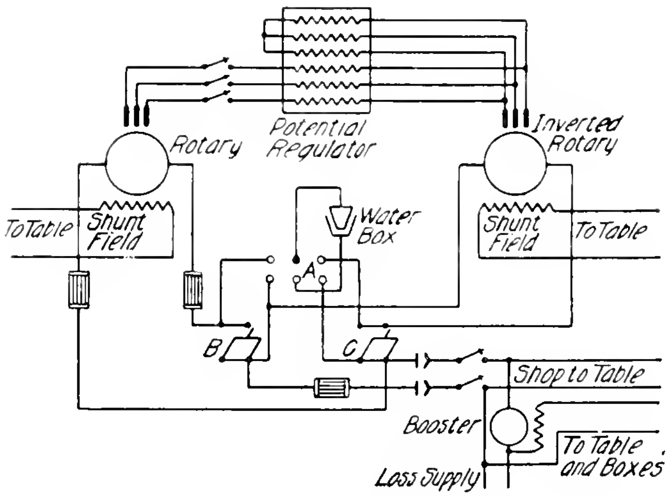


Fig. 33. Connections for Pumping Back Rotary Converters with Regulator

regulator as in the preceding method, the losses can be supplied at the alternating current end. When the alternator is large enough to start the rotaries, the wiring on the direct current end is greatly simplified. The starting panel is omitted and the shunt fields are connected according to the print of connections for the machine. Load is obtained by means of the regulator as before and the test carried out as already described.

If the alternator is too small to start the machines, the latter may be started singly from the direct current side as before, and the two phased together. The alternator is then synchronized with the pair. If only one machine can be started by the alternator, bring it up to speed, open all its circuits, and let it run by its own momentum while the second machine is quickly started. The excitation is then removed from the alternator field and the switches on the first machine are closed. Excite the alternator field and bring both machines up to speed together. After the machines are once started, they can be brought up to speed without an excessive current from the alternator.

Alternating Current Generators

Complete Tests consisting of special tests and temperature tests.

Special tests include saturation and synchronous impedance, and from these the regulation of the machine is calculated as follows:

Let V = normal voltage line, C = amperes line, R = hot resistance between lines.

For three-phase machines $C = \frac{\text{Kw.}}{\text{Voltage} \sqrt{3}}$

For two-phase machines $C = \frac{\text{Kw.}}{2\ \text{Voltage}}$

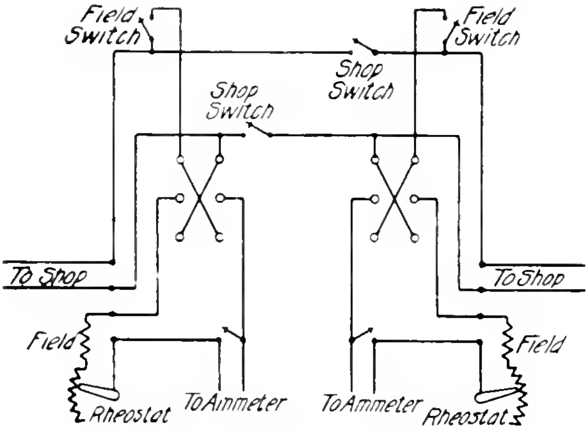


Fig. 34 Table Connections for Rotary Converter Pump Back

For three-phase machines, voltage drop in armature, $C_1 R_1 = \frac{\sqrt{3}\, CR}{2}$

For two-phase machines $C_1 R_1 = CR$.

Let a_1 = amperes field on saturation curve corresponding to $V + C_1 R_1$ and a_2 = amperes field on the synchronous impedance curve corresponding to C.

The amperes field required to produce normal rated voltage with full load on the generator will be $a_3 = \sqrt{a_1^2 + a_2^2}$.

Let the voltage on the saturation curve corresponding to $a_3 = V_1$.

Then the per cent. regulation $= \frac{V_1 - V}{V}$

If it is desired to calculate the regulation of the machine at any power factor, then C becomes $\frac{C}{\%\ P.F.}$ and $a_3 = \sqrt{a_1^2 + a_2^2 + 2a_1 a_2 \sin \theta}$

when θ is the angle of which the per cent. power factor is the cosine.

Input-output efficiency test is made by the input-output method.

Standard efficiency test is made by the method of losses.

The calculation of a standard efficiency test is made as follows:

Let V_L = volts line

W_b = output $= \sqrt{3}\, V_L\, C_L$ for three-phase and $2\, V_L\, C_L$ for two-phase

C_L = amperes line R_1 = hot res. of armature between lines

C_1 = amperes field

R_2 = hot res. of field

W_1 = open circuit core loss corresponding to $V_L + CR$ on the core loss curve

W_2 = short circuit core loss corresponding to C_L on the short circuit loss curve

W_3 = friction and windage obtained from core loss test

C_1 is calculated for each load, as in the test for regulation.

CR = the drop in the armature $= \sqrt{\tfrac{3}{2}}\, C_L\, R_1$ for three-phase machines and $C_L\, R_1$ for two-phase.

$\Sigma W = W_1 + \tfrac{1}{3}\, W_2 + W_3 + \tfrac{3}{2}\, C_L\, R_1 + C_1^2\, R_2$ for three-phase machines

$= W_1 + \tfrac{1}{3}\, W_2 + W_3 + 2\, C_L^2 R_1 + C_1^2 R_2$ for two-phase machines

Watts input $= W_a = W_b + \Sigma W$

Efficiency $= \frac{W_b}{W_a}$

W_3 need not be considered if the machine is furnished without base, shaft or bearings.

The above method of calculation is used when the machine is to operate at unity power factor.

If it is desired to calculate the efficiency at any power factor, the following calculations must be made.

$C_L = \frac{\text{Kw.}}{V_L \times \sqrt{3} \times \%\ \text{P.F.}}$ and

$W_b = \sqrt{3} \times V_L \times C_L \times \%\ \text{P.F.}$ for three-phase machines.

$C_L = \frac{\text{Kw.}}{V_L \times 2 \times \%\ \text{P.F.}}$ and

$W_b = 2\, V_L \times C_L \times \%\ \text{P.F.}$ for two-phase machines.

C_1 should be calculated for various power factors as given under regulation.

The change in the line current will affect C_1, W_1, W_2, and the C^2R of the armature. See Fig. 35 and Table XIII.

Non-inductive normal load heat runs consist in running the machine under normal load at unity power factor until constant temperatures are reached. These final temperatures are then recorded and readings taken of regulation with unity power factor.

Non-inductive overload heat runs consist in bringing the machine to normal load temperatures, applying the overload at unity power factor for the specified time, and recording the overload temperatures. Readings for regulation at unity power factor should be taken.

Normal load and overload power factor heat runs are made in the same way as normal and overload non-inductive runs, except that the machine is operated at a specified power factor. Wattmeters should be used with the voltmeter and ammeters to determine the power factor.

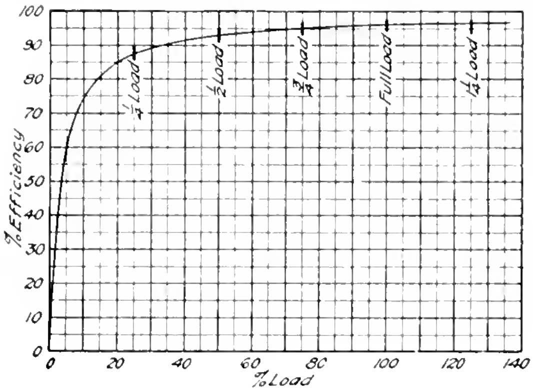
SYNCHRONOUS MOTORS

The preliminary tests taken on synchronous motors consist of drop on spools, air gap, resistance measurement, balancing of phase voltages, phase rotation and running free minimum output.

Complete tests consist of special tests and normal and overload heat runs.

Special tests consist of starting tests, open and short circuited core loss, saturation, synchronous impedance, no load and full load phase characteristics, and wave form. The method of taking phase characteristics has previously been described.

Starting tests should be made both with and without a compensator, if the motor is of a new type and rating and is to be started with a compensator when installed. If the motor does not form part of a motor-generator set, it should be belted to a generator so that it will have some load at starting.



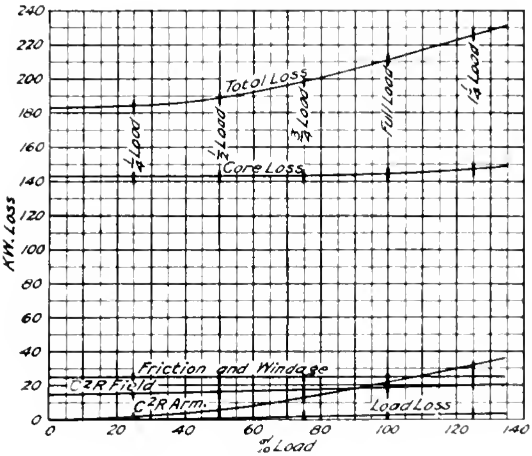


Fig. 35. Efficiency and Losses on a 5000 Kw., 11000 Volt, 3-Phase A.C. Generator

TABLE XIII—Eff. and Losses of a 5000 Kw., 11000 V., 28-Pole, 60-Cycle, 3-Phase Generator

% Load	0	25	50	75	100	125
Volts Line	11000	11600	11000	11000	11000	11000
Amps. Line	0	65.5	131	196.5	262	317
Amps. Fld.	220	224	228	235	245	257
CR		12	24	36	48	50
V+CR	11000	11012	11024	11036	11048	11050
Core Loss	143000	143000	143100	143600	144100	147000
1/3 Short Cir. Core Loss	—	—	200	580	1300	2500
C^2R Arm.	0	1330	5320	12000	21300	31100
C^2R Fld.	14500	15000	15600	16600	18000	19800
Friction	25000	25000	25000	25000	25000	25000
Total Losses	182500	184330	189220	197700	209700	225400
Kw. Output	0	1250	2500	3750	5000	6250
Kw. Input	182.5	1434	2689	3948	5210	6475
% Efficiency	0	87.3	93.0	95.0	96.0	96.5

Res. Arm. (Line) .1927 Ohms 25° C. .207 Ohms Hot.
Res. Fld. .2795 Ohms 25° C. .3005 Ohms Hot.

The motor should first be tested for starting without the compensator. The center line of one pole is placed in line with the center line of the frame and 180 electrical degrees

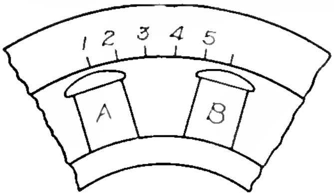


Fig. 36

marked off in a clockwise direction from this line on the head end of the motor. The total length of this scale should be two-thirds of the distance between the center lines of adjacent poles for three-phase machines, one-half for two-phase machines, and one-third for six-phase machines. The scale should be divided into four equal parts, each division line being numbered. On each one of these scale divisions, the center line of the marked pole should be placed and the motor started. Thus five tests are made to insure that the motor will not stick in any position. See Fig. 36.

With the pole A moved to position No. 1 and the machine at rest, sufficient current should be sent through the armature to give a reasonable reading of amperes and volts on the various phases, and induced volts on the field. The induced volts field should be read by a potential transformer and alternating current voltmeter. These readings are taken to determine which phase gives maximum readings of current and voltage.

The voltmeter and ammeter should be placed in this phase and the armature current increased until the motor starts. Volts armature, amperes armature and induced volts field should be simultaneously read. The starting voltage is now held constant until the motor comes to synchronism, and the time required to reach this point recorded. The machine attains synchronism when the induced volts on the field fall to zero. The machine is then shut down and the tests are repeated for each of the other positions.

If a motor shows a tendency to remain at half speed, the alternating current voltage should be increased until the motor breaks from half speed and comes up to synchronism, the voltage required to accomplish this being held until full speed is reached and then recorded.

If the test is required to be made with a compensator, the motor should be set with its field in the position where greatest starting current is taken and allowed to rest in that position for at least six hours until the oil is well pressed out of the bearings. This is done in order to obtain the worst starting conditions likely to occur in normal operation. Connections are then made to the lowest tap of the compensator, and with normal voltage held on the line the starting switch of the compensator is closed. If the motor fails to start, the voltage must at once be switched off and connections made with the next higher taps on the compensator, and so on until the motor starts. Readings should be taken on each of the taps of the compensator in the starting position, with the machine

TABLE XIV Starting Test on a 425 Kw., 11000 V., 8-Pole, 25-Cycle, 3-Phase Syn. Motor

	Volts Line			Amp. Line			Ind. Volts per Spool	Pos. at Start	Time to Syn.
	1-2	2-3	1-3	1	2	3			
Rest	1340	1430	1480	15	17.5	15.2	52	1	
Start			2650		35		90.7		
Syn.	2650	2650	2650	9.2	9	8.9			66 Sec.
Rest	1255	1340	1340	15	16	13.6	47	2	
Start		2560			30		88.3		
Syn.	2560	2560	2560	9.5	9.3	9.2			70 Sec.
Rest	1155	1300	1320	15	14	12.7	45	3	
Start			2380	29.5			84.7		
Syn.	2380	2380	2380	10	10.2	10			70 Sec.
Rest	1248	1260	1165	15	12.8	13.8	44	4	
Start		2590		33			80.8		68 Sec.
Syn.	2590	2590	2590	9	9.3	9.5			
Rest	1400	1308	1302	15	13.9	16.2	49	5	
Start	2620					32	87		
Syn.	2620	2620	2620	8.9	9.1	9.3			64 Sec.

Is there any tendency to stick at half speed? No.

at rest, to determine the voltage ratio of the taps of the compensator. All these tests should be made with the field circuit of the motor open, and enough time allowed between trials to permit the compensator to cool, since it is designed for intermittent service only. Table XIV.

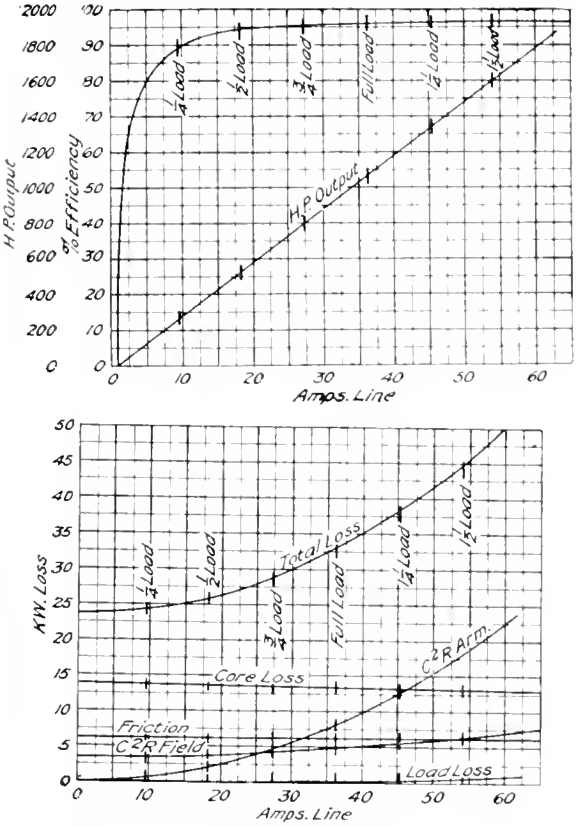


Fig. 37. Efficiency and Losses on a 1070 H P., 13200 Volt, 3-Phase Synchronous Motor

Input-output efficiency test is made by the input-output method.

Standard efficiency tests are made by the method of losses. In calculating efficiency, the same nomenclature is used as that employed for alternating current generators. C_1 is either taken from the phase characteristics or is calculated in the same manner as for alternating current generators.

Watts input $W_a = V_L C_L + C_f^2 R_2$.

Watts output $= W_b = W_a - \Sigma W$.

$$\text{Efficiency} = \frac{W_b}{W_a}$$

W = open circuit core loss corresponding to $V_L - CR$ on the core loss curve.

$$\text{Horse-power output} = \frac{W}{746}$$

See Table XV and Fig. 37.

The non-inductive load heat run is made as follows: Run the machine under load at unity power factor until it has reached constant temperature and record temperatures. Take readings of regulation at normal and no load and full load phase characteristics.

The non-inductive overload heat run consists in bringing the machine to normal load temperature, applying the overload for the specified time, recording temperatures and taking readings of regulation at unity power factor.

Normal load power factor heat run is similar to the normal load non-inductive run, except that the machine is operated at a specified power factor. Wattmeters should be used as described for alternating current generators.

Overload power factor heat run is similar to the overload non-inductive run, except that the power factor is less than unity.

(To be Continued)

TABLE XV Eff. and Losses of a 1070 H.P., 13200 V., 6-Pole, 25-Cycle, 3-Phase Syn. Motor

% Load	0	25	50	75	100	125	150
Volts Line	13200	13200	13200	13200	13200	13200	13200
Amps. Line		9.5	19.0	28.5	38.0	47.5	57
Amps. Fld.	50.1	50.6	51.0	55.1	59.7	63.8	68.9
CR		34.5	69.0	103	168	172	205
(V−CR)	13200	13165	13131	13097	13032	13028	12995
Core Loss	13900	13800	13700	13600	13500	13400	13300
⅓ Short Cir. Core Lo.		47	107	190	310	473	760
C²R Arm.		565	2265	5100	9040	14100	20400
C²R Fld.	3550	3630	3680	4300	5050	5770	6740
Friction	6272	6272	6272	6272	6272	6272	6272
Total Losses	23722	24314	26024	29462	34172	40015	47442
Kw. Input	23.72	220.63	436.68	651.3	870.05	1089.8	1306.7
Kw. Output	0	196.32	410.66	624.8	835.9	1049.8	1259.3
H.P. Output	0	263.2	550	837	1121	1408	1689
% Efficiency	0	89.0	94.4	95.5	96.4	96.3	96.4

Res. Arm. (Line) 3.86 Ohms 25° C. 4.18 Ohms Hot 47. Res. Fld. 1.34 Ohms 25° C. 1.42 Ohms Hot 40

A MOTOR OPERATED BILLET MILL.

By B. E. Semple

The Indiana Steel Company, Gary, Indiana, started its billet mill in August, 1909. This was the second of the several large motor-

Fig. 1 Last Two Stands of 40 in. Blooming Mill Shown in Foreground; Five Stands of 32 in. Blooming Mill in Background

operated mills installed by this company for the manufacture of steel, that was put into regular operation.

The principal work in this mill is accomplished by five 25 cycle, 3 phase, slip ring type induction motors, the ratings of which are as follows:

2 motors, 14 poles, 2000 h.p., 214 r.p.m., 6600 volts.

3 motors, 36 poles, 6000 h.p., 83 r.p.m., 6600 volts.

These motors are designed to carry full rated load continuously, with a temperature rise not in excess of 40 degrees C.; 25 per cent. overload continuously, with a temperature rise of not more than 50 degrees C.; and 50 per cent. overload for one hour, with a temperature rise not in excess of 60 degrees C.

Like the rail mill motors described in the Review for Feb., 1910, they were purposely designed for heavy rolling mill duty, their proportions being extremely liberal. The entire five motors represent a total weight of 1518 tons, and will carry $3\frac{1}{2}$ times their rated load before dropping out of step.

The method of connecting the motors to the rolls in this mill differs considerably from that employed in the rail mill, except in the case of the two 2000 h.p. motors, which differ only in that the gearing is located in the motor room instead of in the mill proper.

The illustration on page 194 shows the east half of the south motor room, the two motors in the distance being the 2000 h.p. machines which drive the 40 in. blooming rolls. The motor in the foreground is a 6000 h.p. machine, and drives the five stands of 32 in. blooming rolls, each of which is connected to the motor driven shaft through bevel gears.

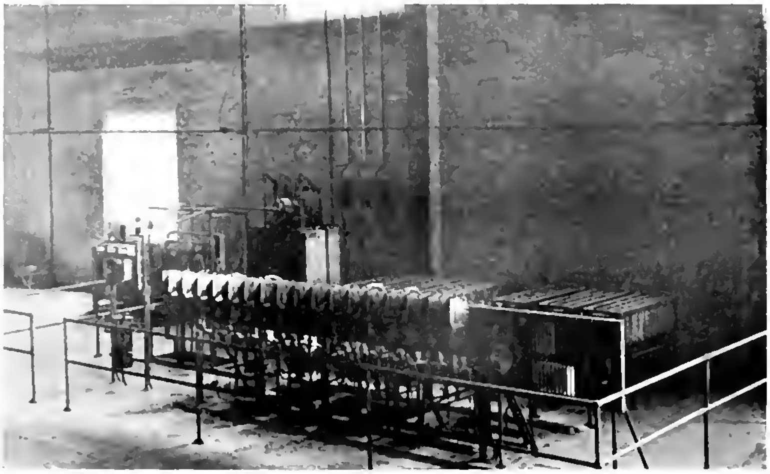


Fig. 2. Primary and Secondary Control for 6000 H.P. Motor

Fig. 1 is a view on the other side of the wall, showing in the left foreground the last two stands of the 40 in. mill, and in the background all five stands of the 32 in. mill; the former driven by the 2000 h.p. motors and the latter by the 6000 h.p. motor.

The west half of the motor room contains another of the three 6000 h.p. motors. This motor operates the 24 in. mill, consisting of six stands of rolls, each connected to the motor driven shaft through bevel gears, and drives from one end only, instead of from both ends, as in the case of the first mentioned 6000 h.p. motor.

Fig. 2 shows the primary and secondary control for the last named motor, the 6600 volt motor-operated primary switch being located in the rear and to the left, and the secondary contactor panel in the front, with the secondary resistance directly behind it. The master controller is located to the left and in front, directly beneath the panel containing the instruments.

In this mill the motors are started and stopped by the motor attendant rather than by the mill operators in the mill proper.

Fig. 3 is a view of the 18 in. mill, comprising five stands of rolls and driven by the third 6000 h.p. motor, shown in Fig. 4. The motor is located in the north motor room, and the connections to the rolls are made through bevel gears, as in the cases of the other 6000 h.p. motors.

Fig. 4 6000 H P Three-Phase Induction Motor

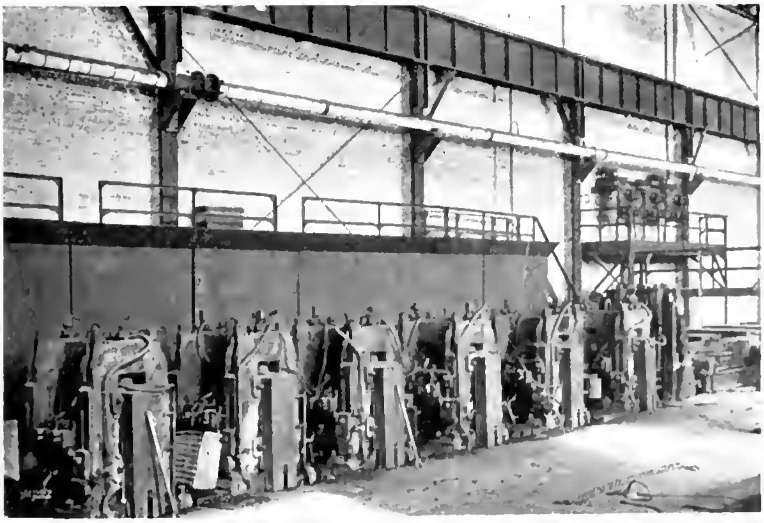


Fig. 3. 18 in. Blooming Mill Operated by 6000 H P Induction Motor

Each of the five motors is equipped with a heavy fly wheel to assist in smoothing out the peaks that would be demanded by the motors from the generating station if the fly wheels were not used. The wheels on the two 2000 h.p. motors are external, as seen in Fig. 6, while in the case of the three 6000 h.p. motors, the additional weight necessary to obtain the desired fly wheel effect is added directly onto the rotor. The fly wheel effect of the 6000 h.p. rotor is equal to 10,330,000 pounds, and that of the 2000 h.p. rotors, 1,720,000 pounds, at a one foot radius.

The 2000 h.p. motors were assembled and tested at the works of the General Electric Company before shipment, and the fly wheels, which are laminated, were assembled at the point of installation. The 6000 h.p. motors were entirely too large to ship, even partially assembled, and consequently were completely assembled at the Gary plant by experts sent from the Company's works.

All of the motors have water-jacketed bearings, those for the 6000 h.p. being 30 in. in diameter and 70 in. long and those for the 2000 h.p., 24 in. in diameter and 60 in. long. However, water is not used on the bearings excepting in instances of heating to such an extent as to demand it; owing, for instance, to the failure of the oiling system.

This mill was designed to roll 4000 tons in twenty-four hours and is the largest straightaway billet mill in existence; it is strictly modern in every detail and its operation throughout has been entirely successful.

The rolling cycle begins with the receipt upon the approach table to the first pass, of an 8000 pound ingot from the reheating furnaces, measuring 20 ft. by 24 ins. sq. section. Twenty-one passes are made in reducing this ingot to either a 2 in. by 2 in., or a $1\frac{3}{4}$ in. by $1\frac{3}{4}$ in. billet.

The first four passes are made in the 40 in. mill, driven by the two 2000 h.p. motors; the next five in the 32 in. mill, driven by a 6000 h.p. motor; the next six in the 24 in. mill, driven by a 6000 h.p. motor; and the final six in the 18 in. mill, also driven by a 6000 h.p. motor.

The apparatus for controlling the five large motors in this mill is almost identical to that employed in the rail mill. Reversing switches are provided in order that the motors may be reversed if necessary, and provision has been made to introduce a predetermined amount of resistance into the secondary circuit to increase the slip and thus allow the fly wheel to share the load with the motor.

The feeder circuits entering this mill are protected against lightning and surges by aluminum cell arresters.

THE ELEMENTS OF TRANSFORMER CONSTRUCTION

Part II

By W. A. Hall

As already mentioned, the prime consideration in the lighting transformer is insulation, particularly between primary and secondary. The material used at this point consists principally of a heavy layer of built-up mica, augmented by high grade material carrying varnished film, which is one of the best insulators. There is thus afforded a certain protection, not only under normal conditions, but also under those of severe overload, short circuit, or external fire, which may completely disintegrate the internal transformer before the windings come together and thus allow the high potential of the primary to pass to the secondary line, with possibly serious consequences. While the transformers are designed for operation at 2400 volts or less, they are regularly tested by the manufacturer, between primary and secondary, at not less than ten thousand volts, the average breakdown strength being probably more than double that amount. The other insulation between turns, layers, sections and coils are generally fibrous, untreated materials, particularly adapted to receive and retain the oil-proof insulating compound which is applied by high pressure to the coils after they have been subjected to vacuum and which permeates the innermost fibres and interstices, forming a compact structure. This serves to preserve, protect, insulate and conduct away the heat generated within during operation. The otherwise spongy mass of wire and insulation is thus also made capable of resisting the mechanical stresses. Fig. 11 shows a group of transformers finished and ready for test. An interesting comparison with the design of a quarter of a century may be had by referring to Fig. 10, which shows one of the first commercial transformers made in this country.

Next in importance are durability, reliability and longevity, to insure continuity of service and low rate of depreciation. These features demand superior insulation and mechanical construction and moderate temperatures, the latter with particular reference to an even distribution thereof. It is now common practice to make the case tight and fill it with a specially prepared oil, completely submerging the transformer. In operation, the heat starts a natural circulation upward

Fig 10. Transformer of Quarter Century Ago

Errata: April Review, page 182, 2d column, ... should read Figs. 3, 4 and 5, page 183, 2d column, 5th line from bottom, should read Fig. 4

in the center, from the warm transformer outward to the sides of the case at the top, and thence by contact with the cooler sides of the case downward to the bottom, when it is cooled ready for return through the transformer. In addition to its cooling properties, the oil possesses a very high insulating quality, and in consideration is practically indispensable.

Small masses of coil must be opened by ventilating channels which will direct the oil to their innermost parts in the course of its circulation; while the larger masses must be subdivided into several coils interspersed by generous channels which will give the cooling medium access to parts alike, thus maintaining uniform low temperatures.

The primary wires of small transformers, which are of very small cross-section, are round, all other conductors being of rectangular section. The latter improve the space factor and afford ample bearing surfaces to resist crushing of insulation through mechanical stresses, and operate in conjunction with the coil filler to produce a solidity of coil of even temperature to prevent unequal expansion and contraction. These precautions, well executed, insure reliability and long service.

Closely following these qualities in importance comes efficiency. A consideration of this factor must take account of a somewhat unusual condition, which may be summed up as follows: These transformers are built in sixteen standard sizes ranging from 6/10 kw. to 50 kw., the average of all transformers built being about 7½, although as is evident, sizes smaller than this predominate in number. These small units are installed on lighting circuits in vast numbers, and their use is at present increasing at the rate of more than 50,000 per annum. These circuits are excited continuously night and day at normal voltage, and since the core loss of the transformer is dependent only upon the voltage of the system, it is constant for all loads on the transformer, including no load. The copper loss varies as the square of the load, and for ordinary service is considered to be about equivalent to that corresponding to full load for three hours, for each day. From this fact alone, the ratio of these two losses in a well-designed transformer might be expected to be one to eight. In operation, however, the cost of supplying the energy for the two purposes is not equal. The core loss is maintained largely during hours of light load, when plant efficiency is at a minimum. On the other hand, the copper loss is largely carried at a time when the station is operating at highest efficiency, but when it is frequently taxed to supply the demand for power, and the loss then becomes a limitation on the output. It would be difficult to fix the exact cost of supplying this waste energy, but the

Fig. 11. Group of Small Transformers Completed and Ready for Test

mean of a number of values obtained from many of the large stations places it at 1 cent per kilowatt hour for core loss and 1 cents per kilowatt hour for copper loss; whence, in consideration of the time during which each is maintained, the relative costs are as 2:1.

In designing the transformer, other factors enter to distort this relation. With existing materials, cost of labor and present practice, it costs more, generally speaking, to produce a transformer with low core loss than one with low copper loss. Coincident with high core loss is likely to be high magnetizing current, which is detrimental to satisfactory operation. Opposed to this, however, is the fact that the regulation—another measure of merit—varies substantially in direct proportion to the copper loss and should be kept low. Likewise, the temperature during operation depends primarily upon the copper loss and demands a small value. Core loss also affects temperatures somewhat, although to a less degree than the copper loss, owing to more ready means of dissipation.

A compromise between these many dependent variables of manufacture and operation, as well as cost of depreciation, interest on investment, and other fixed charges, has resulted in a design which gives substantially equal losses in the smallest sizes, and in the largest sizes a copper loss twice that of the core loss; the losses of the intermediate sizes having a relation varying along a smooth curve between these extremes. The full load efficiencies vary from 95 per cent. on the smallest to 98.5 per cent. on the largest sizes, disclosing the fact that these small pieces of apparatus, without moving parts, transform energy at a very high efficiency.

A multiple transformer must not only operate continuously with good efficiency, but at the same time must maintain a constant potential on the secondary lines at all loads within rating. In other words, its regulation (defined as the per cent. of secondary voltage variation from no load to full load) must be very low. The principal factor affecting regulation is the voltage loss caused by the ohmic resistance of the copper, commonly termed the IR drop. In fact, the other principal component, reactive drop, need not be considered in approximations, except under special conditions of load involving low power factors. Since the IR drop bears the same relation to the normal voltage that the copper loss does to the transformer capacity, the regulation of a transformer may be estimated with a fair degree of accuracy by dividing the copper loss by the capacity of the transformer, both expressed in the same units. The actual regulation can never be better than this; in fact, it will be usually about 5 per cent. higher.

Fig. 12. General View of Winding and Clamping Pancake Coils for Large Shell Type Transformers

Now the evolution from this lighting transformer to others in this group consists merely in magnitude of figures and the accentuation of certain characteristics, due to either the physical proportions or a change in the demands of service for which it is intended. The same fundamental factors enter into the design and construction of each, although their relative importance is modified. For example, the output of transformers is approximately proportional to their weights, or masses; the losses, therefore, are also proportional to this factor. The only means of dissipating these losses, however, is in form of heat, through the surfaces of the transformers. That is, the losses or heat units to be dissipated increase as the cube of the linear dimension, whereas the surfaces increase only as the square. Obviously, then, if the same temperature of operation is to be maintained, a different means to the accomplishment of that end must be introduced as the unit grows larger. Here, then, is one characteristic which, while negligible in a 6-10 kw. transformer, requires a few oil channels, then more, and finally artificial cooling in the form of air-blast, forced oil circulation, or water-cooling coils immersed in oil, as the size of the unit increases.

In like manner the mechanical strain, which is always exerted in a transformer as the resultant of the magnetic forces, and which tends to tear asunder turns, coils and cores, is quite insignificant in the small transformer protected by its relatively large surface and compact form; but in the large power transformers, this item demands most careful consideration from the designer. Think for a moment of the possibilities for damage when 10,000 kw.—approximately 13,500 h.p.—is suddenly short circuited on a transformer, and it will not be surprising to know that solid coils well constructed and carefully supported on extensive bearing surfaces crush under the enormous pressure developed.

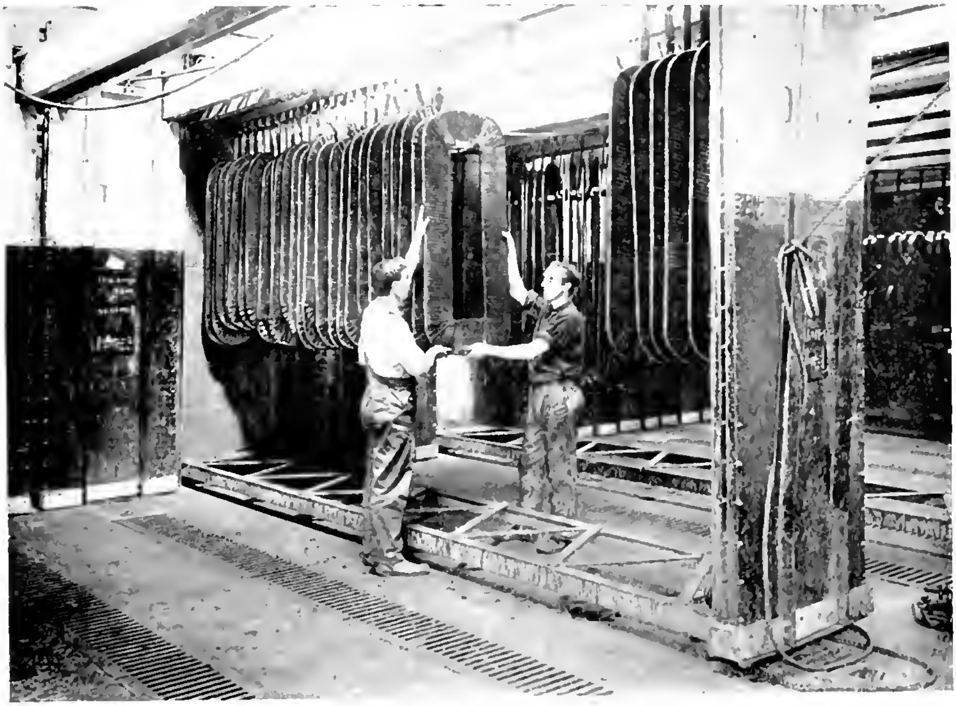


Fig. 13. Removing Shell Type Coils from the Baking Oven in Insulation Department

Efficiency and regulation, so important in the small lighting transformer, become of relatively minor importance. This class of apparatus operates continuously upon transmission lines, the load upon which varies far less than that upon the small lighting transformer, or one operating a small motor load. The regulation drop extends over such a comparatively narrow range that it can be largely corrected by taps in the winding, by means of which the ratio of transformation can be changed.

Again, the position of these large units on long transmission lines, which are subject to sudden excessive rises of potential from either lightning or line disturbances, makes it necessary to strengthen the ends of the windings by supplementary insulation of a very high value; while rushes of current from short circuits must be minimized by an amount of reactance in the design consistent with the best interests of all considerations.

All these requirements, for reasons already cited, have led to the almost universal adoption of the shell type for such service. The air-blast and water-cooled types are constructed much the same fundamentally, although they differ materially in details and external appearance. The coils, both primary and secondary, are wound in the so-called pancake type (Fig. 12); *i.e.*, they employ flat rectangular wire and are wound one turn per layer, in many layers, forming a spiral, the insulation between turns consisting of paper, mica or varnished cambric, or all three together, as conditions demand.

These thin coils are treated with coil filler and wound with a number of layers of tape, depending upon the voltage for which they are designed, each layer being given several coats of insulating varnish, baked on (Fig. 13). These coils are then assembled into groups (Fig. 14) and the groups into complete windings, the primary and secondary being intermixed and the whole interspersed by suitable barriers of insulating collars. The various groups are effectively encased in a box-like structure which, while serving as an electrical and mechanical protection, is so arranged that it will not obstruct the oil channels which are found adjacent to every coil.

These windings are then set up vertically in the bottom frame and the magnetic circuit built around them in the form of rectangular sheets of steel (Fig. 15). The top frame is next added and securely clamped to the bottom, compressing and securing the core. After connection board, leads, etc., are added, the transformer is ready for its casing. If of an air-blast design, the casing is arranged to form a blower, receiving air at its base through a conduit in the floor. The circulation is through channels about the coils and iron, the air gaining access to all parts and conveying heat out through the discharge at top of casing.

If the transformer is designed for water-cooling, it is hung to a heavy cast-iron cover or cap fitting on a tank of boiler steel, and a coil of water pipe placed around it near the top. The whole is then lowered into position in the tank. In operation, these water coils, which are located in the upper or warmer strata of oil, cool the oil so that it falls along

Fig. 14. Assembling Coils for Large Shell Type Transformers

the outside, near the walls of the tank, aiding the natural circulation to the extent that all parts are kept at a substantially uniform temperature.

The air-blast type is used for moderate voltages where cooling water is expensive or unavailable, and has been built for voltages up to 35,000, in sizes up to 5000 kw. The water-cooled type, which is better adapted for high potentials by reason of its superior facilities for insulation afforded by oil immersion, has been constructed for voltages up to 140,000 and capacities up to 10,000 kw. The general construction of this interesting class of apparatus is shown in Fig. 16.

Between these two divisions of the multiple transformers, falls a class of moderate capacity and wide range in voltage. This class demands many turns of small wire and generally follows the core type in design. The units of this class are nearly always installed in buildings or sub-stations where power is generated or received and transformed for testing, for mill work, or for supplying rotary converters for

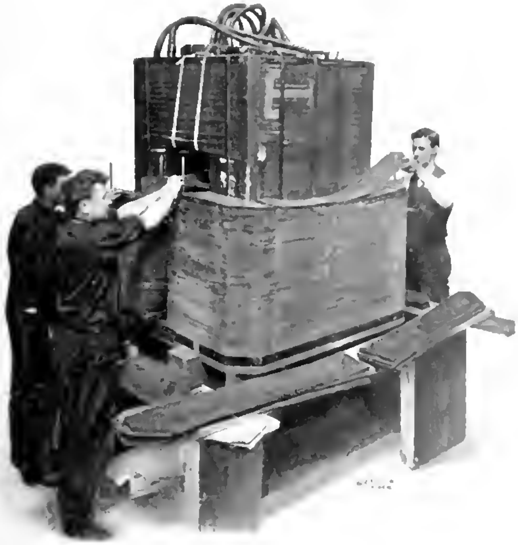


Fig. 15. Building Up the Core of a Large Shell Type Transformer

railway work They differ from the lighting transformer only in that, because of capacity and voltage, they require a greater subdivision of coils, the proper supporting of which demands a more complicated mechanical structure. Fig. 17 shows a representative type of this division.

This class of multiple transformers is completed by a multiplicity of miscellaneous styles to which this paper can only briefly refer, such as sign-lighting, individual incandescent lamp, telephone line insulating, bell-

Fig. 16. Transparent View of 2000 Kw. Water Cooled Transformer

ringing, wireless telegraph, signal, instrument or switchboard, and railway transformers. The wireless and signal transformers are examples of designs employing active elements other than steel and copper; the former, intended for very high frequencies, substituting air for steel in the core, while the latter, for certain reasons, is wound with high resistance wire.

The prime function of the multiple transformers so far described, is to transform electrical energy at a fixed ratio of voltages; and that of the series transformer now to be considered is to make the transformation at a fixed ratio of currents. These two classes, as a matter of fact, perform both of these functions simultaneously, the essential difference being that the relative importance of certain characteristics differs in the two cases. For example, in the multiple transformer, any loss of current in magnetizing the core is important only so far as it affects the voltage regulation or the power factor of the circuit upon which it operates. On the other hand, a considerable loss of this nature in a series transformer is prohibitive. Conversely, the voltage loss in a series transformer is of importance only so far as it affects the current regulation, while in the multiple transformer, it is of the greatest moment.

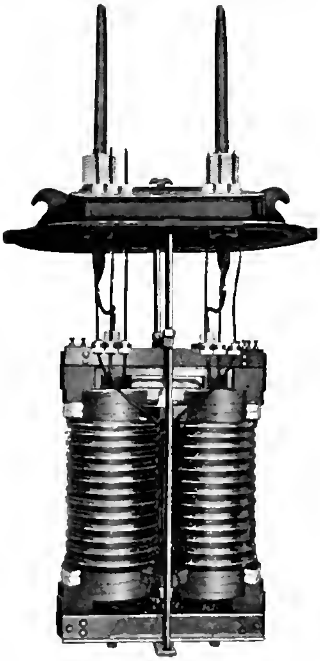


Fig. 17. High Voltage Core Type Transformer for Power and Testing Purposes

By far the most common form of the series class of apparatus is that generally styled "current transformers." These transformers are mounted on the framework of switchboards and introduced into a main bus or feeder as a multiplier and insulator for the instruments that measure the current or power in the feeder, or to operate the protective devices which open the switches in emergencies. Their use with meters measuring large amounts of power delivered to a distributing company or large consumer immediately suggests the necessity of a refinement in accuracy, not required or attainable in the ordinary transformer.

They are called upon to deliver but a fraction of a horse-power; yet, controlling the protective devices, they are by far the most important elements in the structure, assuming a prominence out of all proportion to size or cost. The ratio of test to operating voltage is, on this account, generally three instead of two as in other transformers. Considering the remarks made in the early part of this paper concerning space factor and its effect upon efficiency, it may be rightly inferred that the additional insulation necessary imposes a serious obstacle to accuracy, especially in those transformers that have been built for circuits of 110,000 volts. Fig. 18, which shows a transformer constructed for this voltage, is impressive when the 40 watt output is contrasted with the total height of about 9 feet.

Up to the present time, the best transformers of this class have been made on either a ring core without joints, or of a shell-type design, with joints in the magnetic circuit. The former economizes material at the expense of labor, particularly in winding, where the wire is threaded through the center of the ring—a laborious process for skilled labor. The latter design, necessarily demanding lower magnetic densities and consequently more material to compensate for the detri-

Fig. 18. Current Transformer for 110,000 Volt Circuit

mental effect of the joint in the circuit upon accuracy, is less expensive in labor as the coils may be machine wound and subsequently assembled.

The only other examples of this class of transformers requiring mention here are those used in compounding self-excited generators, and those inserted in series lighting circuits carrying arc or incandescent lamps of a certain current rating, for the purpose of operating a local circuit carrying series lamps of the same or different type but of different current capacity. The first of these is inserted in the line from the generator and transforms a portion of the current, which is then rectified to direct current and sent through the field coils of the machine. Neither requires the extreme accuracy of the switchboard or current transformer, although the capacities are much larger and operating voltages moderately high. In construction and appearance, they resemble small multiple transformers.

Thus far we have considered transformers with stationary parts and fixed characteristics. We now come to the third general class of apparatus, in which, by means of moving parts, a combination of the properties of the two previous groups is acquired. The constant current transformer, by which name this third class is usually known, is made upon a long slender shell-type core with pancake coils. In the simplest form, there is one primary and one secondary coil, occupying not more than a quarter of the length of the core window. The primary is fixed at the lower end of this space by means of a suitable clamping device attached to the core clamps. The secondary is hung by flexible cables to rocker arms and counterbalanced by weights, so that it is free to move throughout the length of the window; although it naturally rests upon the secondary because heavier than the counter weight. The primary is connected in multiple with the line supplying energy, and the secondary in series with the lighting line of series arc or incandescent lamps.

If the coils are separated as far as possible and the circuit closed, the magnetic field established by the primary is opposed by that of the secondary, and the coils are forced apart by this electromagnetic force. Most of the lines of force are driven back and cross the windows, or "leak" to the outer legs, while a small portion threads the secondary, producing voltage and current in the line. Now, if the counter weight is lessened, the weight of the coil causes it to overcome the repulsion and to settle nearer the primary, embracing more flux and therefore developing more current and voltage and reducing the reactive or leakage flux. By a suitable adjustment of the weights, any current value within the limits of the design may be obtained. The number of lamps on the line may vary at will, demanding more or less voltage, but the coil will always float upon the leakage flux, threading enough to give the voltage necessary to maintain constant current on the secondary lines. This action is not unlike that of a floating body, which always displaces its own weight, regardless of the specific gravity or density of the supporting medium.

The fourth or final group, as we have classified them, broadly designated regulators, performs a function quite similar to that of the apparatus just considered, but in a different manner. The secondary voltage rather than the current is the factor regulated, although the same apparatus may be adjusted to control current under certain special conditions of load.

The principal purpose of these devices is to receive a voltage which, although nominally of constant value, nevertheless varies excessively, due to poor regulation of generating and distributing apparatus under heavy or changing loads, and convert this into one of constant value. They are generally installed in a generating or sub-station, on feeders supplying energy to the centers of heaviest load upon the system, that the proper voltage may be maintained at these important points.

These "feeder regulators," as they are commonly called, are designed in two general types, both of which are made for either hand or automatic control. The simpler form of this device consists of either a core-type or shell-type transformer, the secondary of which is subdivided into several equal coils successively cut in or out of circuit by means of a switch. The other, or induction type, is in reality a generator of special design, in which the rotor is connected in multiple with the primary line, and the stator in series with the feeder.*

In conclusion, it should be observed that this paper presents only a very general view of transforming apparatus, dwelling relatively upon the salient points of the prevalent type, the multiple transformer. Again let it be pointed out that all of the other classes, types and forms possess inherently the same characteristics of design and operation, which differ only in relative importance, depending upon the requirements of the service for which they are intended.

*Note. Description of these regulators will be found in the issues of the Review for July 1908 and June 1909. *Editor.*

HYPERBOLIC FUNCTIONS AND THEIR APPLICATION TO TRANSMISSION LINE PROBLEMS

PART II

By W. E. Miller

Sign Convention

The positive direction of rotation has been taken as contra-clockwise, as this is the convention usually employed in mathematics including trigonometry. Steinmetz uses the

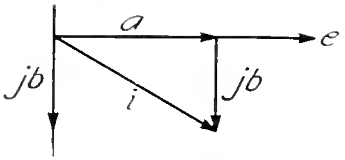


Fig. 5

opposite notation which has advantages also. In the clockwise rotation impedance is written $r-jx$; in the contra-clockwise rotation it is written $r+jx$.

A leading current is represented in the contra-clockwise notation, $i=a+jb$; $a-jb$ representing a lagging current, jb being drawn downwards as shown in Fig. 5.

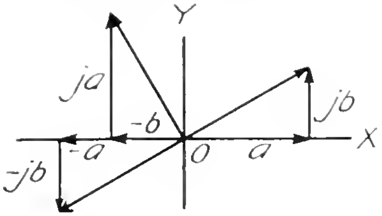


Fig. 6

If a vector is multiplied by j, it rotates it contra-clockwise through one right angle. For instance, if the vector $a \pm jb$ is multiplied by j, the result is $ja \mp b$, which means that a has twisted forward through one right angle and b also, which now lies in the opposite direction to the original direction of a. If a further multiplication by j is performed, the result is $-a \mp jb$ and the vector has been rotated into the third quadrant, and so on. Similarly, multiplying by $-j$ rotates the vector clockwise or in the negative direction. See Fig. 6.

Forms Used for Complex

The complex $a+jb$ is often written $\sqrt{a^2+b^2}\,\angle\theta$ where $\theta = \tan^{-1}\left(\frac{b}{a}\right)$. Another form in which the complex is written is $\sqrt{a^2+b^2}\,(\cos\theta + j\sin\theta)$ this form being immediately obtained from inspection of Fig. 5. This method of writing the complex is very useful in many cases, for instance, when it is required to write down the complex of a current which lags or leads a voltage taken as the standard phase, and the power factor is given. In this case, $i=\sqrt{a^2+b^2}\,(PF \mp j\sqrt{1-PF^2})$. For example, if the power factor is .90 lagging and the R.M.S. current is 120 amperes, then $i = 120\,(.90 - j\sqrt{.19}) = 108 - 52.3j$.

Meaning of $\sqrt{a+jb}$

The value of this quantity is required later, hence, the following method is given to show how to extract its square root:

Let $\sqrt{a+jb}=c+jd$ then $a+jb=c^2-d^2+2jcd$

Then, since the real parts must be equal to one another, and also the unreal,

$$a=c^2-d^2 \text{ and } b=2cd, \text{ hence } c^2+d^2=\sqrt{a^2+b^2}$$

Now $c+jd=\sqrt{c^2+d^2}\,(\cos\theta^1+j\sin\theta^1)$ where $\theta^1 = \tan^{-1}\left(\frac{d}{c}\right)$

And $a+jb=\sqrt{a^2+b^2}\,(\cos\theta+j\sin\theta)$ where $\theta = \tan^{-1}\left(\frac{b}{a}\right)$ or $\tan\theta=\frac{b}{a}$

$$\text{But } \tan\theta = \frac{b}{a} = \frac{2cd}{c^2-d^2} = \frac{2\frac{d}{c}}{1-\frac{d^2}{c^2}} = \frac{2\tan\theta^1}{1-\tan^2\theta^1}$$

$$=\tan 2\theta^1$$

Therefore $\theta^1=\frac{\theta}{2}$ hence, as $c+jd=\sqrt{c^2+d^2}\,\angle\theta^1$

and $c^2+d^2=\sqrt{a^2+b^2}$ and $\theta^1=\frac{\theta}{2}$ or $\frac{\tan^{-1}\left(\frac{b}{a}\right)}{2}$

it follows that $\sqrt{a+jb}=(a^2+b^2)^{\frac{1}{4}}\,\angle\dfrac{\tan^{-1}\left(\frac{b}{a}\right)}{2}$

or $\sqrt{a+jb}$

$$=(a^2+b^2)^{\frac{1}{4}}\left(\cos\frac{\tan^{-1}\left(\frac{b}{a}\right)}{2}+j\sin\frac{\tan^{-1}\left(\frac{b}{a}\right)}{2}\right) \quad (16)$$

Hence, the rule is as follows: Find the fourth root of the sum of the squares of a and b. Find the value of the angle whose tangent is $\frac{b}{a}$, then halve it and find the cosine and sine of half the angle. If this angle is ϕ the resulting complex can be written

$$(a^2+b^2)^{\frac{1}{4}}\,[\cos\phi+j\sin\phi]$$

If the original complex was $\sqrt{jb-a}$, the angle whose tangent is $\left(\frac{b}{-a}\right)$ lies in the second quadrant, halving it, however, brings it back into the first quadrant, where the sine and cosine are both positive. Hence, $\sqrt{jb-a}$ must have the positive sign placed between its components. Similar rules apply for any root, and in general

$$\sqrt[n]{a+jb} = (a^2+b^2)^{\frac{1}{2n}}\left(\cos\frac{\tan^{-1}\left(\frac{b}{a}\right)}{n}+j\sin\frac{\tan^{-1}\left(\frac{b}{a}\right)}{n}\right)$$

Division by Complex

If the value of $\frac{a+jb}{c+jd}$ is required, multiply both numerator and denominator by $c-jd$; then

$$\frac{a+jb}{c+jd}=\frac{(a+jb)(c-jd)}{(c+jd)(c-jd)}=\frac{ac+bd+j(bc-ad)}{c^2+d^2}$$

which eliminattes the j term from the denominator and brings the result into the form $p+jq$. If the denominator had been $c-jd$, the multiplier should, of course, be $c+jd$ in order to clear the denominator of terms involving j.

The following example is given here showing the application of this rule. Take the ordinary equation connecting volts and amperes in an inductive circuit

$v=ri+L\frac{di}{dt}$, i being equal to $I\sin pt$ where $p=2\pi f$.

Then this equation can be written $v=ri+jLpi$ or $i=\frac{v}{r+jLp}=v\frac{r-jLp}{r^2+L^2p^2}$ which immediately solves the problem and shows that the current lags behind the e.m.f. by an angle $\tan^{-1}\frac{Lp}{r}$.

Hyperbolic Complex

These functions are involved in the solution of transmission line problems (with distributed capacity, self induction and leakage). They appear in the form $\cosh(x+jy)$ and $\sinh(x+jy)$.

By the addition and subtraction formulæ (14 and 15) which must apply generally, the following formulæ are at once obtained:

$\cosh(x\pm jy)=\cosh x\cos jy\pm\sinh x\sin jy$ and
$\sinh(x\pm jy)=\sinh x\cos jy\pm\cosh x\sin jy$

Now $\cos jy=1+\frac{(jy)^2}{2}+\frac{(jy)^4}{|4}+\text{etc.}=1-\frac{y^2}{2}+\frac{y^4}{|4}-\text{etc.}=\cos y$

Proceeding in a similar manner $\sin jy=j\sin y$ (see formulæ 12 and 13).

Therefore $\cosh(x\pm jy)=\cosh x\cos y\pm j\sinh x\sin y$ (17)

and $\sinh(x\pm jy)=\sinh x\cos y\pm j\cosh x\sin y$ (18)

from which formulæ the hyperbolic complexes have been calculated.

Thus if $\cosh(x+jy)=a+jb$ and $\sinh(x+jy)=c+jd$

Then $a=\cosh x\cos y$ and $b=\sinh x\sin y$
$c=\sinh x\cos y$ and $d=\cosh x\sin y$

Equations (17 and 18) show that $\cosh u$ and $\sinh u$ are periodic with an imaginary period of $2\pi j$, since $\cosh(u+2\pi j)=\cosh u\cos 2\pi+j\sinh u\sin 2\pi=\cosh u$

Similarly $\sinh(u+2\pi j)=\sinh u$. These functions change sign when u is increased by $j\pi$ whence $\cosh(u+j\pi)=-\cosh u$, and similarly for $\sinh u$.

Again by substitution in the addition formulæ, the following holds

$\cosh\left(u+\frac{j\pi}{2}\right)=j\sinh u$ and $\sinh\left(u+\frac{j\pi}{2}\right)=j\cosh u$

also $\cosh\left(u+\frac{3j\pi}{2}\right)=-j\sinh u$ and $\sinh\left(u+\frac{3j\pi}{2}\right)=-j\cosh u$.

If it is necessary, as in long telephone lines, to calculate the hyperbolic functions in which the j term is greater than $\frac{\pi}{2}$, a great saving in labor can be effected by using the above results. For example,

$\cosh(u+2.57j)=j\sinh\left[u+\left(2.57-\frac{\pi}{2}\right)j\right]$
$=j\sinh(u+1.0j)$

$\cosh(u+3.42j)=-\cosh[u+(3.42-\pi)j]$
$=-\cosh(u+.28j)$

$\cosh(u+6.00j)=-j\sinh\left[u+\left(6.00-\frac{3\pi}{2}\right)j\right]$
$=-j\sinh(u+1.29j)$

$\cosh(u+7.00j)=\cosh[u+(7.00-2\pi)j]$
$=\cosh(u+.72j)$

Similar formulæ hold for $\sinh(u+jv)$

The real part of the complex cannot, however, be reduced, only the unreal or j term. Hence, if large values of the real term x or u are required, they must be calculated from a series, if no tables are available, or from the exponential values of the hyperbolics.

Transmission Line Equations

Let r = resistance per mile, L = self induction per mile measured between line and neutral, C = capacity per mile measured between line and neutral, and g = coefficient of dielectric conductance per mile. Let x be the distance to any point of the line measured from the receiving end in miles, e the voltage at any point, and i the current. Then the following equations give the relations between "e" and "i":

$$\frac{di}{dx}=ge+C\frac{de}{dt} \qquad (19)$$

provided that the value of g is independent of the voltage e, which is not true of corona effect; or provided that the voltage is practically constant along the line.

And

$$\frac{de}{dx}=ri+L\frac{di}{dt} \qquad (20)$$

That is to say, the increment of current at any point per infinitely small length equals the vector sum of the leakage current (or the leakage conductance multiplied by the volts at that point) and the capacity current, which is at right angles to the leakage current. In the same way, the increment of voltage at any point per infinitely small length, equals the volts consumed in resistance added vectorially to the inductive volts at right angles to the resistance volts.

Now $C\frac{de}{dt}=jpCe$ since $\frac{de}{dt}$ is at right angles to e

And $L\frac{di}{dt}=jpLi$, since $\frac{di}{dt}$ is at right angles to i

Where $p=2\pi f$

Therefore, $\frac{di}{dx}=(g+jpC)e$ and $\frac{de}{dx}=(r+jpL)i$

Whence, $$\frac{d^2e}{dx^2}=(r+jpL)(g+jpC)e \qquad (21)$$

And $$\frac{d^2i}{dx^2}=(r+jpL)(g+jpC)i \qquad (22)$$

Hence, the solution is hyperbolic, because in both equations, the second differential is proportional to the quantity itself, a law which sinhu and coshu both follow.

Therefore, the solution is

$e=A\cosh mx+B\sinh mx$

And $i=F\cosh mx+D\sinh mx$, of which only two of the constants are arbitrary.

And $m^2=(r+jpL)(g+jpC)$

If the receiving end terminal values of e and i be E_r and I_r respectively, the general solution is

$$e=E_r\cosh mx+m_1 I_r\sinh mx \qquad (23)$$

$$i=I_r\cosh mx+\frac{E_r}{m_1}\sinh mx \qquad (24)$$

Where x = distance in miles, measured from the receiving end, and

$$m_1=\frac{m(g-jpC)}{g^2+p^2C^2} \quad \text{and} \quad \frac{1}{m_1}=\frac{g+jpC}{m}$$

If E_s and I_s are given at the sending end, and the line is measured from that point towards the receiving end, equations 23 and 24 become

$$e=E_s\cosh mx-m_1 I_s\sinh mx \qquad (25)$$

$$i=I_s\cosh mx-\frac{E_s}{m_1}\sinh mx \qquad (26)$$

Where x is the distance in miles measured from the sending end.

Calculation of Constants

As already stated, $m^2=(r+jpL)(g+jpC)$

In the majority of lines, except those using wires of small diameter at very high voltage, where corona effect is noticeable, g, the leakage conductance, can be neglected.

Then, $m^2=(r+jpL)\,jpC=pC\,(jr-pL)$

Therefore, $m=\sqrt{pC}\,(r^2+p^2L^2)^{\frac14}\ \dfrac{\tan^{-1}\left(\frac{r}{-pL}\right)}{2}$

$$=\sqrt{pC}\,(r^2+p^2L^2)^{\frac14}\left(\cos\frac{\tan^{-1}\left(\frac{r}{-pL}\right)}{2}+j\sin\frac{\tan^{-1}\left(\frac{r}{-pL}\right)}{2}\right) \qquad (27)$$

The above is, of course, of the form $a+jb=m$

Since $$m_1=\frac{m}{jpC}=\frac{(a+jb)(-j)}{pC}=\frac{b-ja}{pC} \qquad (28)$$

and $$\frac{1}{m_1}=\frac{pC}{b-ja}=\frac{pC(b+ja)}{b^2+a^2} \qquad (29)$$

The tables for m, m_1 and $\frac{1}{m_1}$, in the Supplement have been calculated from these formulæ, C being given in farads per mile and L in henrys per mile.

Volt and Current Phase Shift and Power Propagation Velocity

Equations 23 and 24 prove that when there is no load current, there is a complete reversal of phase in volts and amperes along a transmission line in a distance $x=\frac{\pi}{b}$ where $(a+jb)=m$ because both $\sinh mx$ and $\cosh mx$ change sign every half period πj. In a distance

$\frac{2\pi}{b}$ the amperes and volts are in the same phase respectively as they are at the receiving end. Hence, if the frequency be f, then the velocity of propagation of the voltage or current wave along the line will be $v = \frac{2\pi f}{b}$.

This must not be taken as the velocity of the power wave along the line, as the apparent velocity of the current and volt wave vary at different points from the receiving end and the shift of phase does not vary uniformly along the line, owing to capacity current, the current leading the volt wave 90 degrees at the receiving end. If a lagging load current, however, is taken at the receiving end, the power factor can be approximately unity along the line, in which case the volts and current are nearly in phase at every point and the velocity of either gives the velocity of the power wave along the line. In the majority of lines used for long distance work, the resistance is not large enough to affect the velocity and in such cases the velocity of power propagation is practically equal to the velocity of light. For $r = o$, the velocity is

$$\frac{2\pi f}{p\sqrt{LC}} = \frac{1}{\sqrt{LC}}$$

or independent of the frequency. From this formula, the formula for the natural period of a transmission line can be derived equal to $\frac{1}{4l\sqrt{LC}}$ where l is the length of the line; $\frac{1}{\sqrt{LC}}$ being the velocity of light nearly, the expression only representing the velocity of light when the self induction inside the wires is negligible, which is true of very high frequencies, practically perfect conductors, etc. The natural frequency of the fundamental wave, for a transmission line 400 miles long is about 115, the velocity of power propagation being approximately. 1.8 per cent. less than the velocity of light. The closer the wires are together or the larger they are, the slower does the power travel, and the velocity can be taken as lying between 1.5 and 2.5 per cent. less than the velocity of light. For transmission lines, 184,000 miles per second can be taken, as an average velocity.

It must be remembered that power is a double frequency quantity and cannot, therefore, be represented vectorially in the same plane as a vector of different frequency; hence, if the power wave is obtained by multiplying the complexes of current and volts together, difficulties are encountered. The best way to obtain the electric power is to plot the instantaneous values of the current and volts along the line, the values of which are immediately given by equations 23 and 24. Then multiply the instantaneous values together and plot the power curve from the result. The distance between the maxima, minima, or corresponding points on this curve multiplied by double the line frequency gives the velocity of power propagation along the line: the distance between the maxima on this curve will, of course, be half that between the maxima on the current or volt curve, provided that practically unity power factor obtains through the distance taken.

The shift of phase of volts or amperes along commercial transmission lines is not large, since the maximum frequency used is only 60 cycles and with this frequency the half period length is about 1500 miles. In long telephone lines, on the contrary, shift of phase is very large and will amount to a number of complete reversals along the line owing to the necessarily high frequency used in speech. 800 per second being a representative frequency.

Approximate Formulæ for Short Lines

Since $\cosh u = 1 + \frac{u^2}{2} + \frac{u^4}{4} +$

for small values of u

$$\cosh u = 1 + \frac{u^2}{2} \text{ nearly}$$

Similarly $\sinh u = u$ nearly.

Hence for short lines, if $mx = x(p + jq)$

$$e = E_r\left(1 + \frac{x^2(p^2 - q^2)}{2} + jx^2pq\right) + m_1 I_r(p + jq) \quad (23)$$

$$i = I_r\left(1 + \frac{x^2(p^2 - q^2)}{2} + ix^2pq\right) + \frac{E_r}{m_1}(p + jq) \quad (24)$$

and

$$e = E_s\left(1 + \frac{x^2(p^2 - q^2)}{2} + ix^2pq\right) - m_1 I_s(p + jq) \quad (25)$$

$$i = I_s\left(1 + \frac{x^2(p^2 - q^2)}{2} + ix^2pq\right) - \frac{E_s}{m_1}(p + jq) \quad (26)$$

These formulæ are accurate to 1 per cent. for lines, 120 miles long at 60 cycles and 150 miles long at 25 cycles, greater accuracy being obtained for shorter lines.

Corona Effect

The escape of electricity through the atmosphere from one wire of a transmission line to another is an example of the increase of conductivity of a gas due to high dielectric stress. The conductivity of gases is enormously augmented under special conditions; such as, when subjected to radio activity, when the temperature is raised above a certain value, when drawn from the neighborhood of flames or electric arcs, or after being in contact with incandescent metals or carbon, etc. A gas through which an electric discharge is passing is also affected in a similar manner, this being the cause of the increase in conductivity of the air between transmission lines when the voltage rises above a certain critical value. The physical aspect of these phenomena has been studied by many scientists, notably by Kelvin, J. J. Thomson, Rutherford, Hittorf, etc., and a very full discussion of the whole matter has been given in Thomson's work "Conduction of Electricity Through Gases."

According to one of the modern theories of matter, each atom or molecule is composed of or associated with negative and positive ions or minute electrified particles, the negative ion possessing a mass small compared to that of the hydrogen atom, and the positive ion a larger mass than that of the negative ion. The electric charge of these ions is a constant. On this assumption, the following discussion may help to picture what happens when the voltage stress is increased in the dielectric between two conductors, beyond the dielectric strength and the gas becomes ionized. It can, however, only be regarded as a rough approximation to the phenomena.

Capacity Current

Suppose that a potential difference is applied to two electrodes separated by an air space, the potential being gradually increased. At first, the current passing across the air, which completes the electric circuit, is exceedingly small and consists of a displacement or charging current in the surrounding dielectric. The greater part of this current is due to an ether displacement, but part is caused by a displacement of the ions, which are elastically attached to the gas molecules. The strain or displacement of the ions in each molecule is greatest when the voltage stress is at a maximum, the ions then being at rest and the current zero. If the voltage is alternating, at the moment the voltage passes through zero, the ions in the molecule are in midswing and move at their highest velocity; and the displacement current is then maximum. Thus the elastically controlled displacement current in the air constitutes a small part of the capacity current between the electrodes and is in quadrature with the voltage. This is, of course, also true of the ether displacement current. As practically no friction enters into the motion which beats rhythmically with the voltage, no energy loss occurs in the dielectric, the energy being alternately potentially stored in the dielectric and kinetically released in the moving ions.

Corona Current

If now the voltage is further increased, the electric stress at a certain critical point becomes sufficiently great to tear off some of the ions attached to the gas molecules. This disruption occurs first, in a layer of air a short distance from the surface of the electrode or conductor, since although the electric stress is greatest at the surface of the conductor, it has been found that the dielectric strength of the air immediately surrounding the conductor is considerably higher than that further off. For small conductors, the breakdown point is approximately .07 inches distant from the surface. Here the ions are first released and are then free to move under the force of the electric field in the same way as an electrically charged pith ball moves in an electrostatic field. At the moment of release, the inertia of these ions is small and, therefore, their speed is rapidly accelerated until they are stopped by collision with other gas molecules or ions. If, at the moment of collision, the kinetic energy of the ion is above a certain value, it may shake off other ions, and in this manner the whole space between the electrodes becomes filled with electrified particles or ions, the positive, on the average, all moving in one direction, and the negative in the opposite direction. Of these collisions, some may cause ionic recombinations and a neutralization of the electric charge, the number of recombinations increasing if the gas pressure is raised. Hence, a transfer of electricity occurs from one conductor to another, the carriers being the ions torn off the molecules, either by the electric stress or by collision, the current at any point being proportional to the number of ions passing per second. At every collision molecular vibration is started and part of the electric energy is transformed into heat. If the voltage is still further increased, a larger number of ions are released which attain a greater velocity between molecules and cause more heat waste and current. It follows, that this current is independent of frequency, and has, therefore, the same value at a given voltage, whether the voltage alternates or is held constant.

Directly the voltage falls below the critical value for ionization, all action ceases, only to begin again when the voltage rises to its proper value in the opposite direction. This is practically true, except that a minute time lag exists, which is short compared to the period of commercial frequencies. It will be readily seen from the above that the current is a true convection current and is in phase with the voltage. It is, therefore, at right angles to the capacity current.

If the pressure of the gas be diminished, the number of gas molecules between the conductors is proportionally decreased, and therefore the distance between the gas molecules is correspondingly increased. Under such circumstances, the ions have, on the average, a longer path to travel before collisions occur and, therefore, their speed and kinetic energy are greater at collision. Hence, each collision is more likely to tear off other ions from the molecules, and as the number of recombinations producing neutral ions is diminished, the current is increased. If the gas pressure be further decreased, the ionization current, for a given voltage stress, increases until at a certain critical pressure where the number of molecules per unit volume has been very much reduced, the current becomes maximum, that is, the space is saturated with ions and on a further decrease of pressure, the current falls.

Under the conditions which exist in high voltage transmission lines, it is found that a decrease of pressure near the atmospheric pressure causes a distinct increase of corona loss, and when pressures as low as 20 in. are encountered, the loss is considerable. As the height of many transmission lines exceeds 8,000 ft., the highest point reached by the Central Colorado Power Line being 13,700 ft., it is abundantly evident that the relation of pressure to corona loss is of the first importance.

Since the critical voltage for No. 2 wire is in the neighborhood of 90,000 volts effective or 126,000 volts maximum, only a small part of the cycle is effective in producing corona current at ordinary transmission voltages. If very much higher voltages were employed, not only would the corona current be enormously increased (so long as the saturation point is not reached between the conductors), but also the loss would last during the greater part of the period. If the no load current oscillograph record is taken, a kick in the curve at maximum voltage is very apparent at high voltages when corona is present and the shape of the current wave is considerably altered.

When ionization takes place, a brush discharge can be observed near the surface of the wire, where the greatest number of ions per unit volume occur and the current density is at a maximum. The resistance, therefore, of the air layers surrounding the wire is considerably decreased, and the effective conductor diameter can, therefore, be regarded as greater than that bounded by its metallic surface. This increase in conductor diameter increases the capacity between the conductors and, therefore, the capacity current. Thus, if the loss at no load be measured on a transmission line subject to a large corona loss, the capacity loss cannot well be calculated from formulæ and oscillograph records should be taken if the corona and capacity loss require separating. The high inductive capacity of insulator material increases the voltage stress near the wires where they are fastened to the insulators, and hence the corona loss is increased at these points as well as the capacity loss.

Mr. H. J. Ryan considers these matters in his paper before the American Institute of Electrical Engineers, February 26, 1904, and a considerable amount of work has been done by Messrs. C. F. Scott, R. D. Mershon and others, especially in connection with the effect of the barometric pressure on corona loss. Many more experiments are, however, needed, before the phenomena can be considered as subject to calculation. The variation of corona loss with voltage, size of wire, spacing between conductors, atmospheric pressure, state of atmopshere and wire surface, and many other conditions must be determined before equations can be formed to give reliable results.

Capacity Loss

The extra current carried by the conductor due to corona is exceedingly small and can be neglected; in consequence, the i^2r loss in the conductor is negligible. The loss all occurs in the dielectric between the conductors. Thus, for constant voltage along the line, which will obtain at no load in lines up to 200 miles long at 25 cycles, the corona loss per mile is constant along the line; it being, independent of frequency. The capacity current loss, on the other hand, all occurs in the conductor, the current varying directly as the voltage and frequency. In this case, practically no loss takes place in the dielectric between the wires.

In lines, up to about 200 miles long at 25 cycles, and in slightly shorter lines at 60 cycles, the capacity current along the line follows practically a straight line law, being a maximum at the generator end and zero at the receiving end. Hence, if r is the resistance per mile of wire, I the capacity current per wire at the generator end, and l is the length of line, the current per mile $i = \frac{I}{l}$ = constant, and the loss for a line l miles in length is $3\int_0^l ri^2l^2dl = i^2rl^3$. The total loss is therefore Al^3 where $A = i^2r$, which is a constant at a given frequency, for a definite size of wire and given line capacity. Hence, the capacity loss for a given transmission line varies as the cube of its length up to the limits of length just given. Above this length, the voltage rises from the generator end toward the receiving end, and the capacity current does not fall off uniformly from the generator end but more gradually; that is, the curve of capacity current along the line is concave towards the abscissa representing line length, provided the line resistance is not too high. The reason for this is that the increase of voltage holds up the current at the generating end, and prevents it decreasing as fast as it does near the receiving end. The total loss, however, with a given voltage at the receiving end, does not vary as rapidly as the cube of the distance of the line length, since the drop in voltage at the generator end reduces the capacity current correspondingly, which more than compensates for the slower drop of current along the line. See Fig. 7.

Calculation of Dielectric Conductance Constant

The curves, Fig. 8, showing corona and capacity loss, have been obtained by substituting a value for g in the transmission line equations. This value was derived from the observed loss along a 50 mile line operating under similar conditions and using the same size of wire and spacing. As, therefore, the voltage is nearly constant, the corona loss may be regarded as approximating the real value provided the capacity current is not seriously altered by the corona loss and that no appreciable insulator loss exists. Note the change in phase at generator and receiving ends due to corona indicated on Fig. 9.

The dielectric conductance coefficient was calculated as follows: The total loss of a 50 mile line at no load was experimentally found to be 25 kw., of which 3 kw. was calculated as capacity loss, and the remainder assumed as corona loss. The voltage was

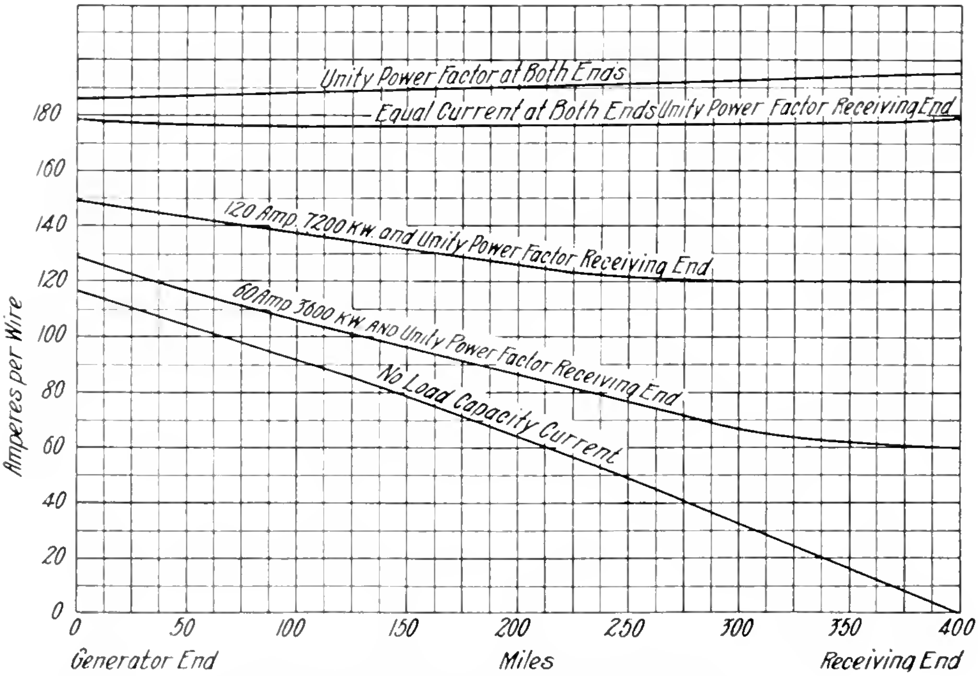


Fig. 7. Capacity Current at 60 Cycles along Three-Phase Line 400 Miles in Length, Using Three No. 0000 Wires Spaced 10 ft. Apart, 104,000 Volts between Wires at Receiving End.

110,000 volts between wires. Then the loss per mile equals $\frac{22000}{50} = 438$ watts per mile.

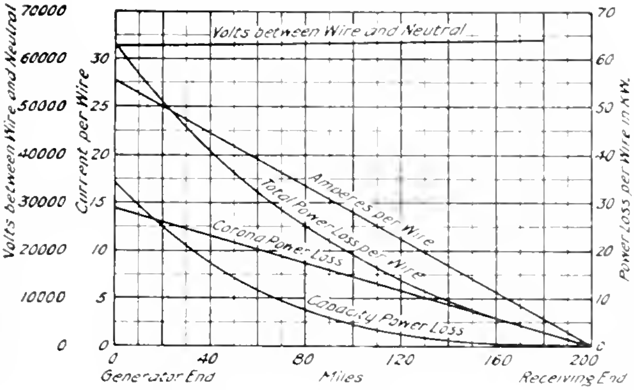


Fig. 8. Amperes, Volts and Power Losses (Capacity and Corona) at no Load along 200 Mile Three-Phase Line using Three No. 1 Wires 8 Ft. Apart, Operating at 25 Cycles, with 110,000 Volts between Wires at Receiving End

Then since the dielectric conductance is $\frac{1}{r}$ where r is the dielectric resistance per mile between wires, and since $\frac{V^2}{r}$ = the loss per mile, therefore, $\frac{1}{r} = \frac{438}{110,000^2} = .036 \times 10^{-6} = g$.

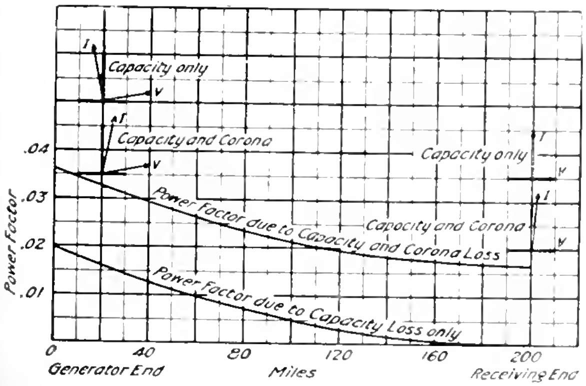


Fig. 9. Power Factors Due to Corona and Capacity Losses along 200 Mile Line at 25 Cycles

Corona effect is less masked by capacity loss at 25 cycles than at 60 cycles, and the example was, therefore, chosen at the lower frequency. The constant m in the transmission line equations, where g is included is

$$\sqrt{(r^2 + p^2L^2)(g^2 + p^2C^2)}\left[\cos\frac{\tan^{-1}\theta}{2} + j\sin\frac{\tan^{-1}\theta}{2}\right]$$

where $\tan^{-1}\theta = \frac{p(Lg + Cr)}{rg - p^2LC}$

From these values m_1 and $\frac{1}{m_1}$ can be readily calculated.

(To be Continued)

UNDERGROUND ELECTRICAL DISTRIBUTION

By W. E. Hazeltine

Supply Dept., General Electric Company

The ungainly appearance and danger of overhead electrical wires have in a large measure been accountable for the adoption of the underground system of distribution.

While the first cost of an underground system exceeds that of an overhead, security of operation tends to counter-balance this difference, for underground conductors are entirely free from the effects of storms and weather conditions.

One of the earliest attempts at placing wires underground was over fifty years ago when Professor Morse of Boston undertook to install a telegraph line between Washington and Baltimore. His method of laying was by means of a large plow drawn by sixteen yoke of oxen, the cable being placed on a reel secured to the plow and played out in the furrow as the plow advanced. It is well known that this attempt proved unsuccessful.

Several years after, the so-called "pump log" was brought into use. This consisted of eight-foot lengths with a 3-inch bore, the ends butting together with socket joints and laid directly in the trench. Logs were sometimes of plain wood and, again, treated with tar or creosote as a preservative.

The cement-lined iron pipe was also used to a considerable extent, but this type of conduit proved unsatisfactory, one disadvantage being that the pipe was affected by electrolysis and that the inside coating of cement sometimes caused corrosion. Both types proved inadequate to the requirements of an underground conduit.

The theoretical conduit should be one that in itself possesses high insulating properties; one upon which the action of water, gas and chemical elements have no effect, and one which is permanent and practically indestructible. These requirements are found in the vitrified clay conduit, which is best adapted to the purpose and in addition is comparatively low in first cost and in expense of installing.

Another type of conduit, which is at present used to some extent, is the fibre conduit. It is made from wood fibre treated with an asphalt compound which the makers claim renders it water, acid and alkaline proof. The standard length is about five feet, with a 3 in. bore and is smooth inside; therefore, cables are safe from injury when being drawn in. This type of conduit is usually laid in concrete and lengths are joined by a butt joint which keeps them in alignment.

To return to the vitrified clay conduit, this is without doubt the most popular type in use. Duct sections are supplied with one, two, three, four, six, nine and twelve holes, the standard single duct being 18 in. in length and 3 in. internal diameter. Sections of more than six ducts are difficult to handle and are not made to a great extent on account of the liability to warp during manufacture.

The flexibility of this system allows obstructions such as gas, water and sewer pipes, to be overcome by laying the duct line over or under them, and in some cases to split the duct line, placing part above and part underneath. In any case, ducts should be laid with such a gradual grade as to permit cables to be pulled in without injury to the lead sheath. Also, the use of short lengths permits the laying of curves of long radius, oftentimes doing away with additional manholes. The duct is generally laid on a bed of concrete, usually 3 in. thick, surrounded by walls and covered with concrete of the same thickness.

In laying single duct, a mandrel about 30 in. long, slightly smaller than the internal diameter of the hole and having a rubber gasket on the end slightly larger than the diameter of the hole, is drawn through the duct as it is being laid. This removes all loose particles of cement and stones and makes sure that there are no obstructions to injure the cables; further, care should be taken to insure that ducts are perfectly aligned.

In laying a section of conduit the engineer in charge should lay out his grades so that all the ducts in each section drain into one manhole, or else break the grade so as to drain into two adjacent manholes, thus preventing injury to the cables after they are installed, from the freezing of water which may find its way into the duct line and settle in any pocket there may be.

For long straight runs, when there are no obstructions, the multiple forms of duct are usually used. These are laid in practically the same manner as the single ducts, except that joints are aligned by the use of dowel pins.

One objection to multiple duct is, that between any two duct sections there is only one wall and it is impossible to break joints as with single duct; therefore, there is a possibility of a burnout in one duct finding its way to a neighboring one.

With single conduit, where there are two thicknesses of wall between any two ducts and where joints can be staggered, this danger is practically eliminated. Single duct, however, requires experienced labor in installing, while multiple duct may be laid by ordinary laborers.

Manholes are necessary in order to facilitate the drawing in or out of cables in the system and are generally located at street intersections or at sharp bends in the duct line. The maximum distance between holes should not exceed 500 feet, for at greater distances the cable is liable to break or stretch from the excessive strain during the process of pulling.

The general manhole construction is of brick, although the present tendency is towards concrete holes whenever possible, as the average cost of concrete manholes is approximately two-thirds that of first class brick. Concrete holes are usually made from wooden forms of take-down design which may be used indefinitely. Bottoms of manholes are usually of concrete, with a hollow in the center which allows water to gather. When possible, connection with the sewer through a trap should be provided to remove any surface water which may work in around the cover.

Referring to manhole covers, authorities do not agree as to whether a single or double cover should be used. The single cover simply fits in a cast iron frame at street level. Inside of this there is sometimes another cover resting on a rubber gasket, bolted and secured so as to prevent water entering. The main disadvantage of this inner cover is that, in case sewer gas or illuminating gas escaping from leaky mains finds its way into the hole, there is no way of escape and this accounts for the majority of manhole explosions which occur.

It is believed by many authorities that the single cover is preferable and this should be supplied with several air holes to allow gas to escape. Theoretically these vent holes should be conical in shape with the small opening on top to prevent them from becoming clogged. It is true that surface water finds its way through these vents into the hole, but this is taken care of by the sewer connection. It is well known that, with a large number of cables carrying heavy loads, considerable heat is generated and a large percentage of this is dissipated through the surrounding earth, but by using perforated manhole covers, it may be got rid of more easily.

In order to support the cables which must necessarily pass through the manhole it is customary to provide some sort of a device on which they may rest. In brick holes, brick shelves are built into the sides at suitable distances apart upon which cables are placed. Also with concrete manholes the wooden forms may be so designed as to provide for concrete shelves. The use of shelves for cable-supports is especially desirable, for in case of trouble occurring on one cable, the neighboring cables are protected to a certain extent from injury. Oftentimes with brick or concrete manholes, iron cable racks, provided with arms adjustable at will, are built in.

A conduit line composed of a large number of ducts is undesirable, one reason for this being that it is almost impossible to support a large number of cables in one manhole. It is advisable, therefore, to divide the underground lines from the generating station, installing a portion through two or more streets, if possible; but if the station is so situated that the entire output must pass through one street, a single conduit line with twin manholes may be used.

With a single duct line entering the station it is rather difficult to dispose of the cables satisfactorily.

Coming to the question of cable, the size of duct determines in a way the size of cable to be used. For the standard 3 in. duct for working pressures of 1500 volts or less, the largest single conductor that should be installed is a 2,500,000 cir. mil., or a concentric 1,000,000 cir. mil. cable, while the largest three-conductor cable is one of 400,000 cir. mils. From 1500 to 3000 volts, the largest single conductor should be a 2,000,000 cir. mil. cable or a concentric cable of 750,000 cir. mils.; and the largest three-conductor cable, one of 400,000 cir. mils. For 6000 volts (usually three-phase delta connected), the largest three-conductor cable is one of 250,000 cir. mils.; for 13,000 volts, 3-conductor 4/0; and for 20,000 volts, 3-conductor 1/0.

As the cost of the duct line is independent of the cable cost, it is advisable to choose such cable as will reasonably fill the duct area, thereby cutting down the conduit investment to a minimum for the amount of energy transmitted. In laying out an underground system, it is advisable to provide extra ducts to take care of future requirements.

For underground work, three types of insulation are used; *viz.*, paper, varnished cambric and rubber; paper being the cheapest, varnished cambric intermediate and rubber the most expensive. For dry ducts, where there is no danger from corrosion of the lead sheath or where electrolysis is absent or may be guarded against, paper cables may be used. Paper is also used to a great extent for trunk lines. Paper cable must not be used without a lead sheath, for the life of a paper cable is dependent upon the sheath, the presence of moisture causing the insulation to break down almost immediately. Electrolysis, therefore, proves disastrous to paper cables.

Varnished cambric cables have all the good qualities of paper cables and may be used in almost any place where rubber cables could be used. These cables are built up of successive layers of lapped, varnished cambric tape, with plastic compound between layers, this compound permitting the layers to slide on themselves when the cable is bent, without reducing the thickness of insulation between conductor and lead. This type of insulation is waterproof, and the ends of the cable do not necessarily have to be sealed to prevent moisture entering, as with paper cable. This is also true of rubber insulated cable. Since varnished cambric tape is used in insulating, the copper core must be in the center of the cable, while with rubber insulation for heavy copper cores, used for horizontal runs at high temperature, there is a tendency for the rubber to soften, thus allowing the core to drop and reduce the thickness of insulation between copper core and lead sheath.

Varnished cambric cables with a braided finish may be used for inside work, as the insulation does not absorb moisture. These cables, unlike paper insulated ones, are not seriously affected by electrolysis.

Rubber insulated cables are used where there is constant moisture and almost invariably for submarine use.

Paper cables may be bent to a radius equal to eight times the outside diameter of the cable, while rubber and varnished cambric may be bent to a radius of six times this value.

For direct current low tension and railway feeders, single conductor cables are generally used. In some cases where two or three small feeders run parallel for any considerable distance, it is frequently desirable to combine them into one large cable running to the station.

For the grounded side of street railway feeders, or the neutral of three-wire Edison systems, a bare wire may be used, but this should not be run in the same duct with leaded cables. An ordinary weatherproof finished wire is often substituted for this bare wire.

Low tension feeder cables are frequently of the two-conductor concentric type with pressure wires in the outer conductor. The carrying capacity is slightly less than that of a two-conductor cable leaded flat as there is less chance of radiation; but the concentric type is easier to install and is much more economic of duct space.

For alternating current single-phase two-wire systems, the duplex type is preferable unless many taps are called for, and if so, single conductors are sometimes used on account of the greater ease in making joints.

The largest solid conductor recommended is 4; larger conductors are too stiff to handle and should be made stranded.

Duplex or figure 8 cables larger than 250,000 cir. mils. are liable to kink in handling and are not used to any great extent. For larger cables the two conductors may be stranded up with fillers to make them round, and the lead applied. Any size of duplex (Fig. 8) cable must have special care in installing to prevent kinking.

For three-phase work, it is advisable to use three-conductor cables; for, with this construction, there is no loss theoretically in the lead sheath, and, if necessary, telephone cable may be run in the same duct system without disturbance.

On low tension systems, single conductors are frequently used on account of the ease in making service taps.

The chief advantages in using three-conductor cable are: cost of installing is less and installation is easier, while the first cost of a three-conductor is approximately the same as that of three single conductor cables.

Three-phase cables are more economical of duct space than either single or two-conductor cables. Three-phase Y connected cables are generally run with grounded neutral and the thickness of insulation between conductor and ground need only be seven-tenths the insulation between conductors, thereby allowing a slightly larger cable to be installed in conduit than a three-phase delta connected, where insulation between conductors and between conductor and ground is the same.

The general practice in three-phase cable work is to use the so-called split type of insulation, placing half of the total thickness required on each conductor, stranding the three conductors up with jute fillers to make round, wrapping the three conductors with the second half of insulation, and applying the lead finish. This makes a more compact cable than when applying all the insulation on each conductor and is somewhat cheaper.

For arc circuits, single-conductor and also duplex cables are in general use. Where several circuits run parallel for any distance, they are sometimes combined into a multiple-conductor cable, for if several single conductors are run in one duct the lead sheath is liable to be injured in installing, and if one cable burns out, it is likely to injure one or more conductors.

One danger in underground cables which should be guarded against is electrolysis, for no manufacturer will guarantee his product against electrolytic action. The amount of electrolysis depends primarily on how near the cables are to electric railway lines, the distance they run parallel, and the condition of the return circuit of the railway, also the proximity of water pipes and gas mains. Electrolytic action occurs at the point where current leaves the lead sheath; therefore, with leaded cables, it is customary where this danger exists to provide suitable grounds at intervals along the system.

Sometimes this is accomplished by driving an iron pipe into the earth at each manhole. This can be tested out with an electric current of about 110 volts, connecting one side of circuit to pipe and other side to an adjacent hydrant, and then driving in pipe until sufficient current passes to make sure that a good ground is obtained. It may be necessary to drive as much as thirty feet of pipe or more in dry soil before a good ground is reached. It is sometimes customary to provide grounds by burying large copper plates in the earth, embedded in coke. In any case all lead sheaths in the manhole should then be connected to ground.

With railway systems, the negative side of the generator is usually grounded and the lead sheath of the return circuit should be connected to the negative side of generator by suitable copper cable. If precautions are taken, the danger from electrolysis may be reduced to a minimum.

After the duct line is installed it is good practice to pass a mandrel through each duct, thus removing all obstacles and making sure that ducts align. This is sometimes accomplished with rods about three feet long, provided with a coupling device, and as many rods as are required to reach from one manhole to another are successively joined.

At the same time that the mandrel is pulled through, an iron "fish" wire is also drawn in and left until it is desired to install cables in that particular duct, when the fish wire serves to pull through the heavy rope which is fastened to cable by a cable grip.

There are several methods of pulling cable. Short runs of light cable are sometimes pulled in by hand, but for heavy cable it is necessary to use some form of winch or manhole capstan. Both electric and gasoline-driven winches are being used with success.

It is advantageous in drawing in cable to have a man in the manhole where he can watch cable and make sure that it is not being pulled in faster than it is unreeled, thus preventing sharp bends which might prove injurious. He can also smear the sheath with a cheap grade of vaseline, which in the case of heavy cables makes them slide easier.

All cables to be installed in one duct should be drawn in at the same time, for if a cable is pulled in afterwards, it is almost sure to injure the lead of cables already installed. It is also poor practice to draw out one cable from among one or more others.

Enough slack should be allowed to permit cables being passed around the sides of manhole, and also to permit jointing, for occasionally cable ends are injured during the process of drawing in, necessitating cutting back far enough to remove injured portion.

With single conductor cables, where a butt joint is used, the ends in the manhole should overlap slightly, and for multiple conductor cables, where joints are staggered, the overlap should be enough to take care of this.

Ends of duct should be provided with lead collars on which the cable rests, thus preventing sharp corners of duct from injuring the lead sheaths. It is also good practice to use rubber bushings made of old hose between iron hangers and cable, which prevent leakage of stray current from one cable to another.

Cables in manholes are often protected by asbestos listing or by enclosing them in split duct, thus preventing the danger of a burnout on one cable from affecting another. This also protects cables against injury from careless workmen and prevents their being used for steps in descending into a manhole. All sharp bends should be avoided.

With high voltage leaded cables of 2500 volts and over, there is a tendency to puncture the insulation at the ends of lead sheath; therefore end bells are required at the station end of system, and also at the farther end where cables change from the leaded underground type to the braided overhead. These are generally of spun brass wiped to the lead sheath, their object being to flare out the lead, thus preventing a breakdown at the ends.

With paper insulated cables, the bells are made long so as to allow of the joint being made inside the bell. A cap is provided, through which the overhead cable end passes, and after the joint is completed, the bell is filled with a compound which prevents moisture entering and also acts as an insulator.

Underground systems when connected to overhead should be protected from lightning discharges by suitable arresters placed on second or third pole from the end of the cable.

It is desirable, after cables are installed and connected, to test them for five minutes with about twice the working pressure to make sure that there are no weak points due to imperfect jointing, or injury during installation.

Junction boxes are a necessity on low voltage systems and are installed in manholes at feeding points or street intersections so that in case of local trouble the feeders and mains may be disconnected.

Services are usually run from manholes or from service boxes located between manholes at street surface. Iron pipe is frequently used, so laid as to drain into manhole. For long services, cable with band iron armor finish is laid directly in the earth. The band iron protects the cable from injury, but it is customary to place a heavy plank over the cable so that in future excavations workmen will not injure the cable with a pick.

Service cables are sometimes connected to mains through service boxes placed in manholes. This arrangement is inconvenient in case of trouble; therefore it is customary to place service boxes on customers' premises.

There are several installations of so-called Edison tube systems still in use, but at present the popular drawing-in system which this article deals with is used almost exclusively throughout the country.

MOTIVE EQUIPMENT FOR ELECTRIC AUTOMOBILES

By H. S. Baldwin

Since the introduction of the electric automobile manufacturers of electrical apparatus have been active in the development of automobile equipments, consisting of motors, controllers and resistances designed to give the most efficient and economical service and to conserve the battery.

In the earlier automobiles, designers generally employed two low-speed motors, each of which operated the driving wheels by means of single reduction spur gears. Of late years, however, this practice has been largely abandoned in favor of the single motor and countershaft with double reduction chain transmission.

The advantages claimed for the single motor drive may be briefly summed up as follows:

1. It affords a material saving in weight, cost and space occupied, as against two motors of practically the same capacity.

2. By the use of double reduction gearing with countershaft, it is possible to design the motor for higher speed, which tends to lessen weight and insure electrical efficiency.

3. It further permits the motor to be mounted on the chassis, well up from the ground, which arrangement was not possible with the single reduction gear drive of the past.

It was realized by the General Electric Company that the high-speed single motor drive represented the simplest, most practical and efficient form of equipment that could be offered, and as a result they proceeded with the development of the so-called GE-1020 line of motors, of uniform mechanical construction throughout.

In addition to motive equipment, this Company supplies specially designed charging equipments, comprising rectifiers, motor generator sets, switch boards, rheostats complete with controlling panels, and many other useful and desirable appliances.

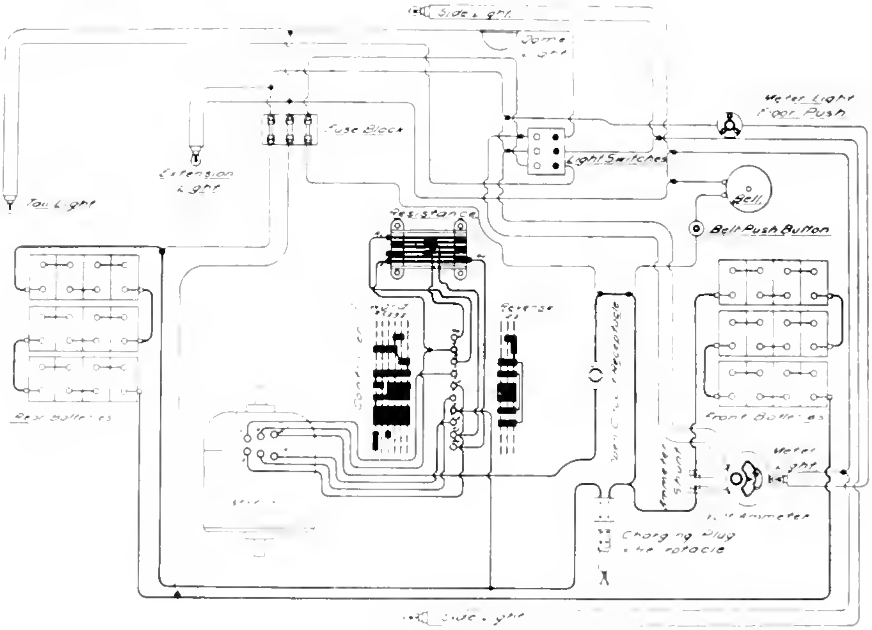


Fig. 1. Diagram of Connections of Electric Automobile Equipment

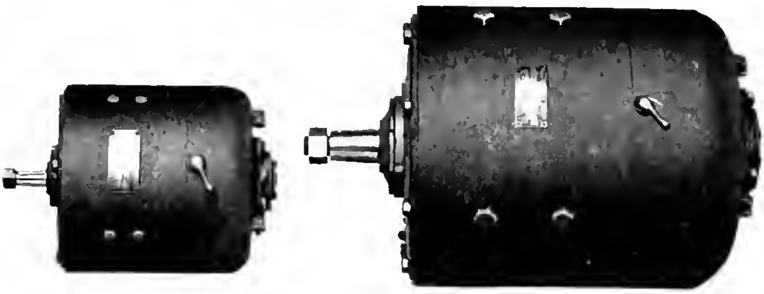
In order to meet the requirements of automobile manufacturers, the motors have been made in six different sizes, each of which can be supplied in several electrical ratings. It will readily be seen that this line is the most complete ever offered, and that a motor can be selected for any vehicle, from the smallest runabout to the heavy 5-ton truck.

The motors are of unique mechanical design (Fig. 2), the frame and one head being made from a single piece cylindrical steel casting, machined from end to end. By this construction the minimum of weight and maximum of strength are combined. This feature is original with these motors and is not to be found in those of other make.

It is of paramount importance to protect the storage battery, and all of the motors under consideration are designed with this object in view. They have a steep torque curve and give about five times the torque for two-and-a-half times the current, throughout the limits of their capacity. It might be well to add a word of explanation as to this statement. To obtain long life and efficient operation, the storage battery should not be discharged more rapidly than at the one hour rate. To start and accelerate an electric automobile requires approximately five times the running torque. Again, the average maximum grade encountered in cities is about 7.6 per cent., to climb which also requires about five times normal torque. It will, therefore, readily be seen that a properly designed electric automobile motor, having the above characteristics, will accelerate the vehicle and climb any ordinary grade without exceeding the one hour discharge rate of the battery.

The standard motors have cast iron heads fitted with the most improved annular ball bearings, which somewhat increase the efficiency, reduce the overall length of the frame and require only occasional lubrication. All electrical factors are liberal, permitting these motors to be run at high overloads for considerable periods of time without injury. The commutators are composed of a large number of bars, and observations covering several years' use of motors in service indicate that the commutation is practically perfect, great care having been taken to secure this result. Special graphite brushes of large area are used and the current per square inch of brush contact is lower than usually obtains in electric motor practice.

Two motors, namely the GE-1022 and the GE-1027, have only recently been added to the line, the former being suitable for 3-ton



Runabout Type; Weight 150 Lb. 5-Ton Truck Type; Weight 660 Lb.

Fig. 2. General Electric Automobile Motors

and the latter for 5-ton single motor trucks. All motors are of the 4-pole type, and with the exception of the smaller sizes for runabouts are designed to operate at 85 volts, experience indicating this voltage to be most advantageous when the lead battery is employed. The runabout motors are built to operate at 48 or 60 volts, as desired.

Special attention is called to the fact that all motors are constructed so that the shaft can be removed without disturbing the commutator or winding. This feature affords great flexibility and permits a change of shaft at small expense, to accommodate special conditions or when worn.

In the manufacture of the field coils, railway practice is closely followed, especially as regards insulation and treatment; thus the coils are adapted to withstand severe service conditions. Copper is used liberally throughout in the complete line of motors. This is especially true as regards the field coils, a feature which, together with high grade brushes, ball bearings, and commutators of

STANDARD AUTOMOBILE MOTORS

Type	Volts	Amps	R P M.	Vehicle	Controller Speeds	
					Forward	Backward
GE-1028	48	26	2000	Runabouts	6	3
GE-1020	85	20	2000	Light delivery	6	3
GE-1025	85	22	1200	1000 lb. del.	4	2
GE-1026	85	28	1200	2000 lb. del.	4	2
GE-1022	85	40	1200	3-ton truck	4	2
GE-1027	85	60	900	5-ton truck	4	2

small diameter, insures the highest possible electrical efficiency, so important when the storage battery is the source of power.

It will readily be seen that the General Electric automobile motors are practically universal in form, and can be adapted to many different methods of suspension and mounting. By use of the accurately machined motor frame, it is possible to meet all practical requirements of automobile manufacturers as to mounting, since supporting brackets or cradle can be attached directly to the steel casting by means of screws. This results in quicker deliveries and lower costs, for the reason that a large amount of engineering and developmental expense is eliminated.

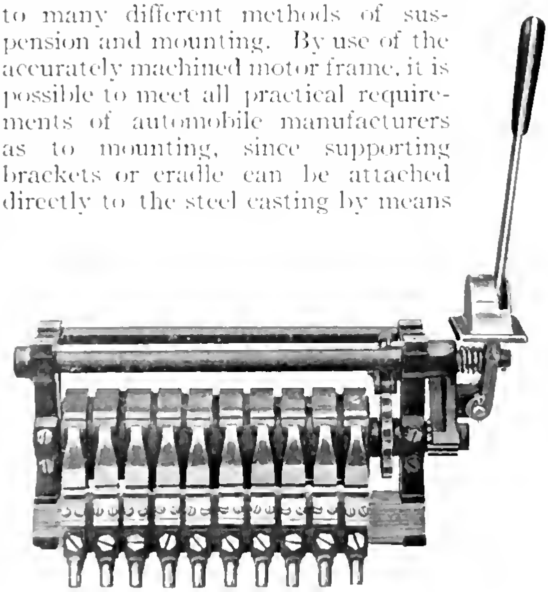


Fig. 3. New Controller for Automobile Motor

A good controller is scarcely less important than a good motor, and it is essential that each be selected with reference to the other and the nature of the service to which the automobile is to be put. All General Electric automobile controllers embody the continuous torque principle, which insures freedom from jolts due to opening of circuit when passing from series to multiple connection of field coils. This is an important feature, which adds much to the pleasure of operating small cars and to the life of large trucks. With the single motor equipment, series parallel arrangement of fields is the standard form of control, resistance being used on intermediate steps. In the case of controllers for pleasure vehicles, it is customary to have a comparatively large number of points, to permit of slow operation in cities where the traffic is congested, and higher speed over park and country roads. Commercial trucks as a rule do not require this fine gradation of speed and, therefore, have only sufficient notches to safe-guard the chain or gearing of the transmission.

A new controller has recently been designed (Fig. 3), which contains all the good points of the several types heretofore offered, with the additional advantage that many of the same parts can be used for different systems of connection, thereby insuring uniformity of construction. The new controller is of the cylindrical drum type and is operated by a pinion and sector at one end. The sector is mounted on a countershaft which carries the operating hand lever. Drum contacts are made from drawn copper tubing, screwed in place on a treated wood drum, and horn fibre spacers are inserted to insure smoothness of operation and to prevent sparking. Contact fingers are of rolled copper stock, secured to phosphor bronze springs. The controller is designed throughout with a view to withstanding rough usage.

An operating handle of new design has been provided, made from drop-forged steel and having the advantage that it can be formed to suit the automobile manufacturer. This is very desirable, since there is a great diversity of opinion as to shape of seat and body outline.

To make the equipment complete, a light cast iron grid resistance is employed (Fig. 4). This again is of sturdy construction and heavily insulated with mica. All terminals are drop-forged.

An important point in connection with these motive equipments is that the terminals, leads and contacts of each component part are marked with letters in accordance with the wiring diagram, so that the necessary connections in an electric automobile can be made by those not having special electrical knowledge.

Fig. 4. Cast Iron Grid Rheostat

APPARENT CHANGE OF RATIO OF TRANSFORMATION IN THREE-PHASE TRANSFORMERS

By G. Faccioli

Sometime ago three single-phase transformers were installed to operate a rotary converter. The primaries of the three transformers were connected "Y", and the secondaries "Y" diametrical. The difference of potential between primary lines was 11,000 volts, and the normal voltage of each secondary winding 210 volts.

The three transformers were connected to the high tension feeders (11,000 volts) and the voltage across each secondary winding was measured at no load. This voltage resulted to be 235 volts instead of 210.

The leg voltage corresponding to 11,000 volts "Y" is 6360 volts and the ratio of the transformer windings was exactly 6360:210; therefore there was no apparent reason for the higher secondary voltage. An investigation of the trouble immediately disclosed the fact that the secondary voltage was increased at no load from 210 to 235 volts by a triple frequency component of the voltage.

A brief review of the phenomena involved in the case will probably prove of some interest.

It is known that if a single-phase transformer is excited by a sinusoidal electromotive force, the magnetizing current is considerably distorted, owing to the characteristics of the iron in the core.

Fig. 1 shows the curve of exciting current of a 25 kw. transformer at normal excitation. The electromotive force applied across the exciting winding was a perfect sine wave, and its effective value 460 volts. The analysis of the complex wave of current gives the following results: If the maximum value of the complex wave is assumed to be 100, the fundamental component will have a maximum value of 57.3, the third harmonic a maximum value of 30.2, the 5th harmonic a maximum value of 10.6, and the 7th harmonic a maximum value of 2.96. The predominant overtune of this wave is, therefore, the third harmonic, and this is generally the case with every transformer.

Now let us take three of these 25 kw. transformers and connect their exciting windings in "Y", leaving the secondary windings disconnected, then apply across the lines 795 volts, which corresponds to a leg voltage of 460 volts. Each of the three transformers requires for its magnetization a triple frequency current, and since the electromotive forces across each transformer are 120 degrees apart, it is evident that the magnetizing currents and their high frequency components will have the same phase displacement. The triple harmonics of the magnetizing currents will then be displaced 120 degrees; but 120 degrees constitutes exactly one wave length of the triple harmonic, and therefore the three triple frequency components of the magnetizing current in the three transformers will be in phase with each

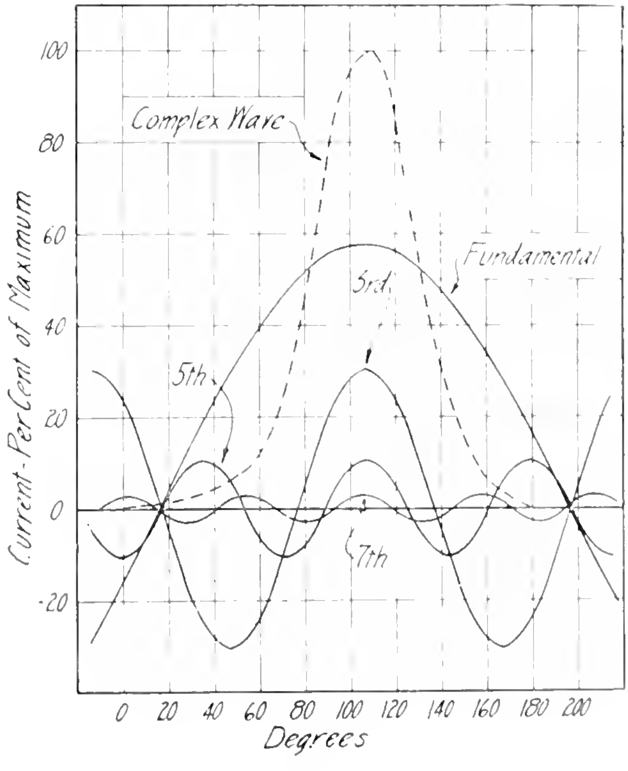


Fig. 1

other. The arrows in Fig. 2 represent the directions of the three triple frequency currents in the legs of the "Y" at any instant. It is obvious that under these conditions such currents cannot flow, and therefore the flux in each core can no longer be a sinusoidal flux and the electromotive force across each individual transformer cannot be a sine wave. In other words, although a sinusoidal e.m.f. is applied be-

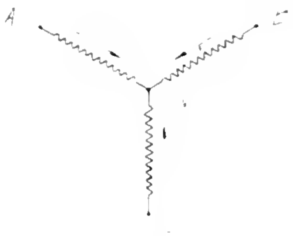


Fig. 2

tween AB, BC, and CA, the electromotive forces across AN, BN and CN must contain some high frequency components which are necessary to restore the equilibrium.

795 volts were applied across the lines of the "Y" system, giving a leg voltage of 460 volts, and the electromotive force across AN, BN and CN was measured and resulted to be 525 volts instead of 460. The secondary windings of the transformers were not connected together. Fig. 3 gives the curve of this electromotive force and its analysis. If the maximum value of the complex wave is taken as 100, the maximum values of the fundamental and the 3rd and 5th harmonics are respectively 64.5, 33.3 and 2.2. The wave of the line current was taken at the same time and is given in Fig. 4. The analysis of this current wave gives 100 maximum complex, 84.2 maximum fundamental, 21.8 maximum 5th, and 3.3 maximum 7th. This current is then free from third harmonics, as we had anticipated; but the triple frequency distortion, which could not appear in the wave of current, appears in the wave of electromotive force. If we neglect the 5th harmonic, which is comparatively small, and assume that the electromotive force across each transformer is composed of a fundamental and third harmonic, we can immediately deduce the value of this third harmonic.

The fundamental is equal to 460 volts (the normal leg voltage corresponding to 795 volts across lines) and the third harmonic is equal to

$$\sqrt{525^2 - 465^2} = 250.$$

In fact, it is well known that the effective value of the sum of two effective vectors of different frequency is equal to the square root of the sum of their squares. We see then that the "Y" connection on the exciting side does not allow the flow of any triple frequency currents, and that, in consequence, the voltage across each transformer is composed of a fundamental wave of 460 volts plus a triple frequency component of 250 volts. This latter component is equal in all three transformers and affects equally the three voltages AN, BN and CN. Furthermore, the difference of potential between the point N and the neutral of the generating system is evidently equal to 250 volts, and has a frequency three times the fundamental.

To remedy this distortion of the voltages, two methods can be followed: First, the neutral N of the "Y" can be connected to the neutral of the generating system; and second,

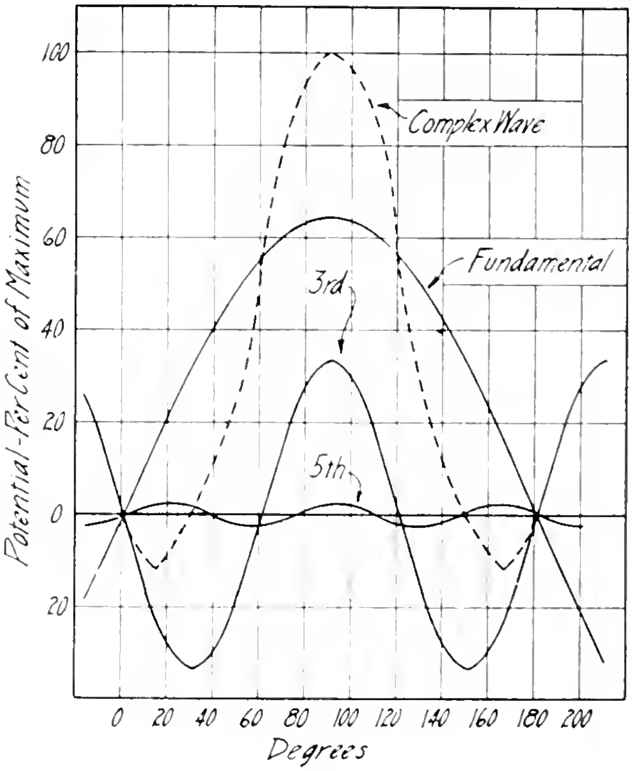


Fig. 3

the secondary windings of the three transformers can be delta connected.

In the first case, the three triple frequency currents of each leg will flow in the neutral wire and the magnetizing current of each transformer will have the same value and shape of wave as in the case of single-phase connection. If follows that the electromotive force across each transformer will be a sine wave and equal to 460 volts. In the second case, the triple frequency currents which cannot flow in the primary winding circulate in the closed secondary delta because the direction of these currents is the same in the three sides of the triangle.

This can easily be seen by remembering that the secondary electromotive force of each transformer must be an exact reproduction of its primary electromotive force. Then, if the primary electromotive force has a triple frequency component, the electromotive force induced across each side of the secondary delta must also have a triple frequency component. These triple frequency electromotive forces induced across each side of the delta assist each other, as shown in Fig. 5, and produce in the closed delta a triple frequency current which is magnetizing in character and excites

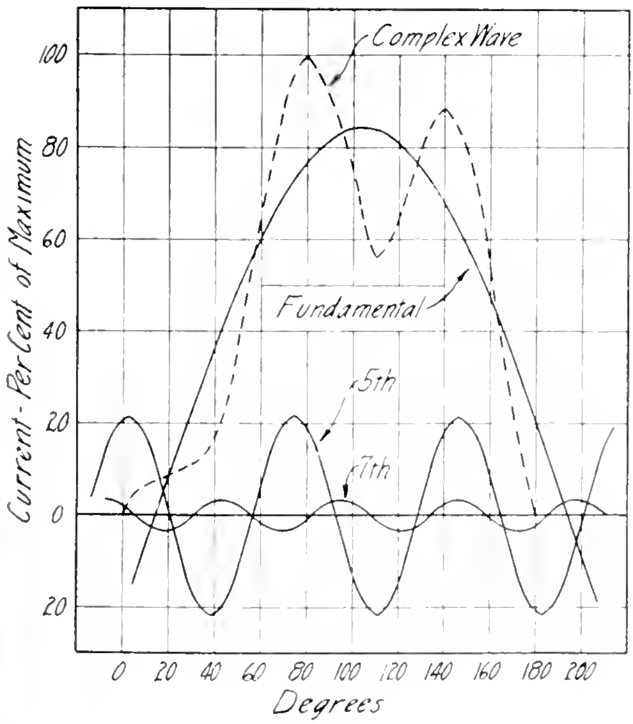


Fig 4

the triple frequency flux necessary to give a sine wave of flux in the transformer. The final result is that across each side of the delta there will be only a small triple frequency electromotive force, active in sending the triple frequency magnetizing current through the resistance and leakage reactance of the windings, and that the voltage across each transformer will be practically a sine wave.

But if the secondary delta is open and the

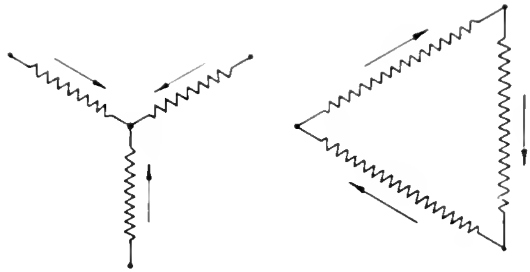


Fig. 5

primary neutral not connected to the neutral of the generating system, each leg of the "Y" has a triple frequency component of the electromotive force across its terminals, which is also present at the terminals of each secondary winding.

The common method of deducing the voltage across the secondary windings of a three-phase system, the primary of which is "Y" connected, consists in dividing the voltage between primary lines by $\sqrt{3}$. This gives the voltage across each leg of the primary, and this voltage multiplied by the ratio of turns gives the secondary voltage. In the case just mentioned, this method of calculation is incorrect, because, as we have seen, the leg voltage of the primary and the voltage across the secondary windings are considerably increased by the presence of a triple harmonic.

This is the reason for the apparent discrepancy in the ratio voltages referred to at the beginning of this article. In that case 11,000 volts were impressed across the primary lines, giving 6360 as the corresponding leg voltage. Since, however, the neutral was not connected to the neutral of the generating system, and the secondary windings were open (diametrical "Y"), a triple frequency component of the voltage was active across each leg of the "Y". This component was reproduced across the terminals of the secondary and increased the secondary voltage from 210 to 235 volts. The value of this component is

$\sqrt{235^2 - 210^2} = 105$ volts on the secondary side. This means that the triple frequency component of the e.m.f. on the primary side must be

$$105 \times \frac{6360}{210} = 3190 \text{ volts.}$$

This is the difference of potential between the neutral of the "Y" and the neutral of the generating system, and the potential across each primary leg is

$$\sqrt{6360^2 + 3190^2} = 7100$$

Now $\frac{6360}{210} = \frac{7100}{235}$, that is to say, the ratio of voltage measured across primary and secondary windings of each transformer is equal to the ratio of the turns; but it is impossible to deduce the leg voltage from the voltage across lines by dividing it by the coefficient 1.73. Conditions of this nature are very frequent in three-phase systems.

If the transformers are loaded, the apparent change in the ratio of voltages disappears at once. Therefore, the presence of the triple frequency e.m.f. in this case has practically no effect on the operation of the transformers.

FURNACE ECONOMY

By F. W. Caldwell

Many power stations are operated uneconomically, due to indifference or ignorance in regard to the operation of the boiler plant.

Although there has been a great deal of discussion concerning the value of determining the quantity of CO_2 (and neglecting other gases) in boiler furnaces, the opinion seems to be very definite that some form of indicating apparatus is of great advantage to the firemen as well as to the plant operator, but that there is no apparatus which can entirely replace the trained eye in determining the best kind of fire.

Perfect combustion, high furnace temperature, high velocity of gases over heating surfaces, and low stack temperature are all advantageous, and the best efficiency of evaporation is attained when all of these are a simultaneous maximum. Gas analysis is influenced by the first two conditions, slightly by the third, not at all by the fourth, and is itself a perfect measure of none.

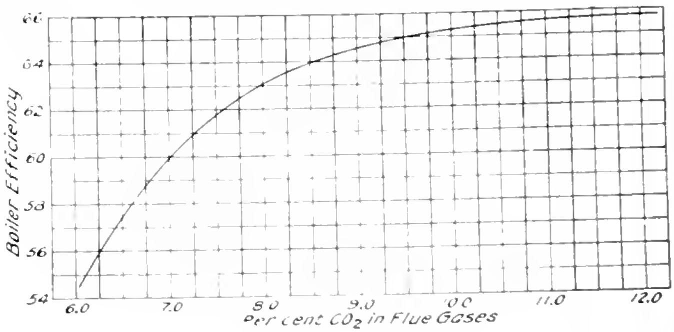
If there are holes in the fire bed, the oxygen content will rise and the amount of carbonic acid will fall in proportion. Gas analysis will reveal the presence of such holes, and so will the eye coupled with an examination of the fire bed with the usual fire tools.

If a fire is thin and is passing too much air, gas analysis will give the same indication that is given when a fire bed contains holes, and it will not determine which of these troubles exists. The usual draft gauge and fire tool are the final instruments and might have been used in the first place. Again, leaks in the setting give this same oxygen indication and must be determined separately, independently of gas analysis.

The most common errors are the admission of too much air to the furnace, uneven fires and poor methods of firing. An analysis of the flue gases is naturally the best evidence of what is taking place in the furnaces.

The flue gases consist principally of nitrogen (N), carbon dioxide (CO_2), oxygen (O_2), and carbon monoxide (CO), the proportions depending upon the amount of air admitted to the furnace, the completeness of combustion and the quality of the coal used.

Generally speaking, a low percentage of CO_2 indicates the admission of too much air to the furnaces and a low boiler efficiency. A high percentage of CO always indicates incomplete combustion and a low boiler efficiency. The correct percentage of CO_2 has always been subject to more or less discussion, the estimate varying from 9 to 14 per cent. Certain boilers which are of the water-tube, internally-fired type, have



Curve Showing Percentage of CO_2 in Flue Gases for Different Boiler Efficiencies given the best results where CO_2 was 15 per cent., although in some types of water-tube boilers, when attempting to run at high values of CO_2, the arches and side walls have been burned out. The correct percentage undoubtedly varies for different boiler settings, the quality of coal burned, etc., but a percentage of 10 to 12 per cent. usually indicates the most economical operation. The attached curve was taken from the Government Boiler Testing Plant at St. Louis, Mo., Bulletin No. 325 of the U. S. Geological Survey. This curve indicates that CO_2 should have in general a value of about 10 per cent. The upward slope of the curve indicates that a higher efficiency is obtained by raising the percentage of CO_2.

The improvement in boiler efficiency effected by increasing the percentage of CO_2 in flue gases from 6 to 11 per cent., as shown in this curve, is 11.8 per cent., and corresponds to a saving of 20 per cent. in the coal burned. This curve probably shows the improvement that could be expected in the average boiler plant. The percentage of CO_2 in the flue gases can be almost entirely regulated by proper damper control, careful firing, etc.

In order to act intelligently, the boiler plant operators must have an analysis of the flue gases as often as possible. Due to the small percentage of CO compared with the total volume of flue gas, the usual gas analysis does not give reliable figures on this content. The usual practice, therefore, is to obtain the percentage of CO_2 only. The oldest method of obtaining this analysis is with the Orsat apparatus, which is very reliable but not automatic. With this apparatus, one man who does nothing else analyzes a sample of the flue gases about every twenty to thirty minutes. Today there are several fairly reliable devices on the market which record the percentage of CO_2 automatically, giving the operator a continuous record to work by.

A very satisfactory method is to have an automatic device before each fireman. This device need not have great accuracy, as anything that makes a mark varying with the firing will constantly urge the man to his best endeavours. If, in addition to this, supervision is exercised by one well trained in the fireroom and the results for the day are accurately summated, a good degree of economy should be secured.

It would appear that the curve can be taken to represent general values, although there is no doubt that a few boiler tests on each type of boiler would indicate that the best results could be obtained by very slightly raising or lowering this curve. There can however, be no question but that a percentage as low as 6 makes a tremendous difference in the economy of the boiler.

BOOK REVIEWS

THEORY AND CALCULATION OF TRANSIENT ELECTRICAL PHENOMENA AND OSCILLATION

By Charles Proteus Steinmetz

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The increasing use of the alternating current within the past few years has rendered the subject of transient phenomena of vital importance; there has been, however, no work available which treated the subject in a thorough and consistent manner. With the publication of Dr. Steinmetz's book, a treatise has been placed in the hands of engineers which, for the first time, adequately discusses these complex phenomena. The book is therefore a pioneer work; it is, in fact, epoch making.

An exact physical definition of the expression "transient phenomena," one which shall be sufficiently inclusive and at the same time non-mathematical and easily understood, is rather difficult to frame. In his preface, the author defines the term by giving the common characteristic of the phenomena. He says: "the characteristic of all transient phenomena is that they are transient functions of the independent variable time or distance." Transient phenomena may be described as all those phenomena that are episodial in character; *i.e.*, that begin at a certain moment or place and vary continuously either gradually or in an oscillatory manner with the time or the distance, finally becoming constant at a maximum or zero value. The building up of a dynamo is a transient phenomena, the rise of current in a circuit upon closing the switch, the discharge of a condenser, the surge in a transmission line, etc., etc.

While the inherent nature of the subject absolutely necessitates the employment of higher mathematics, the author wherever possible has used the simpler algebraic forms; furthermore, after developing the various theories, he has applied them practically to working conditions, and has given concrete numerical examples. This is an especially valuable feature of the work, as it renders the conclusion of the theoretical discussions available to all classes of readers, and thus does not limit the book's usefulness merely to those whose mathematical training enables them to follow the discussions in their entirety.

From such a mass of uniformly valuable material, it is difficult to make selections for special comment. The book covers the subject thoroughly, and considers transient phenomena as involved in generation, transformation, rectification and transmission under both normal and abnormal conditions. A beautifully lucid presentation of the subject of artificial leakage and loading is also included. Skin effect and other properties of wires and cables are fully discussed, as is also the theory of lighting and lightning protection.

THE ELECTRIC SOLICITORS' HANDEOOK

This book is issued by the National Electric Light Association under an editorial committee with Mr. Arthur Williams as chairman, and as might therefore be expected is a thoroughly practical and useful production. It is written for the use of central station solicitors and all others directly interested in the applications of electricity. The book is divided into three chief sections, entitled, "Illuminating Engineering, Heating Engineering and Power Engineering." The three sections are prefaced by some valuable information on business getting and talking points. A complete index is provided which shows a very wide range of subjects dealt with. The use of very concise and simple methods and round numbers, etc., is of course, necessary in a book of this type, but it forms the most valuable addition to the library of the central station man that we have had for a long time.

The range of the book can possibly be best illustrated by a few examples. The following, for instance, are extracts taken at random:

Cost of Central Station Service Compared with Isolated Plants; Horse Power Required to Drive Various Machines; Load Factors for Different Classes of Service; Data on High Pressure Exhaust Fans; Application of Motors to Machine Tools; Electric Heating Calculations; Power Taken by Different Heating Devices; Estimation of Illumination; The Lighting of Factories; Power Consumption of Various Forms of Lamps; Table of Reflection Coefficients; The Electric Motor in the Household; The Electric Motor Compared with the Gas and Gasolene Engine; The Electric Motor Compared with an Isolated Steam Plant; Electric Light Advertising; Specific Advantages of Electric Light; The Relation of the Company to the Consumer; Methods of Keeping Records, Etc.; How to Meet Opposition and Competition.

This book would have been still more valuable if it could have been published at the time the manuscripts were completed by the different competitors now more than two years ago since it now contains a large amount of matter either not available elsewhere or difficult to find. At the time referred to, it must have been a still more exceptional production. We note with pleasure that a large share of the credit of this production belongs to one old employee and one present employee of the General Electric Company.

OBITUARY

James J. Mahony, who had been connected with the General Electric Company since its organization, died on March 19th at Holyoke, Mass., at the home of his sister, Mrs. A. J. McDonald.

Mr. Mahony was born at Worcester, Mass., June 16, 1863. His parents were Maurice and Mary White Mahony, both of Ireland.

He received his education in the Public Schools of Worcester, entering the High School in 1876, where he stood well in all his classes, and in particular showed marked ability in mathematics.

At the end of his third high school year he left school to accept employment at Forehand & Wadsworth's pistol factory, where his father had been employed for some years. He remained with this concern a year or more and then served an apprenticeship as machinist with the McMahone & Carver Tool Company. During this time he also took up the study of engineering and mechanical drawing.

In the spring of 1888 Mr. Mahony entered the employment of the Thomson-Houston Company at Lynn, where for the first six months he worked as a machinist under Mr. John Riddell, and was then transferred to the expert corps. A few months later he was sent to take charge of the installation of car equipments and to supervise the operation of street railway apparatus during their trial period. While in this position he had charge of a number of important railway installations, among others the street railways of Albany and the original West End power station of Boston.

In 1891 the Foreign Department of the Company sent him to Australia to take charge of a number of installations, one of importance being the Sydney Tramways.

Returning about two years later, he was placed in charge of similar work in and about New York City. He erected the electrical machinery in the Kent Avenue power station in Brooklyn and built the first large direct connected generators in both Brooklyn and Boston. He also accomplished a great deal of important inspection work throughout the United States and Canada.

About twelve years ago Mr. Mahony became connected with the Commercial Department of the New York Office; and here, by reason of his tactfulness, diplomacy and unfailing courtesy, he made one of his greatest successes.

In 1905, at the Company's request, he made a trip to South America, from which, after a few months, he returned to his duties at the New York Office, where he remained until the time of his death.

Through his inherent ability and by his own unaided efforts Mr. Mahony rose to a high position in the electrical profession, his sterling character and perseverance commanding the respect and admiration of his associates. He possessed a personal charm that was exceptional.

From his boyhood, he was very fond of outdoor sports, being particularly interested in baseball and golf; he was also an exceptionally expert sailor and was the winner of a number of cups. He was a member of the Engineer's Marine and Field, Dyker Meadow, and Scarsdale Golf and Country Clubs.

The funeral services, which were very largely attended, were held in St. Paul's church, Worcester, and the interment was made at St. John's cemetery.

FORMULAE, CONSTANTS AND HYPERBOLIC FUNCTIONS

FOR

TRANSMISSION LINE PROBLEMS

With Explanation and Examples of their Use

By W. E. Miller

"General Electric Review" Supplement

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FORMULÆ, CONSTANTS AND HYPERBOLIC FUNCTIONS

FOR

TRANSMISSION LINE PROBLEMS

NOTE. In using the formulæ given below, the following points should be noted:

All voltages given in the formulæ must be those between wire and neutral. That is, the line voltage for three-phase lines must be divided by $\sqrt{3}$ before substituting in the equations, and must be divided by 2 for single-phase lines. The currents are given in amperes per wire. Hence, the power lost, delivered or generated, calculated from the equations, only refers to one phase and must be multiplied by 3 to obtain the total power in three-phase lines, and by 2 in the case of single-phase lines.

Phase Convention

When the voltage is given at some point, as at the receiving or generating end, it is usually taken as the standard phase, and all other voltages or currents, calculated or given, refer to this phase. Thus, according to the sign convention adopted throughout *viz*, contra clockwise rotation, the given voltage v (say at the receiving end) is written v without any j term. If the voltage or current at any point is $a+jb$, the $+$ sign indicates that the voltage or current leads the voltage v by the angle $tan^{-1}\frac{b}{a}$; a negative sign would show that they lag behind the voltage v by the same angle. The form $-a+jb$ indicates that the current or voltage at the point considered leads the voltage v, at the receiving end, by the angle $tan^{-1}\left(\frac{b}{-a}\right)$, that is, by an angle greater than 90°.

A current or voltage $a+jb$ means that a amperes or volts are in phase with the standard voltage phase and b amperes or volts are in quadrature with the standard phase. The prefix j is equal to $\sqrt{-1}$, therefore, $j\times j=-1$. The resultant value of voltage or current $a\pm jb=\sqrt{a^2+b^2}$. The product $(a+jb)(c+jd)=ac-bd+j(bc+ad)$ and so on. For division $\frac{1}{a+jb}=\frac{a-jb}{a^2+b^2}$ and so on.

The cosine of the angle that the current leads or lags the voltage at any point is the power factor at that point. Hence, if the power factor is given (at the receiving end say) the current $i=a\pm jb$ at this end can be obtained from the formula $\sqrt{a^2+b^2}\,(PF\pm j\sqrt{1.0-PF^2})$. Thus if the resultant effective current is 100 amperes at .80 P.F. lagging, $i=100(.80-j\sqrt{1.0-.64})$ $=80-60j$ and must be substituted in the equations, in this form.

Constants m, m_1 and $\frac{1}{m_1}$. Tables II and III, Pages 6 and 7

These are calculated to include the capacity and self-induction between wire and neutral, and the resistance per mile of single wire, whether for three-phase or single-phase lines.

When calculating single-phase lines, the constants determined for the wire spacings lying in a plane must not be used, but only those for triangular spacings. The constants for spacings in a plane must only be used for three-phase lines, when a sufficient number of transpositions has been made to produce balanced electrical conditions along the line.

The constants for any wire spacings between those given can be readily determined by interpolation. As noted in the tables, the values for m and $\frac{1}{m_1}$ must be divided by 1000. The values of m_1 are correct as they stand.

Resistance

The resistances included in the constants refer to hard drawn stranded copper wires, the value of the resistance used being given in the tables. If the resistance of a given line is slightly greater or less than that for which the tables have been calculated, the proper percentage increase or decrease in the constants can be obtained from Table I, page 5.

Hyperbolic Tables. Tables IV to XIII, Pages 8 to 17 inclusive

The values of *cosh* $(x+jy)$, where x is given in the top row and y in the extreme left or right hand column will be found in the columns headed a and b, and the values of *sinh* $(x+jy)$ in the columns headed c and d. Hence, the value of *cosh* $(x+jy)$ will be $a+jb$, and *sinh* $(x+jy)=c+jd$. The values of these functions lying between those tabulated can be readily obtained by interpolation, see example A.

Equations

The accurate equations for transmission lines are given below, provided the generator voltages and currents are simple harmonic functions of the time, and there is no corona effect.

When the electrical conditions are given at the receiving end and E_r = volts at receiving end between wire and neutral, I_r the current per wire, e the voltage at any point l, and i the current at the same point. The distance l is given in miles and is measured from the receiving end, then

$$e = E_r \cosh ml + I_r m_1 \sinh ml \qquad (1)$$

$$i = I_r \cosh ml + \frac{E_r}{m_1} \sinh ml \qquad (2)$$

If the conditions are determined at the generator end and E_g and I_g are the voltage and current respectively at this end, then the voltage and current at any point l along the line can be obtained from equations (3) and (4) following, l being measured from the generator end.

$$e = E_g \cosh ml - I_g m_1 \sinh ml \qquad (3)$$

$$i = I_g \cosh ml - \frac{E_g}{m_1} \sinh ml \qquad (4)$$

Approximate Formulæ for Short Lines

These formulæ can be used with an accuracy of 1 per cent. for lines using No. 2 wire up to 120 miles long at 60 cycles and 150 miles at 25 cycles. Greater accuracy will be obtained if larger wires than No. 2 are used, though the difference is immaterial. See example B.

If $m = p+jq$ and the conditions are given at the receiving end, then

$$e = E_r\left(1+\frac{l^2(p^2-q^2)}{2} + jpql^2\right)+I_r m_1 l(p+jq) \qquad (5)$$

$$i = I_r\left(1+\frac{l^2(p^2-q^2)}{2} + jpql^2\right)+\frac{E_r}{m_1} l(p+jq) \qquad (6)$$

If the conditions are given at the generator end

$$e = E_g\left(1+\frac{l^2(p^2-q^2)}{2} + jpql^2\right)-I_g m_1 l(p+jq) \qquad (7)$$

$$i = I_g\left(1+\frac{l^2(p^2-q^2)}{2} + jpql^2\right)-\frac{E_g}{m_1} l(p+jq) \qquad (8)$$

A. Example of Accurate Solution

Three-phase line, 300 miles long using hard drawn stranded copper wire No. 000 B.&S. triangularly spaced, with wires 10 ft. apart. Frequency 60 cycles.

From the tables $m = \dfrac{.421+2.11j}{1000}$ $\quad m_1 = 392 - 78.0j \quad \dfrac{1}{m_1} = \dfrac{2.44+.485j}{1000}$.

Suppose the following conditions are determined at the receiving end. Line voltage 104,000 volts, or 60,000 volts between wire and neutral. Load current 100 amperes at receiving end at .90 power factor lagging. Then, $E_r = 60{,}000$ and $I_r = 100(.90 - j\sqrt{1.0^2 - .9^2}) = 90 - 43.5j$. If the power factor had been unity $I_r = 100$, or if .9 leading $I_r = 90+43.5j$.

At the sending or generating end, $ml = \dfrac{(.421+2.11j)\,300}{1000} = .126+.633j$.

Then by interpolation from the tables of hyperbolics, the following values are obtained:

$\cosh ml = \cosh(.126+.633j) = .812+.075j$,

$\sinh ml = \sinh(.126+.633j) = .102+.597j$

The interpolation can be obtained as follows:
From the tables

$cosh(.12+.62j) = .820+.070j$

$cosh(.12+.64j) = .808+.072j$

Therefore, $cosh(.12+.633j) = .812+.072j$
From tables

$cosh(.14+.62j) = .822+.081j$

$cosh(.14+.64j) = .810+.083j$

Therefore, $cosh(.14+.633j) = .814+.082j$
But $cosh(.12+.633j) = .812+.072j$
Therefore, $cosh(.126+.633j) = .812+.075j$

By the same method $sinh(.126+.633j)$ can be determined. The above steps, for obtaining the interpolations, were given more for the purpose of showing how to use the tables than for determining the values of the functions; since with a little practice, it will be found that practically all values can be immediately obtained from the tables by inspection.

Substituting in equation (1) the voltage at the generator end is given as follows:

$$e_g = 60{,}000(.812+.075j)+(90-43.5j)(392-78j)(.102+.597j)$$
$$= 48{,}700+4500j+17{,}500+16{,}500j = 66{,}200+21{,}000j$$

Hence $e_g = \sqrt{66200^2+21000^2} = 69{,}500$ volts at generator end, between wire and neutral.

The generator voltage leads the receiving voltage by the angle $tan^{-1} \frac{210}{662} = tan^{-1} .318 = 17° 39'$.

To find the current of the generator end, substitute in (2), then

$$i_g = (90-43.5j)(.812+.075j) + \frac{60{,}000(2.41+.485j)(.102+.597j)}{1000}$$
$$= 76.3-28.3j-1.7+90.2j = 74.6+61.9j$$

Therefore, generator current $= \sqrt{74.6^2+61.9^2} = 96.8$ amperes per wire.

The generator current, therefore, leads the voltage at the receiving end by the angle $tan^{-1} \frac{61.9}{74.6}$ $= tan^{-1} .83 = 39° 42'$.

Therefore, the current at the generator end leads the voltage at the generator end by the angle $(39° 42') - \text{angle}(17° 39') = 22° 03'$.

The power factor at the generator end is, therefore, $cos(22° 03') = .927$ leading.

Transmission efficiency is thus $\frac{60{,}000 \times 100 \times .90}{69{,}500 \times 96.8 \times .927} = .87$

The total power delivered by the transmission line is $3 \times 60{,}000 \times 90 = 16{,}200$ kw., the total power lost in transmission being 2,400 kw.

To obtain the regulation, find the voltage at the generator end with no load current, that is, since $I_r = 0$.

$e_g = 60{,}000(.812+.075j) = 48{,}700+4{,}500j = 48{,}900$ volts between wire and neutral.

Hence, a voltage rise occurs between wires of $20{,}600 \times \sqrt{3}$ volts $= 35{,}500$ volts at the generator end when the load is increased from nothing to 100 amperes at .90 power factor lagging at the receiving end, with constant voltage at the receiving end.

Since $I_r = 0$ at no load, the capacity current is

$$i_g = \frac{60{,}000(2.41+.485j)(.102+.597j)}{1000} = 90.2j - 1.7 = 90.2 \text{ amperes per wire.}$$

At no load, the voltage at the generator end leads the voltage at the receiving end by the angle $tan^{-1}\left(\frac{4.5}{48.7}\right) = tan^{-1} .093 = 5° 19'$; and the current at the generator end leads the voltage at the receiving end by the angle $tan^{-1}\left(\frac{90.2}{-1.7}\right) = tan^{-1}(-53.1) = 91° 04'$.

Hence, the current at the generator end leads the voltage at the generator end by the angle $(91° 04') - (5° 19') = 85° 45'$; hence, the power factor at no load is $cos(85° 45') = .074$ leading; and the total no load transmission loss due to capacity current is $.074 \times 3 \times 48{,}900 \times 90.2 = 980$ kw.

B. Example of Solution by Approximate Formulæ

Three-phase line 100 miles long, using hard drawn stranded copper wires No. 0 B.&S. wires equally spaced in a plane and 8 ft. between wires. Frequency 25 cycles.

In this case, suppose that the generator conditions are determined, being 50,000 volts between wire and neutral, and 100 amperes per wire at unity power factor.

From the tables $m = \frac{.555 + 1.025j}{1000}$ $\quad m_1 = 470 - 254j \quad \frac{1}{m_1} = \frac{1.65 + .88j}{1000}$

Therefore, ml at the receiving end is $.0555 + .1025j$ and since $ml = pl + jql$ therefore, $pl = .0555$ and $ql = .1025$.

By substituting these values in formula (7), the received voltage is obtained

$$e_r = 50{,}000\left(1 - \frac{.0074}{2} + .0057j\right) - 100(470 - 254j)(.0555 + .1025j)$$

$$= 49{,}800 + 280j - 5{,}200 - 3{,}420j = 44{,}600 - 3{,}140j.$$

Therefore, the received voltage is $\sqrt{44.600^2 + 3{,}140^2} = 44{,}800$ volts between wire and neutral, and this voltage lags behind the voltage at the generator end by the angle $tan^{-1}\left(\frac{-314}{4460}\right)$ $= tan^{-1}(-.0701) = -4° 02'$.

The current at the receiving end is given by substituting in equation (8)

$$i_r = 100(.996 + .0057j) - \frac{50{,}000(1.65 + .88j)(.0555 + .1025j)}{1000}$$

$$= 99.6 + .57j - .10 - 10.9j = 99.5 - 10.3j = 100 \text{ amperes per wire.}$$

Therefore, the current received is 100 amperes which lags behind the voltage at the generator end by the angle $tan^{-1}\left(\frac{-10.3}{99.5}\right) = tan^{-1}(-.1035) = -5° 55'$.

Hence, this current lags behind the voltage at the receiving end by the angle $(5° 55') - (4° 02') = 1° 53'$ and the power factor at the receiving end is $cos(1° 53') = .9995$ lagging.

Since the received current at no load is 0, the capacity current is given by the equation

$$I\left(1 + \frac{l^2(p^2 - q^2)}{2} + jpql^2\right) = \frac{E}{m_1}l(p + jq)$$

therefore, capacity current $I = \frac{.10 + 10.9j}{.996 + .0057j} = \frac{(.10 + 10.9j)(.996 - .0057j)}{.996^2 + .0057^2}$

that is, capacity current or I at no load $= .161 + 10.9j$

hence, the capacity current is 10.9 amperes per wire and leads the voltage at the sending end by the angle $tan^{-1}\frac{10.9}{.161} = tan^{-1}66.5 = 89° 08'$. Thus the power factor at the sending end at no load is $cos(89° 08') = .0151$.

By substituting the capacity current or I at no load in equation (7), the voltage at the receiving end at no load can be obtained, and therefore the regulation at the receiving end between no load and 100 amperes. Substituting the values

$$e_r = 49{,}800 + 280j - (.161 + 10.9j)(470 - 254j)(.0555 + .1025j)$$

$$= 49{,}800 + 280j + 363 - 572j = 50{,}200 - 292j.$$

Thus the received voltage is 50,200 volts, lagging by a small angle behind the generator voltage.

The regulation at the receiving end is, therefore, 50,200−44,800=5,400 volts between wire and neutral, or betwen wires $=\sqrt{3}\times 5{,}400=9{,}300$ volts drop between no load and 100 amperes load at the receiving end, when the generator voltage is kept constant.

Example of how to use Table No. I

Assume that the No. 00 wire used in a transmission line operating at 25 cycles has a resistance of .423 ohms per mile, instead of .417 ohms as given in the tables for m, etc. Then, in this case, the increase of resistance is 1.4% nearly. Hence, the following changes must be made in m, m_1 and $\frac{1}{m_1}$ in accordance with Table No. 1.

The real term of m must be increased $1.4\times.9\%=1.3\%$ nearly

The j term of m must be increased $1.4\times.4\%=0.6\%$ nearly

The real term of m_1 must be increased 0.6% and the j term 1.3% nearly

The real term of $\frac{1}{m_1}$ must be decreased $1.4\times0.2\%=0.3\%$ nearly

The j term of $\frac{1}{m_1}$ must be increased $1.4\times0.3\%=0.1\%$ nearly.

If the resistance were 1.4% less instead of greater, the values must be decreased where they were increased in the above example and *vice versa*.

TABLE I

Percentage change of constants m, m_1 and $\frac{1}{m_1}$ for change in resistance

For every 1% variation in resistance, change the real and j terms in the constants by the percentage amounts given in the table. If the resistance is increased, the + sign means, increase the term and − sign decrease the term. The opposite rule holds when the resistance is decreased. This table covers both methods of spacing and any distance between wires.

Wire B.&S.	R in Ohms per Mile	60 cycles: m Real +%	m j Term +%	m_1 Real +%	m_1 j Term +%	$\frac{1}{m_1}$ Real −%	$\frac{1}{m_1}$ j Term +%	25 cycles: m Real +%	m j Term +%	m_1 Real +%	m_1 j Term +%	$\frac{1}{m_1}$ Real −%	$\frac{1}{m_1}$ j Term +%
250,000	.222	+.75	None	None	+.75	None	+.75	+.85	+.05	+.05	+.85	−.10	+.70
0000	.263	+.70	None	None	+.70	None	+.70	+.80	+.20	+.20	+.80	−.10	+.50
000	.330	+.70	None	None	+.70	None	+.70	+.80	+.30	+.30	+.80	−.15	+.35
00	.417	+.70	None	None	+.70	−.05	+.65	+.90	+.40	+.40	+.90	−.20	+.30
0	.525	+.75	+.05	+.05	+.75	−.05	+.55	+.90	+.50	+.50	+.90	−.25	+.15
No. 1	.665	+.85	+.10	+.10	+.85	−.10	+.60	+.70	+.30	+.30	+.70	−.25	+.15
No. 2	.835	+.90	+.20	+.20	+.90	−.15	+.55	+.50	+.20	+.20	+ 50	−.20	+.10

★ TABLE II

Values of m, m_1 and $\frac{1}{m_1}$ per mile for triangular spacing at 25 and 60 cycles

Spacing between Wires Inches	60 CYCLES m Divide by 1000	60 CYCLES m_1	60 CYCLES $\frac{1}{m_1}$ Divide by 1000	25 CYCLES m Divide by 1000	25 CYCLES m_1	25 CYCLES $\frac{1}{m_1}$ Divide by 1000	Spacing between Wires Inches
	250,000 B &S R = 222 ohms per mile			250,000 B &S. R = 222 ohms per mile			
72	322 + 2 11j	346 − 52 7j	2 82 + .429j	306 + 918j	361 − 120j	2 61 + 870j	72
96	306 + 2 10j	362 − 52 7j	2 70 + 394j	294 + 912j	377 − 121j	2 41 + 772j	96
120	294 + 2 09j	376 − 52 8j	2 60 + 366j	.283 + 907j	390 − 122j	2 33 + 730j	120
144	287 + 2 09j	387 − 53 1j	2 53 + 347j	276 + 906j	401 − 122j	2 27 + 691j	144
	No. 0000 B &S R = 263 ohms per mile			No. 0000 B &S. R = .263 ohms per mile			
72	374 + 2 11j	352 − 62 2j	2 76 + 486j	362 + 932j	372 − 141j	2 35 + 892j	72
96	357 + 2 10j	368 − 62 4j	2.63 + 445j	337 + 927j	389 − 141j	2 26 + 822j	96
120	344 + 2 10j	382 − 62 7j	2 65 + 418j	326 + 922j	402 − 142j	2 21 + 780j	120
144	334 + 2 09j	391 − 62 7j	2 49 + 399j	.316 + 915j	411 − 142j	2 17 + .749j	144
	No. 000 B &S R = 33 ohms per mile			No. 000 B &S. R = .33 ohms per mile			
72	467 + 2 12j	362 − 78 0j	2 64 + 568j	420 + 960j	391 − 171j	2 14 + 937j	72
96	437 + 2 12j	378 − 78 0j	2 63 + 521j	.403 + 953j	406 − 172j	2 09 + 885j	96
120	421 + 2 11j	392 − 78 0j	2 44 + 485j	390 + 946j	420 − 173j	2 04 + .840j	120
144	408 + 2 11j	403 − 78 0j	2 38 + 460j	381 + 941j	430 − 174j	2 00 + 809j	144
	No. 00 B &S. R = 417 ohms per mile			No. 00 B &S R = 417 ohms per mile			
72	556 + 2 16j	372 − 97 0j	2 52 + 652j	497 + 995j	414 − 207j	1 93 + 962j	72
96	536 + 2 14j	391 − 97 8j	2 40 + 600j	482 + 989j	434 − 211j	1 86 + .907j	96
120	617 + 2 13j	405 − 98 1j	2 33 + 565j	468 + 980j	445 − 213j	1 83 + 876j	120
144	504 + 2 13j	414 − 98 2j	2 29 + 545j	456 + 972j	463 − 213j	1 81 + 850j	144
	No. 0 B &S. R = 525 ohms per mile			No. 0 B &S R = 525 ohms per mile			
72	678 + 2 18j	385 − 120j	2 36 + 737j	591 + 1 05j	446 − 260j	1 71 + 960j	72
96	663 + 2 17j	402 − 121j	2 28 + 685j	569 + 1 03j	458 − 253j	1 67 + 924j	96
120	633 + 2 16j	416 − 121j	2 22 + 649j	554 + 1 02j	470 − 256j	1 64 + 892j	120
144	615 + 2 15j	424 − 121j	2 17 + 622j	541 + 1 01j	479 − 256j	1 62 + 866j	144
	No. 1 B &S R = 665 ohms per mile			No. 1 B &S R = .665 ohms per mile			
72	826 + 2 23j	403 − 149j	2 17 + 803j	691 + 1 10j	476 − 300j	1 61 + 946j	72
96	791 + 2 21j	418 − 149j	2 11 + 755j	670 + 1 09j	495 − 304j	1 47 + 901j	96
120	766 + 2 20j	430 − 150j	2 07 + 725j	666 + 1 08j	607 − 307j	1 44 + 873j	120
144	749 + 2 19j	441 − 151j	2 03 + 695j	640 + 1 07j	616 − 309j	1 43 + 865j	144
	No. 2 B &S. R = 835 ohms per mile			No. 2 B &S R = 835 ohms per mile			
72	989 + 2 29j	422 − 182j	2 00 + 860j	800 + 1 17j	518 − 364j	1 31 + 896j	72
96	946 + 2 27j	438 − 182j	1 94 + 810j	779 + 1 16j	536 − 360j	1 28 + 861j	96
120	920 + 2 26j	460 − 183j	1 90 + 776j	756 + 1 14j	548 − 362j	1 27 + 840j	120
144	905 + 2 26j	460 − 184j	1 88 + 751j	744 + 1 14j	659 − 364j	1 26 + 821j	144

★ This table can also be used for single-phase lines.

★ TABLE III

Values of m, m_1 and $\frac{1}{m_1}$ per mile for equally spaced wires lying in a plane at 25 and 60 cycles

Spacing between Wires Inches	60 CYCLES m Div. by 1000	60 CYCLES m_1	60 CYCLES $\frac{1}{m_1}$ Div. by 1000	25 CYCLES m Div. by 1000	25 CYCLES m_1	25 CYCLES $\frac{1}{m_1}$ Div. by 1000	Spacing between Wires Inches
	250,000 B & S R = .222 ohms per mile			250,000 B & S R = .222 ohms per mile			
72	.310 − 2.11j	360 − 52.8j	2.71 − .398j	.296 − .917j	375 − 121j	2.41 − .780j	72
96	.297 − 2.11j	376 − 52.8j	2.60 − .366j	.284 − .913j	390 − 121.5j	2.34 − .729j	96
120	.286 − 2.10j	388 − 52.9j	2.53 − .345j	.275 − .910j	404 − 122j	2.27 − .687j	120
144	.278 − 2.09j	397 − 52.9j	2.47 − .329j	.268 − .909j	415 − 122j	2.22 − .654j	144
	No. 0000 B & S R = .263 ohms per mile			No. 0000 B & S R = .263 ohms per mile			
72	.361 − 2.11j	365 − 62.3j	2.65 − .453j	.340 − .929j	386 − 141j	2.29 − .840j	72
96	.345 − 2.10j	380 − 62.5j	2.57 − .422j	.326 − .924j	401 − 142j	2.21 − .786j	96
120	.332 + 2.10j	396 − 62.5j	2.47 − .390j	.316 − .920j	416 − 142.6j	2.16 − .742j	120
144	.324 + 2.09j	405 − 62.6j	2.41 − .373j	.308 − .917j	426 − 143j	2.10 − .706j	144
	No. 000 B & S R = .33 ohms per mile			No. 000 B & S R = .33 ohms per mile			
72	.439 + 2.12j	374 − 77.4j	2.56 − .530j	.406 + .956j	406 − 172j	2.10 − .894j	72
96	.421 + 2.12j	390 − 77.6j	2.47 + .491j	.391 + .949j	420 − 173j	2.05 − .846j	96
120	.406 − 2.11j	405 − 77.9j	2.38 − .457j	.379 − .943j	434 − 174j	1.98 − .797j	120
144	.396 + 2.11j	416 − 78.0j	2.32 − .434j	.370 − .939j	445 − 176j	1.95 − .766j	144
	No. 00 B & S. R = .417 ohms per mile			No. 00 B & S R = .417 ohms per mile			
72	.540 − 2.16j	388 − 97.0j	2.42 − .605j	.484 + .990j	426 − 208j	1.89 + .924j	72
96	.519 + 2.15j	403 − 97.1j	2.36 + .666j	.469 + .984j	443 − 211j	1.84 − .877j	96
120	.500 + 2.13j	416 − 97.5j	2.27 − .632j	.456 + .977j	458 − 214j	1.79 − .838j	120
144	.487 + 2.12j	425 − 97.5j	2.23 + .612j	.447 − .973j	467 − 215j	1.76 + .812j	144
	No. 0 B & S. R = .525 ohms per mile			No. 0 B & S R = .525 ohms per mile			
72	.657 + 2.18j	398 − 120.0j	2.30 − .695j	.673 + 1.038j	456 − 251j	1.68 + .930j	72
96	.630 + 2.17j	415 − 120.5j	2.22 − .646j	.655 + 1.025j	470 − 254j	1.65 − .880j	96
120	.609 − 2.16j	428 − 121.0j	2.16 − .611j	.642 + 1.020j	485 − 257j	1.61 − .864j	120
144	.595 + 2.16j	439 − 121.0j	2.11 − .586j	.630 + 1.011j	496 − 260j	1.58 − .830j	144
	No. 1 B & S R = .665 ohms per mile			No. 1 B & S R = .665 ohms per mile			
72	.802 + 2.23j	418 − 150.0j	2.12 − .760j	.673 + 1.095j	493 − 303j	1.465 + .902j	72
96	.769 + 2.21j	432 − 150.0j	2.06 + .716j	.665 + 1.084j	509 − 307j	1.440 + .868j	96
120	.745 + 2.20j	445 − 150.5j	2.02 + .682j	.638 + 1.070j	520 − 309j	1.420 − .846j	120
144	.726 + 2.19j	456 − 151.0j	1.95 + .654j	.626 + 1.064j	531 − 312j	1.395 − .820j	144
	No. 2 B & S R = .835 ohms per mile			No. 2 B & S R = .835 ohms per mile			
72	.959 + 2.28j	435 − 183j	1.95 − .820j	.780 + 1.160j	532 − 358j	1.290 − .870j	72
96	.924 + 2.27j	452 − 184j	1.88 − .770j	.769 + 1.150j	550 − 363j	1.266 − .836j	96
120	.898 + 2.26j	465 − 185j	1.85 − .739j	.741 + 1.135j	562 − 366j	1.250 − .814j	120
144	.881 + 2.25j	476 − 186j	1.82 + .712j	.729 + 1.127j	570 − 359j	1.235 − .800j	144

★ This table may be used for three-phase lines only when a sufficient number of transpositions has been made to obtain balanced electrical conditions along the line. In no case must the table be used for single-phase lines. The table can be used, whether the plane in which the wires lie is vertical or horizontal.

TABLE IV

Values of cosh (x + jy) = a + jb and sinh (x + jy) = c + jd

y	x = 0.00 a	b	c	d	x = 0.02 a	b	c	d	x = 0.04 a	b	c	d	x = 0.06 a	b	c	d	x = 0.08 a	b	c	d	y
0.00	1.000	0.00	0.00	.000	1.000	.000	.020	.000	1.001	.000	.040	.000	1.002	.000	.060	.000	1.003	.000	.080	.000	0.00
.02	1.000	0.00	0.00	.020	1.000	.000	.020	.020	1.000	.001	.040	.020	1.002	.001	.060	.020	1.003	.002	.080	.020	.02
.04	1.000	0.00	0.00	.040	1.000	.000	.020	.040	1.000	.002	.040	.040	1.001	.002	.060	.040	1.002	.003	.080	.040	.04
.06	.998	0.00	0.00	.060	.998	.001	.020	.060	.999	.002	.040	.060	1.000	.004	.060	.060	1.001	.005	.080	.060	.06
.08	.997	0.00	0.00	.080	.997	.002	.020	.080	.998	.003	.040	.080	.999	.005	.060	.080	1.000	.006	.080	.080	.08
.10	.995	0.00	0.00	.100	.995	.002	.020	.100	.996	.004	.040	.100	.997	.006	.060	.100	.998	.008	.080	.100	.10
.12	.993	0.00	0.00	.120	.993	.002	.020	.120	.994	.005	.040	.120	.995	.007	.060	.120	.995	.010	.080	.120	.12
.14	.990	0.00	0.00	.140	.990	.003	.020	.140	.991	.006	.040	.140	.992	.008	.059	.140	.993	.011	.079	.140	.14
.16	.987	0.00	0.00	.159	.987	.003	.020	.159	.988	.006	.040	.159	.989	.010	.059	.159	.990	.013	.079	.159	.16
.18	.984	0.00	0.00	.179	.984	.004	.020	.179	.985	.007	.039	.179	.986	.011	.059	.179	.987	.014	.079	.179	.18
.20	.980	0.00	0.00	.199	.980	.004	.020	.199	.981	.008	.039	.199	.982	.012	.059	.199	.983	.016	.078	.199	.20
.22	.976	0.00	0.00	.218	.976	.004	.020	.218	.977	.009	.039	.218	.978	.013	.059	.218	.979	.017	.078	.218	.22
.24	.971	0.00	0.00	.238	.971	.005	.019	.238	.972	.010	.039	.238	.973	.014	.058	.238	.974	.019	.078	.239	.24
.26	.966	0.00	0.00	.257	.966	.005	.019	.257	.967	.010	.039	.257	.968	.015	.058	.257	.969	.021	.077	.258	.26
.28	.961	0.00	0.00	.277	.961	.006	.019	.277	.962	.011	.038	.277	.963	.017	.058	.277	.964	.022	.077	.278	.28
.30	.955	0.00	0.00	.296	.955	.006	.019	.296	.956	.012	.038	.296	.957	.018	.057	.296	.958	.024	.076	.297	.30
.32	.949	0.00	0.00	.315	.949	.006	.019	.315	.950	.013	.038	.315	.951	.019	.057	.315	.952	.025	.076	.316	.32
.34	.943	0.00	0.00	.334	.943	.007	.019	.334	.944	.013	.038	.334	.945	.020	.057	.334	.946	.027	.075	.335	.34
.36	.936	0.00	0.00	.353	.936	.007	.019	.353	.937	.014	.037	.353	.938	.021	.056	.353	.939	.028	.075	.354	.36
.38	.929	0.00	0.00	.371	.929	.007	.019	.371	.930	.015	.037	.371	.931	.022	.056	.372	.932	.030	.074	.372	.38
.40	.921	0.00	0.00	.389	.921	.008	.018	.389	.922	.016	.037	.389	.923	.023	.055	.390	.924	.031	.074	.390	.40
.42	.913	0.00	0.00	.408	.913	.008	.018	.408	.914	.017	.037	.408	.916	.024	.055	.409	.916	.033	.073	.409	.42
.44	.906	0.00	0.00	.426	.906	.009	.018	.426	.906	.018	.036	.426	.907	.026	.054	.427	.908	.034	.073	.427	.44
.46	.896	0.00	0.00	.444	.896	.009	.018	.444	.897	.018	.036	.444	.898	.027	.054	.445	.899	.035	.072	.445	.46
.48	.887	0.00	0.00	.462	.887	.009	.018	.462	.888	.019	.035	.462	.889	.028	.053	.463	.890	.037	.071	.463	.48
.50	.878	0.00	0.00	.479	.878	.010	.018	.479	.879	.019	.035	.479	.880	.029	.053	.480	.881	.038	.070	.480	.50
.52	.868	0.00	0.00	.497	.868	.010	.017	.497	.869	.020	.035	.497	.870	.030	.052	.498	.871	.040	.070	.499	.52
.54	.857	0.00	0.00	.514	.857	.010	.017	.514	.858	.021	.034	.514	.859	.031	.052	.515	.860	.041	.069	.516	.54
.56	.847	0.00	0.00	.531	.847	.011	.017	.531	.848	.022	.034	.531	.849	.032	.051	.532	.850	.042	.068	.533	.56
.58	.836	0.00	0.00	.548	.836	.011	.017	.548	.837	.022	.033	.548	.838	.033	.050	.549	.839	.044	.067	.550	.58
.60	.825	0.00	0.00	.564	.825	.011	.016	.564	.826	.023	.033	.564	.827	.034	.049	.565	.828	.045	.066	.566	.60
.62	.814	0.00	0.00	.581	.814	.012	.016	.581	.816	.024	.033	.581	.816	.035	.049	.582	.817	.046	.065	.583	.62
.64	.802	0.00	0.00	.597	.802	.012	.016	.597	.802	.024	.032	.597	.803	.036	.048	.598	.805	.048	.064	.599	.64
.66	.790	0.00	0.00	.613	.790	.012	.016	.613	.791	.025	.032	.613	.792	.037	.047	.614	.793	.049	.063	.615	.66
.68	.777	0.00	0.00	.629	.777	.013	.016	.629	.778	.025	.031	.629	.779	.038	.047	.630	.780	.050	.062	.631	.68
.70	.765	0.00	0.00	.644	.765	.013	.015	.644	.766	.026	.031	.645	.767	.039	.046	.646	.767	.052	.061	.646	.70
.72	.752	0.00	0.00	.659	.752	.013	.015	.659	.753	.026	.030	.660	.754	.040	.045	.660	.754	.053	.060	.661	.72
.74	.738	0.00	0.00	.674	.738	.013	.015	.674	.739	.027	.030	.675	.740	.041	.044	.675	.740	.054	.059	.676	.74
.76	.725	0.00	0.00	.689	.725	.014	.014	.689	.726	.027	.029	.690	.727	.042	.044	.690	.727	.055	.058	.691	.76
.78	.711	0.00	0.00	.703	.711	.014	.014	.703	.712	.028	.029	.704	.713	.043	.043	.704	.713	.056	.057	.705	.78
.80	.697	0.00	0.00	.717	.697	.014	.014	.717	.698	.029	.028	.718	.699	.043	.042	.718	.699	.057	.056	.719	.80
.82	.682	0.00	0.00	.731	.682	.015	.014	.731	.683	.029	.027	.732	.684	.044	.041	.732	.684	.058	.055	.733	.82
.84	.667	0.00	0.00	.744	.667	.015	.013	.744	.667	.030	.027	.745	.668	.045	.040	.745	.669	.060	.053	.746	.84
.86	.652	0.00	0.00	.758	.652	.015	.013	.758	.652	.030	.026	.759	.653	.046	.039	.759	.654	.061	.052	.760	.86
.88	.637	0.00	0.00	.771	.637	.015	.013	.771	.637	.031	.026	.772	.638	.046	.038	.772	.639	.062	.051	.773	.88
.90	.622	0.00	0.00	.783	.622	.016	.012	.783	.622	.031	.025	.784	.623	.047	.037	.784	.624	.062	.050	.786	.90
.92	.606	0.00	0.00	.796	.606	.016	.012	.796	.606	.032	.024	.797	.607	.048	.036	.797	.608	.064	.049	.799	.92
.94	.590	0.00	0.00	.808	.590	.016	.012	.808	.590	.032	.024	.809	.591	.048	.035	.809	.592	.065	.047	.811	.94
.96	.574	0.00	0.00	.819	.574	.016	.011	.819	.574	.033	.023	.820	.575	.049	.034	.820	.576	.066	.046	.822	.96
.98	.557	0.00	0.00	.830	.557	.017	.011	.830	.557	.033	.023	.831	.558	.050	.033	.831	.559	.066	.044	.833	.98
1.00	.540	0.00	0.00	.841	.540	.017	.011	.841	.540	.034	.022	.842	.541	.050	.032	.843	.542	.067	.043	.844	1.00

TABLE V

Values of cosh (x + jy) = a + jb and sinh (x + jy) = c + jd

y	x = .10 a	b	c	d	x = .12 a	b	c	d	x = .14 a	b	c	d	x = .16 a	b	c	d	x = .18 a	b	c	d	y
0.00	1.005	.000	.100	.000	1.007	.000	.120	.000	1.010	.000	.140	.000	1.013	.000	.161	.000	1.016	.000	.181	.000	0.00
.02	1.005	.002	.100	.020	1.007	.002	.120	.020	1.010	.003	.140	.020	1.013	.003	.161	.020	1.016	.003	.181	.020	.02
.04	1.004	.004	.100	.040	1.006	.005	.120	.040	1.009	.006	.140	.040	1.012	.006	.160	.040	1.016	.007	.180	.041	.04
.06	1.003	.006	.100	.060	1.005	.007	.120	.060	1.008	.008	.140	.061	1.011	.010	.160	.061	1.014	.011	.180	.061	.06
.08	1.002	.008	.100	.080	1.004	.010	.120	.080	1.007	.011	.140	.081	1.010	.013	.160	.081	1.013	.014	.180	.081	.08
.10	1.000	.010	.100	.100	1.002	.012	.120	.101	1.005	.014	.140	.101	1.008	.016	.160	.101	1.011	.018	.180	.102	.10
.12	.998	.012	.099	.121	1.000	.014	.120	.121	1.003	.017	.139	.121	1.006	.019	.160	.122	1.009	.022	.180	.122	.12
.14	.995	.014	.099	.141	.997	.017	.119	.141	1.000	.020	.139	.141	1.003	.022	.159	.142	1.006	.026	.179	.142	.14
.16	.992	.016	.099	.160	.994	.019	.119	.160	.997	.022	.138	.161	1.000	.025	.159	.161	1.003	.029	.178	.162	.16
.18	.989	.018	.098	.180	.991	.022	.119	.180	.994	.025	.138	.181	.997	.029	.158	.181	1.000	.032	.178	.182	.18
.20	.986	.020	.098	.200	.987	.024	.118	.200	.990	.028	.138	.201	.992	.032	.168	.202	.996	.036	.177	.202	.20
.22	.981	.022	.098	.219	.983	.026	.118	.220	.986	.031	.137	.220	.988	.035	.157	.221	.992	.039	.177	.221	.22
.24	.976	.024	.097	.239	.978	.028	.117	.240	.981	.033	.136	.240	.983	.038	.156	.241	.987	.043	.176	.242	.24
.26	.971	.026	.097	.258	.973	.031	.116	.259	.975	.036	.136	.259	.978	.041	.156	.260	.981	.046	.175	.261	.26
.28	.966	.028	.096	.278	.968	.033	.116	.279	.970	.039	.136	.280	.973	.044	.156	.281	.976	.050	.174	.281	.28
.30	.960	.030	.095	.297	.962	.036	.115	.298	.964	.041	.134	.299	.967	.048	.154	.299	.971	.053	.173	.301	.30
.32	.954	.031	.095	.316	.956	.038	.115	.317	.958	.044	.133	.318	.961	.051	.152	.319	.964	.057	.172	.320	.32
.34	.948	.033	.094	.335	.950	.040	.114	.336	.952	.047	.132	.337	.955	.054	.151	.338	.958	.060	.171	.339	.34
.36	.941	.035	.094	.354	.943	.042	.113	.356	.945	.049	.131	.356	.948	.057	.160	.357	.951	.064	.169	.358	.36
.38	.934	.037	.093	.373	.936	.045	.112	.374	.938	.052	.130	.375	.941	.059	.149	.376	.944	.067	.168	.377	.38
.40	.926	.039	.092	.391	.928	.047	.111	.392	.930	.055	.129	.393	.933	.062	.148	.394	.936	.070	.166	.395	.40
.42	.918	.041	.091	.410	.920	.049	.110	.411	.922	.057	.128	.412	.925	.065	.147	413	.928	.073	.165	.414	.42
.44	.910	.043	.091	.428	.912	.051	.109	.429	.914	.060	.127	.430	.916	.068	.146	.431	.919	.077	.164	.433	.44
.46	.901	.044	.090	.446	.902	.053	.108	.447	.904	.062	.126	.448	.907	.071	.144	.449	.910	.080	.162	.451	.46
.48	.891	.046	.089	.464	.893	.055	.107	.465	.895	.065	.125	.467	.898	.074	.142	.468	.901	.083	.160	.469	.48
.50	.882	.048	.088	.482	.884	.057	.106	.482	.887	.067	.123	.484	.889	.077	.141	.485	.892	.087	.158	.487	.50
.52	.872	.050	.087	.500	.874	.060	.104	.501	.877	.069	.122	502	.879	.080	.140	.503	.882	.090	.157	.505	.52
.54	.861	.051	.086	.617	.863	.062	.103	.518	.865	.072	.121	.519	.868	.082	.138	.520	.871	.093	.155	.522	.54
.56	.851	.053	.086	.534	.853	.064	.102	.536	.855	.074	.119	.536	.858	.085	.136	.537	.861	.096	.153	.540	.56
.58	.840	.055	.084	.551	.842	.066	.100	.553	.844	.077	.118	.554	.847	.087	.134	.555	.850	.099	.151	.557	.58
.60	.829	.056	.082	.567	.831	.068	.099	.568	.833	.079	.116	.570	.836	.091	.132	.571	.838	.102	.149	.573	.60
.62	.818	.058	.081	.584	.820	.070	.098	.585	.822	.081	.114	.587	.824	.093	.130	.588	.827	.105	.147	.590	.62
.64	.806	.060	.080	.600	.808	.072	.097	.602	.810	.083	.112	603	.812	.096	.128	.604	.815	.108	.145	.607	.64
.66	.794	.061	.079	.616	.796	.074	.095	.618	.798	.086	.110	.619	.800	.098	.127	.620	.803	.111	.143	.623	.66
.68	.781	.063	.078	.632	.783	.076	.094	.634	.785	.088	.109	.635	.787	.101	.125	.636	.790	.114	.140	.639	.68
.70	.769	.064	.076	.647	.771	.078	.092	.649	.773	.090	.108	.650	.775	.103	.123	.652	.777	.116	.138	.654	.70
.72	.756	.066	.075	.662	.758	.079	.091	.664	.759	.092	.106	.665	.762	.105	.121	.667	.764	.118	.136	.670	.72
.74	.742	.067	.074	.677	.743	.081	.089	.679	.745	.094	.104	.681	.748	.108	.119	.683	.750	.122	.134	.685	.74
.76	.729	.069	.072	.692	.730	.083	.087	.694	.732	.096	.102	.696	.734	.111	.117	.698	.737	.124	.131	.700	.76
.78	.714	.070	.071	.706	.716	.085	.086	.708	.718	.099	.100	.710	.720	.113	.115	.712	.722	.127	.128	.714	.78
.80	.700	.072	.070	.720	.702	.086	.084	.722	.704	.101	.098	.724	.706	.115	.112	.726	.708	.1[illegible]9	.126	.729	.80
.82	685	.073	.068	.734	.687	.088	.082	.736	.689	.102	.096	.738	691	.118	.110	.740	.693	.132	.123	.743	.82
.84	.670	.074	.067	.747	.672	.090	.080	.749	.674	.104	.094	.751	.676	.120	.107	.753	.678	.134	.120	.756	.84
.86	.655	.076	.065	.761	657	.091	.079	.763	.658	.106	.091	.765	.660	.122	.105	.768	.662	.137	.118	.770	.86
.88	.640	.077	.064	.775	.642	.093	.077	.777	.643	.108	.089	.779	.645	.124	.102	.781	.647	.139	.115	.783	.88
.90	6[illegible]5	.078	.062	.787	.626	.094	.075	.789	.628	.110	.087	.791	.630	.126	.100	.793	.632	.141	.112	.796	.90
.92	609	.080	.061	.800	.610	096	.073	.802	.612	.112	.085	.804	.6[illegible]4	.128	.098	.806	.616	.143	.109	.809	.92
.94	593	.081	.059	.812	.594	.097	.071	.814	.596	.113	.083	.816	.598	.130	.095	.818	.600	.146	.106	.821	.94
.96	577	.082	.057	.823	.578	.098	.069	.826	.580	.115	.081	.827	.581	.132	.093	.829	.583	.148	.104	.832	.96
.98	.560	.083	.056	.834	.561	.100	.067	.836	.563	.116	.078	.838	.564	.134	.090	.841	.566	.150	.101	.843	.98
1.00	.543	.084	.054	.846	.544	.101	.066	.847	.545	.118	.076	.849	.547	.135	.087	.852	.549	.152	.098	.855	1.00

TABLE VI

Values of cosh (x + jy) = a + jb and sinh (x + jy) = c + jd

y	x = .20 a	b	c	d	x = .22 a	b	c	d	x = .24 a	b	c	d	x = .26 a	b	c	d	x = .28 a	b	c	d	y
0.00	1 020	000	201	000	1 024	000	221	000	1 029	000	242	000	1 034	000	263	000	1 039	000	284	000	0.00
.02	1 020	004	201	020	1 024	004	221	020	1 029	005	242	021	1 034	005	263	021	1 039	005	284	021	.02
.04	1 019	008	201	041	1 023	009	221	041	1 028	010	242	041	1 033	010	263	041	1 038	011	284	042	.04
.06	1 018	012	201	061	1 022	013	220	061	1 027	014	241	062	1 032	016	262	062	1 037	017	283	062	.06
.08	1 017	016	200	082	1 021	018	220	082	1 026	019	241	082	1 031	021	262	083	1 036	023	283	083	.08
.10	1 015	020	200	102	1 019	022	220	102	1 024	024	240	103	1 029	026	261	103	1 034	028	282	104	.10
.12	1 013	024	200	122	1 017	027	220	123	1 022	029	240	123	1 027	031	261	124	1 032	034	281	125	.12
.14	1 010	028	199	143	1 014	031	220	143	1 019	034	239	144	1 024	037	260	145	1 029	040	280	146	.14
.16	1 007	032	199	162	1 011	035	219	163	1 015	038	239	164	1 021	042	259	165	1 026	045	279	165	.16
.18	1 004	036	198	183	1 008	040	218	183	1 012	043	238	184	1 017	047	258	185	1 023	051	278	186	.18
.20	1 000	040	197	203	1 004	044	217	204	1 008	048	237	205	1 013	052	257	206	1 019	057	277	206	.20
.22	996	044	197	222	1 000	048	216	223	1 004	053	236	224	1 009	058	256	225	1 014	062	276	226	.22
.24	990	048	196	243	995	052	215	244	999	058	235	245	1 004	064	255	246	1 009	067	275	247	.24
.26	985	052	195	262	989	057	214	263	994	062	234	264	999	067	254	265	1 004	073	274	267	.26
.28	980	056	194	282	984	061	213	284	989	066	232	285	994	072	262	286	999	078	272	288	.28
.30	974	059	192	301	978	066	212	303	983	071	231	305	987	077	251	306	993	084	270	308	.30
.32	968	063	191	321	972	070	211	323	976	076	230	324	981	083	250	325	986	089	269	327	.32
.34	962	067	190	341	966	074	209	342	970	081	228	344	975	088	248	345	980	094	267	347	.34
.36	955	071	188	360	959	078	207	362	963	085	226	363	968	093	246	365	973	100	265	367	.36
.38	948	075	187	378	952	082	206	380	956	090	225	382	961	097	244	384	966	105	263	386	.38
.40	939	078	185	397	943	086	205	398	948	094	223	400	952	102	242	402	957	110	261	404	.40
.42	931	082	184	416	935	090	203	418	939	099	221	420	944	107	240	422	949	115	258	424	.42
.44	923	086	182	435	927	094	201	436	931	103	219	438	935	112	238	440	941	120	256	443	.44
.46	914	089	180	453	918	098	199	455	922	107	216	457	926	116	235	459	931	126	254	461	.46
.48	905	093	178	471	909	102	197	473	913	112	214	475	917	121	233	477	922	131	251	480	.48
.50	895	096	177	489	899	106	195	492	903	116	212	493	908	126	230	495	913	136	249	498	.50
.52	885	100	175	507	889	110	193	509	893	120	209	511	897	130	228	513	902	141	246	517	.52
.54	874	103	172	524	878	114	190	526	882	125	207	528	886	135	225	530	891	146	242	534	.54
.56	864	106	170	542	868	118	188	544	872	128	205	546	876	140	223	549	881	150	239	552	.56
.58	853	110	168	559	856	122	185	561	860	132	202	563	864	144	219	566	870	155	236	570	.58
.60	842	114	166	576	845	125	183	578	849	137	199	580	851	148	216	583	858	160	233	586	.60
.62	830	117	164	593	834	129	181	595	838	141	197	598	842	152	213	601	846	164	231	604	.62
.64	818	120	162	609	821	132	178	611	825	144	194	614	829	157	210	617	833	169	227	620	.64
.66	806	123	159	625	809	136	175	628	813	148	191	631	817	161	207	634	821	174	224	637	.66
.68	793	126	156	642	796	140	172	644	799	162	188	647	803	166	204	650	808	178	220	654	.68
.70	780	130	154	657	784	143	170	660	787	156	185	663	791	170	201	666	795	182	217	669	.70
.72	767	132	152	672	770	146	167	675	773	160	182	678	778	173	198	681	782	186	213	685	.72
.74	753	135	149	687	766	150	164	690	759	163	179	693	763	177	194	696	768	190	209	701	.74
.76	740	138	146	703	743	153	161	706	746	166	175	709	750	181	191	712	754	195	205	716	.76
.78	725	141	143	717	728	156	158	720	731	170	172	723	735	185	187	726	739	200	201	731	.78
.80	711	144	140	732	714	159	155	734	717	173	169	738	721	188	183	741	724	203	197	745	.80
.82	696	147	137	745	699	162	152	749	702	176	165	752	705	192	179	755	708	206	193	760	.82
.84	680	150	134	758	683	165	148	762	686	180	161	765	690	195	175	768	693	210	189	773	.84
.86	665	152	131	773	668	168	144	776	671	183	158	780	674	199	171	783	677	214	185	788	.86
.88	650	155	128	786	653	171	141	790	665	186	154	794	669	203	167	798	662	218	180	802	.88
.90	634	158	125	799	637	174	138	802	640	190	151	806	643	206	162	810	647	222	176	814	.90
.92	618	160	122	812	621	177	134	816	624	193	147	819	627	209	159	823	630	225	171	827	.92
.94	602	162	119	824	604	179	131	828	607	195	143	832	610	212	155	836	613	228	167	840	.94
.96	586	164	115	835	588	182	127	839	591	197	139	843	594	216	151	847	597	231	163	851	.96
.98	568	167	112	847	571	184	123	850	573	200	135	864	576	218	146	858	579	235	168	863	.98
1.00	.551	.169	.109	.858	.553	.186	.120	.861	.556	203	.131	.866	.568	.221	.142	.870	.561	238	153	874	1.00

TABLE VII

Values of cosh (x + jy) = a + jb and sinh (x + jy) = c + jd

y	x = .30 a	b	c	d	x = .32 a	b	c	d	x = .34 a	b	c	d	x = .36 a	b	c	d	x = .38 a	b	c	d	y
0.00	1.046	.000	.304	.000	1.052	.000	.326	.000	1.058	.000	.347	.000	1.065	.000	.368	000	1 073	.000	.389	.000	0.00
.02	1.046	.006	.304	.021	1.051	.006	.326	.021	1.058	.007	.346	.021	1.065	.007	.367	.021	1 073	.008	.389	.021	.02
.04	1.044	.012	.304	.042	1.051	.013	.325	.042	1.057	.014	.346	042	1.064	.015	.367	.043	1.072	.016	.389	.043	.04
.06	1.043	.018	.303	.063	1.050	.019	.324	.063	1.056	.021	.345	.064	1.063	.022	.366	.064	1 071	.023	.388	.064	.06
.08	1.042	.024	.303	.084	1.048	.026	.324	.084	1 055	.028	345	.085	1.062	029	.366	.085	1 070	.031	.387	.086	.08
.10	1.040	.030	.303	.104	1.046	.032	.324	.105	1.063	.036	.344	.106	1.060	.037	.366	.107	1.068	.039	.387	.107	.10
.12	1.038	.036	.302	.125	1.044	.039	.323	126	1.061	.041	.344	.127	1.058	.044	.365	.128	1.066	.047	.386	.129	.12
.14	1.035	.042	.301	.146	1.041	.045	.322	.147	1.048	.048	.343	.148	1.055	061	.364	.149	1 062	.054	.385	.160	.14
.16	1.032	.048	.300	.166	1.038	.052	.321	.167	1.045	.055	.342	.168	1.052	.069	.363	.169	1.069	062	384	.171	.16
.18	1.028	.056	.299	.187	1.036	.058	.320	188	1.042	.062	.341	.189	1.048	.066	.362	.191	1.066	.070	.382	.192	.18
.20	1 024	.061	.298	.208	1.031	.065	.319	.209	1.037	.069	.340	.211	1.044	.074	.360	.212	1.052	.078	.380	.214	.20
.22	1.019	.066	.297	.228	1.026	.071	.317	.229	1.033	.075	.338	.231	1 039	080	.358	.232	1.047	.086	.378	.234	.22
.24	1.014	.072	.295	.249	1.021	.077	.315	.251	1.028	.082	.336	.253	1 034	.087	.356	.264	1.042	.093	.377	.265	.24
.26	1 009	.078	.294	.269	1.016	.083	.314	.271	1 022	.089	.334	.273	1.029	.095	.364	.274	1.037	.100	.375	276	.26
.28	1.004	.084	.293	.289	1.011	.090	.312	.292	1.017	.096	.332	.294	1.024	.102	.353	.295	1.031	.108	.373	.297	.28
.30	.999	.090	.291	.309	1.004	.096	.310	.311	1.011	.102	.331	.313	1.017	.108	.351	.314	1.025	.115	.371	.318	.30
.32	.993	.096	.289	.329	.998	.102	.308	.331	1.004	.109	.329	.333	1.011	.116	.349	.334	1.018	.122	.369	.338	.32
.34	.987	.102	.287	.349	.992	.108	.306	.351	.998	.116	.327	.363	1.004	123	.347	.355	1.012	130	.366	368	.34
.36	.980	.107	.285	.369	.984	.116	.304	.371	.991	.122	.324	.373	.997	.130	.343	.376	1 004	.138	.363	.379	.36
.38	.972	113	.283	.388	.977	.121	.302	.390	.983	.128	.321	.393	.990	.136	.341	.395	997	.145	.361	.398	.38
.40	.963	.118	.280	.407	.968	.126	.300	.409	.975	.134	.319	.412	.981	.143	.339	.414	.988	161	.358	.417	.40
.42	.954	124	.277	426	.960	.133	.297	.428	.966	.141	.317	.431	.973	.150	.336	.435	.980	158	.366	.438	.42
.44	.945	130	.275	.446	.952	.138	.294	.447	.958	.148	.313	.450	.964	.156	.333	.453	.971	.166	.352	457	.44
.46	.936	136	.273	.464	.942	.144	.291	.466	.948	.154	.310	.469	.955	.163	.329	473	.961	.172	.348	.476	.46
.48	.928	140	.270	.483	.933	.150	.288	.485	.939	.160	.307	.488	.945	170	.326	.492	.952	.179	.344	.495	.48
.50	.917	146	.267	.501	.923	.156	.285	.604	.929	.166	.304	.607	.936	.176	.322	510	.942	186	.341	.614	.50
.52	908	.151	.263	.619	.913	.162	.282	.522	.919	.172	.300	.625	.925	.182	.319	530	.932	.193	.338	533	.52
.54	.898	.156	.260	537	.901	.167	.278	.540	.907	.178	.296	.543	.913	.189	.315	.548	.920	.200	.334	.552	.54
.56	.887	.161	.257	.555	.891	.172	.275	.558	.896	.184	.293	.561	.903	.195	.311	.566	.909	.206	.329	.570	.56
.58	.875	166	254	.573	.879	.178	.272	576	.885	.190	.290	.580	.891	.201	.307	.584	.897	212	.325	.588	.58
.60	.863	172	251	.599	.867	.183	.268	.593	.873	.195	.286	597	.879	.207	.303	.601	.885	.219	.321	.605	.60
.62	851	177	.248	.607	.856	.189	.264	.611	.862	.201	.282	.616	.867	.214	299	619	874	.226	.317	.623	.62
.64	.839	181	.244	624	.843	.194	260	.628	.849	.207	.279	.632	.854	.219	295	.636	.861	.233	.312	.641	.64
.66	.826	186	.240	.641	.831	.199	.256	.645	.836	.212	.274	.649	.842	.225	290	.653	.848	.239	.307	658	.66
.68	.813	191	.236	.657	.817	.204	.252	.661	.822	.218	.269	.665	828	.231	.285	.670	.834	.245	.302	.675	.68
.70	800	196	.233	.673	804	.209	249	677	.810	.223	.265	682	.815	.237	.283	.686	821	.251	.297	691	.70
.72	787	200	.229	.689	.791	.214	.244	.693	.796	.228	.261	.698	.801	.242	.276	.702	.807	.256	.293	707	.72
.74	773	205	.224	.705	.776	.219	.240	.709	.781	.234	.255	.714	786	.248	.271	.718	791	.262	.288	.723	.74
.76	758	210	.221	720	.762	.224	.236	.724	.767	.239	.251	.729	.772	254	.267	.734	777	.268	282	.739	.76
.78	744	214	.216	736	.748	.229	.231	739	.753	243	.246	.741	.758	.259	261	.749	.763	.274	.276	754	.78
.80	728	218	.212	.750	733	.233	226	.754	.738	.248	.242	.759	.743	.264	.256	.764	748	.279	.271	.769	.80
.82	714	222	.207	.764	717	.237	.222	769	.722	.254	.236	.774	.727	.269	251	.779	.732	.284	.265	.784	.82
.84	697	227	202	778	.701	242	.217	.782	.706	.257	.231	.787	.711	.274	.245	.793	716	.289	259	.798	.84
.86	682	.230	198	.792	.686	.246	212	797	690	.263	.226	802	.695	279	240	.808	700	.296	.254	.814	.86
.88	666	235	.194	.806	670	.250	.207	.811	674	.266	.220	.817	.679	284	.234	.821	684	.300	.248	.827	.88
.90	650	238	189	819	.654	255	.202	.823	.658	.271	.215	.829	.663	.288	.229	.834	.668	.305	.242	.840	.90
.92	634	242	184	832	.637	.259	.197	.837	.641	.275	.210	.843	.645	.293	.223	.848	.651	.309	.235	.851	.92
.94	617	245	179	845	620	262	192	.849	.625	.280	.204	.855	.629	.297	.216	.861	.634	.314	.229	.867	.94
.96	600	249	176	856	604	.266	186	.861	608	.284	199	.867	.612	.300	.211	.873	617	.319	.223	.879	.96
.98	582	252	169	868	586	.270	181	873	689	.287	.193	.879	.593	.305	205	.884	.598	.323	.216	.891	.98
1.00	565	256	174	880	568	.274	176	.884	.572	.291	.187	.890	.576	.310	.199	.896	.580	.327	.210	.903	1.00

TABLE VIII

Values of cosh (x + jy) = a + jb and sinh (x + jy) = c + jd

y	x = .40 a	b	c	d	x = .42 a	b	c	d	x = .44 a	b	c	d	x = .46 a	b	c	d	x = .48 a	b	c	d	y
0.00	1.081	.000	.411	.000	1.089	.000	.432	.000	1.098	.000	.454	.000	1.108	.000	.476	.000	1.117	.000	.499	.000	0.00
.02	1.081	.008	.411	.022	1.089	.009	.432	.022	1.098	.009	.454	.022	1.108	.009	.476	.022	1.117	.010	.498	.022	.02
.04	1.080	.016	.410	.043	1.088	.017	.431	.044	1.097	.018	.453	.044	1.107	.019	.475	.044	1.116	.020	.498	.046	.04
.06	1.079	.025	.410	.065	1.087	.026	.431	.065	1.096	.027	.452	.066	1.106	.029	.474	.066	1.115	.030	.498	.067	.06
.08	1.078	.033	.409	.086	1.086	.035	.430	.087	1.095	.036	.452	.088	1.105	.038	.474	.089	1.113	.040	.497	.089	.08
.10	1.076	.041	.409	.108	1.084	.043	.430	.109	1.093	.045	.451	.110	1.102	.048	.473	.111	1.110	.050	.496	.112	.10
.12	1.073	.049	.408	.129	1.082	.052	.429	.130	1.091	.054	.450	.132	1.101	.057	.472	.133	1.108	.060	.495	.134	.12
.14	1.070	.057	.407	.151	1.079	.061	.428	.152	1.088	.063	.449	.154	1.098	.067	.471	.155	1.105	.070	.494	.156	.14
.16	1.067	.066	.405	.172	1.075	.069	.427	.174	1.085	.072	.448	.175	1.095	.076	.470	.176	1.102	.079	.493	.178	.16
.18	1.064	.074	.404	.194	1.072	.078	.426	.196	1.081	.081	.446	.197	1.091	.085	.468	.198	1.098	.089	.491	.200	.18
.20	1.059	.082	.403	.215	1.068	.086	.424	.217	1.076	.090	.444	.219	1.086	.095	.466	.220	1.093	.099	.489	.222	.20
.22	1.055	.090	.401	.236	1.063	.094	.422	.238	1.072	.099	.442	.241	1.081	.104	.464	.242	1.089	.109	.487	.244	.22
.24	1.050	.098	.399	.257	1.058	.103	.420	.259	1.067	.108	.440	.262	1.076	.113	.462	.264	1.083	.118	.485	.266	.24
.26	1.044	.106	.397	.278	1.053	.111	.418	.281	1.062	.117	.438	.283	1.071	.123	.460	.284	1.077	.129	.482	.287	.26
.28	1.039	.114	.395	.299	1.047	.120	.415	.302	1.056	.126	.435	.304	1.065	.132	.457	.306	1.071	.138	.479	.309	.28
.30	1.033	.121	.392	.319	1.040	.128	.412	.322	1.049	.134	.432	.325	1.058	.141	.455	.327	1.065	.147	.476	.330	.30
.32	1.026	.129	.389	.340	1.034	.136	.409	.343	1.042	.143	.429	.346	1.051	.150	.451	.348	1.059	.157	.473	.351	.32
.34	1.019	.138	.386	.360	1.027	.144	.406	.364	1.036	.152	.426	.367	1.044	.159	.448	.370	1.052	.166	.470	.372	.34
.36	1.012	.145	.383	.381	1.020	.152	.403	.384	1.029	.160	.423	.387	1.037	.168	.445	.390	1.044	.176	.467	.393	.36
.38	1.004	.152	.381	.401	1.012	.160	.401	.404	1.021	.168	.420	.407	1.029	.177	.442	.410	1.037	.185	.464	.414	.38
.40	.996	.160	.378	.421	1.003	.168	.398	.424	1.012	.176	.417	.427	1.020	.185	.439	.430	1.029	.194	.460	.435	.40
.42	.987	.168	.375	.441	.995	.176	.395	.444	1.003	.185	.414	.447	1.011	.194	.435	.450	1.019	.203	.456	.456	.42
.44	.978	.175	.372	.460	.986	.184	.392	.464	.994	.193	.411	.467	1.002	.203	.431	.470	1.010	.212	.452	.475	.44
.46	.968	.182	.368	.479	.976	.192	.388	.484	.985	.201	.407	.487	.993	.211	.427	.490	1.000	.221	.448	.495	.46
.48	.959	.190	.364	.498	.966	.200	.384	.503	.975	.209	.403	.507	.983	.220	.423	.510	.991	.230	.443	.515	.48
.50	.949	.197	.360	.518	.957	.207	.379	.522	.965	.217	.399	.526	.973	.228	.418	.530	.981	.239	.438	.535	.50
.52	.938	.204	.356	.537	.946	.215	.375	.541	.954	.225	.395	.546	.962	.236	.413	.549	.970	.249	.433	.554	.52
.54	.927	.212	.352	.555	.934	.222	.371	.560	.942	.233	.390	.564	.950	.244	.408	.568	.958	.257	.428	.573	.54
.56	.916	.219	.348	.574	.923	.230	.367	.578	.930	.211	.385	.582	.938	.252	.403	.587	.946	.265	.423	.592	.56
.58	.904	.226	.344	.592	.911	.236	.362	.596	.918	.249	.380	.601	.926	.260	.398	.606	.934	.274	.418	.611	.58
.60	.892	.232	.339	.610	.899	.244	.357	.614	.906	.256	.374	.619	.914	.268	.392	.624	.922	.282	.412	.630	.60
.62	.880	.239	.334	.628	.887	.250	.352	.632	.893	.264	.369	.637	.901	.276	.387	.642	.909	.290	.406	.648	.62
.64	.867	.245	.329	.645	.874	.258	.347	.650	.880	.271	.364	.655	.888	.284	.382	.660	.896	.298	.400	.666	.64
.66	.854	.251	.324	.662	.861	.265	.342	.667	.867	.278	.359	.673	.874	.292	.376	.678	.882	.306	.394	.684	.66
.68	.840	.258	.319	.679	.847	.272	.337	.684	.854	.285	.353	.690	.861	.300	.370	.696	.869	.314	.388	.702	.68
.70	.827	.265	.314	.696	.833	.278	.331	.701	.840	.292	.347	.707	.847	.307	.364	.713	.855	.321	.382	.719	.70
.72	.813	.270	.309	.712	.819	.285	.325	.717	.826	.299	.341	.724	.833	.314	.358	.730	.841	.329	.376	.736	.72
.74	.798	.276	.304	.728	.804	.292	.319	.733	.811	.306	.335	.740	.818	.321	.352	.746	.825	.337	.369	.753	.74
.76	.784	.283	.298	.744	.790	.298	.313	.749	.796	.313	.329	.756	.802	.328	.346	.762	.809	.344	.362	.769	.76
.78	.769	.289	.292	.760	.775	.304	.307	.765	.781	.319	.322	.772	.787	.335	.339	.778	.794	.351	.355	.785	.78
.80	.753	.295	.286	.775	.759	.310	.301	.781	.766	.325	.316	.788	.772	.341	.332	.794	.779	.358	.348	.801	.80
.82	.737	.300	.280	.790	.743	.315	.295	.795	.750	.331	.309	.803	.756	.348	.325	.809	.763	.365	.341	.816	.82
.84	.721	.306	.274	.805	.727	.322	.289	.811	.734	.337	.302	.818	.740	.354	.318	.824	.747	.372	.334	.831	.84
.86	.705	.311	.268	.819	.710	.328	.283	.825	.717	.343	.295	.832	.723	.360	.311	.839	.729	.378	.326	.846	.86
.88	.689	.316	.262	.833	.694	.334	.276	.839	.700	.349	.288	.846	.706	.366	.304	.853	.712	.384	.318	.861	.88
.90	.672	.322	.255	.847	.678	.339	.269	.853	.683	.356	.281	.860	.689	.372	.296	.867	.695	.390	.310	.875	.90
.92	.655	.328	.249	.860	.660	.343	.262	.866	.666	.361	.274	.873	.672	.378	.289	.880	.678	.396	.302	.889	.92
.94	.638	.332	.243	.873	.643	.349	.255	.879	.648	.366	.267	.886	.653	.384	.281	.893	.659	.402	.294	.902	.94
.96	.621	.336	.236	.885	.625	.354	.248	.892	.630	.371	.260	.899	.636	.390	.273	.906	.641	.408	.286	.915	.96
.98	.602	.341	.229	.897	.607	.359	.241	.904	.612	.376	.253	.912	.617	.396	.265	.919	.623	.414	.278	.928	.98
1.00	.584	.346	.222	.910	.588	.364	.234	.916	.593	.381	.246	.924	.598	.400	.257	.931	.604	.420	.270	.940	1.00

TABLE IX

Values of cosh (x + jy) = a + jb and sinh (x + jy) = c + jd

y	x = .50				x = .52				x = .54				x = .56				x = .58				y
	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d	
0.00	1.128	.000	.521	.000	1.138	.000	.544	.000	1.149	.000	.567	.000	1.161	.000	.590	.000	1.173	.000	.613	.000	0.00
.02	1.127	.010	.621	023	1.137	.011	.544	.023	1.149	.011	.567	.023	1.161	.012	.690	.023	1 173	.012	.613	.023	.02
.04	1.126	.021	.521	.045	1.136	.022	.543	.045	1.148	.023	.566	.046	1.160	.024	.589	.046	1.172	.024	.612	.047	.04
.06	1.125	.031	.520	.068	1.135	.033	.542	.068	1.146	.034	.565	.069	1.159	.035	.688	.070	1.171	.037	.611	.070	.06
.08	1.124	.042	.519	.090	1.133	.043	.542	.091	1.144	.045	.564	.092	1.158	.047	.687	.093	1.170	.049	.611	.094	.08
.10	1.122	.062	.518	.113	1.131	.054	.541	.114	1.142	.057	.563	.115	1.157	.059	.586	.116	1.169	.061	.610	.117	.10
.12	1.119	.062	.617	.136	1.129	.065	.540	.136	1.139	.068	.562	.138	1.155	.071	.585	.139	1.167	.074	.608	.141	.12
.14	1.116	.072	.616	.158	1.126	.076	.539	.159	1.136	.079	.560	.161	1.152	.083	.584	.163	1.164	.086	.606	.164	.14
.16	1.113	.082	.515	.180	1.122	.086	.537	.181	1.133	.090	.558	.183	1.149	.094	.582	.185	1.160	.098	.604	.187	.16
.18	1.109	.092	.513	.202	1.118	.097	.535	.204	1.129	.102	.556	.206	1.145	.106	.580	.208	1 155	.110	.602	.211	.18
.20	1.106	.102	.611	.224	1.114	.108	.533	.227	1.125	.112	.554	.229	1.140	.118	.678	.231	1.150	122	.600	.234	.20
.22	1.100	.113	.609	.246	1.109	.119	.531	.249	1.120	.124	.552	.250	1.135	.129	.576	.253	1.145	.134	.698	.256	.22
.24	1.095	.123	.507	.268	1 104	.130	.529	.271	1.115	.135	.649	.273	1.129	.141	.573	.276	1.140	.146	.695	.279	.24
.26	1.089	.134	.504	.290	1.099	.141	.626	.293	1.110	.146	.546	.295	1.123	.152	.570	.299	1.134	158	.692	.302	.26
.28	1.083	.144	.501	.312	1.093	151	.523	.315	1 104	.157	.543	.318	1.117	.163	.667	.322	1.127	.170	.589	.325	.28
.30	1.077	.154	.498	.333	1.087	.161	.520	.337	1.098	.168	.540	.340	1.110	.174	.564	.344	1.120	.182	.685	.348	.30
.32	1.070	.164	.495	.355	1.080	.172	.516	.359	1.091	.179	.537	.362	1 103	.185	.660	.366	1.113	.194	.581	.370	.32
.34	1.063	.174	.492	.376	1.072	.182	.512	.380	1.083	.190	.634	.384	1.095	.196	.556	.388	1.106	.206	.577	.392	.34
.36	1.066	.184	.488	.397	1.064	192	.508	.401	1.075	.200	.630	.405	1.087	.208	.552	.410	1.098	.217	.573	.414	.36
.38	1.047	194	.484	.418	1.056	.202	.504	.422	1.067	.210	.526	.426	1.079	.219	.548	.431	1.090	.228	.669	.436	.38
.40	1.039	.203	.480	.439	1.048	.212	.500	.443	1.058	.220	.621	.446	1.070	.230	.643	452	1.081	.239	.565	.457	.40
.42	1 030	.213	.476	.460	1.039	.222	.496	.464	1.049	.231	.516	.468	1.061	.241	.538	.474	1.072	.250	.660	.479	.42
.44	1.021	.222	.472	.481	1.029	.232	.492	.485	1.040	.241	.511	.490	1.051	.252	.533	.495	1.062	.261	.555	.500	.44
.46	1.011	.232	.467	.501	1.019	.242	.488	.505	1.030	.251	.506	.510	1.041	.263	.528	.516	1.052	.272	.550	.521	.46
.48	1.001	.241	462	.521	1.008	.251	.483	.525	1.019	.261	.501	.531	1.031	.273	623	.537	1 042	.283	.545	.542	.48
.50	.990	.250	.457	.541	.997	.260	.478	.646	1.008	.271	.496	.650	1.020	.283	.518	.557	1.031	.294	.539	.663	.50
.52	.979	.259	.452	561	.986	.270	.473	.565	.997	.281	.491	.571	1.009	.293	.512	.577	1.019	305	.533	.583	.52
.54	.967	.268	.447	.580	.975	.279	.467	.585	.985	.291	.485	.590	.997	.303	.506	.597	1 007	.316	.526	.603	.54
.56	.955	.277	.442	.599	.963	.289	.461	.604	.973	.301	.479	.610	.985	.313	.500	.617	.995	.327	.519	.623	.56
.58	.943	286	.436	.618	.951	298	.455	.623	.961	.310	.473	.630	.973	.323	494	.637	.983	.337	.512	.643	.58
.60	.931	.294	.430	.637	.939	.307	.448	.642	.948	.319	.467	.649	.960	.333	.487	.655	.970	.347	.505	.663	.60
.62	919	.303	.424	.656	.926	.316	.442	.661	.935	.329	.461	.667	.947	.343	.480	.676	.957	.357	.498	.682	.62
.64	.906	.311	418	.674	.912	.325	.436	.679	.922	.338	.466	686	.933	.353	.473	.694	.943	.367	.491	.701	.64
.66	.892	.320	.412	.692	.898	.334	.430	.697	.908	.347	.447	704	.919	.362	.466	.713	.929	.377	.484	.720	.66
.68	.877	.328	406	.709	.884	.343	.424	.715	.894	.366	.440	.722	.905	.371	.469	.731	.914	.386	.477	.738	.68
.70	.862	.336	.399	.726	.870	.351	.417	.733	.879	.365	.433	.739	.890	.380	.451	.749	.899	.395	.469	.756	.70
.72	.847	.344	.392	.743	.855	.359	.410	.750	.864	.374	.426	.757	.875	.389	.443	766	.884	.404	.461	.774	.72
.74	832	.352	.385	.760	.840	.367	.402	.767	.849	.382	.418	.774	.860	.398	.436	.784	.868	413	.453	.792	.74
.76	817	.360	.378	.777	.825	.375	.394	.784	.833	.390	.410	.791	.844	.406	.427	.801	.852	.422	.445	.809	.76
.78	802	367	.371	.793	.809	.383	.386	801	.817	.398	.402	.808	.828	.414	.419	.818	.836	.431	.436	.826	.78
.80	786	.374	363	.809	.793	.390	.378	.817	.800	.405	.394	.824	.811	.423	.411	.834	.819	.440	.427	.843	.80
.82	770	381	356	.824	.776	.398	.371	.833	.783	.413	.386	.840	.794	.431	.403	.850	.802	419	.418	.859	.82
.84	753	388	.348	839	.759	405	.353	.848	.766	.420	.378	.855	.777	.439	.394	.865	.784	.457	.409	.875	.84
.86	736	.395	.340	.854	.742	.412	.356	.863	.749	.428	.370	.871	.760	.447	.385	.880	.766	466	.400	.890	.86
.88	.719	402	.332	.869	.726	419	.347	.877	.732	.435	.361	.886	.742	.454	.376	.895	.748	.473	.391	.905	.88
.90	.701	408	.324	.883	.707	426	.339	.691	.714	.442	.352	.900	.723	.461	.367	.910	.730	.481	.381	.920	.90
.92	683	414	.316	.897	.689	.433	.330	.905	.696	.449	.343	.915	.704	.468	.367	.924	.712	.488	.371	.934	.92
.94	.665	420	.308	910	.671	.439	.321	.918	.678	.456	.334	.928	.685	.475	.348	.938	.693	.495	.361	.948	.94
.96	647	426	299	.92[illegible]	653	.446	.312	.931	.669	.462	.325	.940	.666	.482	.339	.952	.674	.602	.351	.962	.96
.98	.628	.432	[illegible]90	.936	634	451	.303	.944	.640	.469	.315	.954	.647	.489	.329	.966	.656	.509	341	.975	.98
1.00	.609	.438	.281	.949	.615	.467	.293	.957	.620	.475	.305	.966	.627	.496	.319	.977	.634	.516	.331	.988	1.00

TABLE X

Values of cosh (x + jy) = a + jb and sinh (x + jy) = c + jd

y	x = .60 a	b	c	d	x = .62 a	b	c	d	x = .64 a	b	c	d	x = .66 a	b	c	d	x = .68 a	b	c	d	y
0.00	1.185	.000	.637	.000	1.198	.000	.660	.000	1.212	.000	.685	.000	1.226	.000	.709	.000	1.240	.000	.734	.000	0.00
.02	1.185	.013	.637	.024	1.198	.013	.660	.024	1.212	.014	.685	.024	1.226	.014	.709	.025	1.240	.015	.734	.025	.02
.04	1.184	.025	.637	.047	1.197	.026	.659	.048	1.211	.027	.684	.049	1.225	.028	.708	.049	1.239	.029	.733	.050	.04
.06	1.183	.038	.636	.071	1.195	.040	.659	.072	1.210	.041	.683	.073	1.224	.042	.707	.074	1.238	.044	.732	.074	.06
.08	1.181	.051	.635	.095	1.193	.053	.658	.096	1.209	.055	.682	.097	1.222	.057	.706	.098	1.237	.069	.731	.099	.08
.10	1.179	.064	.633	.118	1.191	.066	.657	.120	1.207	.068	.681	.121	1.220	.071	.705	.123	1.235	.073	.729	.124	.10
.12	1.176	.076	.632	.142	1.188	.079	.656	.144	1.204	.082	.679	.146	1.217	.086	.703	.147	1.232	.088	.727	.149	.12
.14	1.172	.089	.630	.166	1.185	.092	.654	.168	1.201	.095	.677	.170	1.213	.099	.701	.172	1.228	.103	.725	.174	.14
.16	1.169	.101	.628	.189	1.181	.105	.652	.190	1.198	.109	.675	.193	1.209	.113	.699	.195	1.224	.116	.723	.197	.16
.18	1.166	.114	.626	.212	1.177	.118	.650	.214	1.194	.122	.673	.217	1.205	.127	.697	.219	1.220	.131	.721	.222	.18
.20	1.162	.126	.624	.235	1.173	.131	.648	.238	1.190	.136	.670	.241	1.200	.141	.694	.244	1.215	.146	.719	.247	.20
.22	1.158	.139	.622	.258	1.169	.144	.645	.261	1.185	.149	.667	.264	1.195	.154	.691	.267	1.210	.161	.716	.270	.22
.24	1.163	.151	.619	.281	1.164	.157	.642	.285	1.180	.163	.664	.289	1.190	.169	.688	.292	1.204	.175	.713	.295	.24
.26	1.147	.164	.616	.304	1.158	.170	.639	.308	1.174	.176	.661	.313	1.184	.182	.684	.315	1.198	.189	.709	.319	.26
.28	1.140	.176	.612	.327	1.151	.183	.636	.332	1.167	.190	.658	.336	1.177	.196	.680	.340	1.192	.203	.705	.344	.28
.30	1.132	.188	.608	.350	1.143	.196	.631	.354	1.159	.202	.654	.360	1.170	.210	.676	.363	1.185	.217	.700	.367	.30
.32	1.126	.200	.604	.373	1.135	.208	.627	.377	1.151	.215	.650	.383	1.163	.223	.672	.386	1.177	.231	.695	.391	.32
.34	1.117	.212	.600	.396	1.127	.220	.623	.400	1.143	.228	.645	.405	1.155	.236	.667	.409	1.169	.245	.690	.414	.34
.36	1.109	.224	.596	.418	1.119	.233	.619	.422	1.135	.241	.640	.428	1.147	.250	.662	.432	1.160	.259	.685	.437	.36
.38	1.101	.236	.591	.440	1.111	.245	.614	.444	1.126	.254	.635	.450	1.138	.263	.657	.455	1.151	.272	.680	.460	.38
.40	1.092	.248	.586	.462	1.102	.257	.609	.466	1.117	.266	.630	.472	1.129	.276	.652	.477	1.141	.285	.675	.483	.40
.42	1.082	.260	.581	.484	1.093	.270	.604	.488	1.107	.279	.625	.496	1.119	.289	.646	.499	1.131	.299	.669	.506	.42
.44	1.072	.272	.576	.505	1.083	.282	.598	.510	1.097	.292	.619	.518	1.109	.302	.640	.521	1.121	.312	.663	.528	.44
.46	1.062	.283	.571	.526	1.072	.293	.592	.532	1.087	.305	.613	.539	1.093	.315	.634	.543	1.110	.325	.657	.550	.46
.48	1.051	.294	.566	.547	1.061	.305	.686	.553	1.076	.317	.607	.561	1.087	.327	.628	.565	1.099	.338	.650	.572	.48
.50	1.040	.305	.659	.568	1.050	.316	.580	.574	1.065	.329	.601	.581	1.076	.339	.622	.587	1.088	.351	.643	.594	.50
.52	1.028	.316	.553	.589	1.038	.328	.573	.595	1.053	.341	.595	.693	1.064	.351	.615	.608	1.076	.364	.636	.615	.52
.54	1.016	.327	.546	.610	1.026	.340	.566	.615	1.040	.353	.588	.624	1.051	.363	.608	.629	1.063	.377	.629	.636	.54
.56	1.004	.338	.539	.630	1.014	.361	.559	.636	1.027	.364	.581	.645	1.038	.375	.601	.650	1.050	.389	.621	.657	.56
.58	.991	.349	.532	.650	1.001	.362	.552	.655	1.014	.375	.573	.666	1.024	.387	.593	.671	1.036	.401	.613	.678	.58
.60	.978	.359	.525	.669	.988	.373	.545	.675	1.000	.386	.565	.686	1.010	.399	.585	.691	1.022	.413	.605	.699	.60
.62	.964	.370	.518	.688	.974	.384	.537	.695	.986	.397	.557	.706	.996	.411	.577	.711	1.008	.425	.597	.719	.62
.64	.950	.380	.511	.707	.960	.394	.529	.715	.972	.408	.549	.725	.982	.423	.569	.731	.991	.437	.588	.739	.64
.66	.936	.390	.504	.726	.946	.405	.521	.734	.959	.419	.541	.745	.968	.434	.560	.751	.980	.449	.579	.769	.66
.68	.922	.400	.496	.745	.931	.415	.513	.753	.944	.430	.533	.764	.954	.445	.551	.771	.965	.461	.570	.779	.68
.70	.907	.410	.487	.764	.916	.425	.505	.771	.929	.440	.524	.782	.939	.456	.542	.790	.950	.472	.560	.799	.70
.72	.891	.420	.479	.782	.901	.435	.497	.789	.912	.451	.515	.800	.923	.467	.533	.809	.934	.483	.551	.818	.72
.74	.875	.430	.471	.799	.885	.445	.488	.808	.895	.461	.506	.819	.907	.478	.524	.827	.917	.494	.541	.836	.74
.76	.859	.439	.462	.816	.869	.455	.479	.825	.879	.471	.497	.837	.890	.488	.514	.845	.900	.505	.531	.854	.76
.78	.843	.448	.453	.833	.852	.464	.470	.842	.863	.481	.487	.854	.873	.498	.504	.863	.883	.516	.521	.872	.78
.80	.826	.457	.444	.850	.835	.474	.460	.858	.846	.491	.477	.871	.855	.508	.494	.880	.865	.526	.511	.890	.80
.82	.809	.466	.435	.866	.818	.483	.451	.874	.829	.500	.467	.888	.837	.518	.484	.897	.847	.536	.500	.907	.82
.84	.791	.475	.426	.882	.800	.491	.441	.890	.812	.509	.457	.904	.819	.527	.474	.913	.829	.546	.489	.924	.84
.86	.773	.483	.416	.898	.782	.501	.431	.906	.794	.518	.447	.921	.801	.536	.463	.929	.810	.656	.478	.940	.86
.88	.755	.491	.406	.914	.764	.510	.421	.922	.776	.527	.437	.936	.782	.545	.452	.945	.791	.565	.467	.956	.88
.90	.737	.499	.396	.929	.746	.518	.411	.938	.755	.536	.426	.951	.763	.554	.441	.960	.772	.574	.456	.972	.90
.92	.718	.507	.386	.944	.726	.526	.401	.953	.735	.545	.415	.966	.743	.563	.430	.975	.752	.583	.444	.987	.92
.94	.699	.516	.376	.958	.707	.533	.390	.967	.715	.553	.404	.981	.723	.572	.418	.989	.732	.592	.432	1.001	.94
.96	.680	.522	.366	.972	.687	.541	.379	.981	.695	.561	.393	.995	.703	.580	.406	1.003	.712	.600	.420	1.015	.96
.98	.661	.529	.355	.986	.667	.549	.368	.994	.675	.568	.382	1.008	.683	.588	.394	1.017	.691	.608	.408	1.029	.98
1.00	.641	.536	.344	.998	.646	.556	.367	1.008	.655	.575	.370	1.020	.662	.596	.382	1.031	.670	.616	.396	1.043	1.00

TABLE XI

Values of cosh (x + jy) = a + jb and sinh (x + jy) = c + jd

y	x = .70				x = .72				x = .74				x = .76				x = .78				y
	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d	
0.00	1.255	.000	.759	.000	1.271	.000	.784	.000	1.287	.000	.809	.000	1.303	.000	.835	.000	1.320	.000	.861	.000	0.00
.02	1.255	.015	.759	.025	1.271	.016	.784	.025	1.286	.016	.809	.026	1.303	.017	.835	.026	1.319	.017	.861	.026	.02
.04	1.254	.030	.768	.050	1.270	.031	.783	.051	1.285	.032	.808	.051	1.302	.033	.834	.052	1.318	.034	.860	.053	.04
.06	1.253	.045	.757	.075	1.269	.047	.782	.076	1.284	.049	.806	.077	1.301	.050	.833	.078	1.317	.052	.859	.079	.06
.08	1.251	061	.756	.100	1.267	.063	.781	.102	1.282	.065	.806	.103	1.300	.067	.832	.104	1.316	.069	.858	.106	.08
.10	1 249	.076	.755	.125	1.265	.078	.780	.127	1.280	.081	.805	.129	1.298	.083	.831	.130	1.314	.086	.857	132	.10
.12	1.246	.091	.753	.150	1.262	.094	.778	.153	1.277	.097	.803	.154	1.295	.100	.829	.156	1.311	.103	.855	.158	.12
.14	1.242	.106	.751	.176	1.259	.110	.776	.178	1.274	.113	.801	180	1.292	.117	.827	.183	1.307	.121	.853	.185	.14
.16	1.239	121	.749	200	1.255	.125	.773	.202	1.270	.129	.798	.204	1.288	.133	.825	.207	1.303	137	851	.210	.16
.18	1.235	.136	.746	.224	1.251	.140	.770	.228	1.265	.145	.795	.230	1.284	.149	.822	.234	1.299	154	.848	.236	.18
.20	1 230	.151	.743	.249	1.247	.156	.767	.253	1.260	.161	.792	.256	1.279	166	.819	.260	1.294	.171	.845	.263	.20
.22	1.225	.165	.740	.274	1.242	.172	.764	.278	1.255	.176	.788	.280	1 273	.182	.815	.284	1.288	.188	.841	.288	.22
.24	1.219	.180	.737	.298	1.236	.187	.760	.303	1.249	.192	.784	.306	1.267	.199	.811	.310	1.282	.205	.837	.314	.24
.26	1 212	.195	.733	.323	1.229	.202	.756	.328	1.243	.208	.780	.331	1 260	.215	.807	.335	1.275	.221	.833	.339	.26
.28	1.206	210	729	.348	1.222	.217	.752	.353	1.236	.224	.776	.356	1.253	.231	.802	.361	1.268	.239	.828	366	.28
.30	1.199	.224	.725	.371	1.214	.232	.748	.377	1.229	.239	.772	.381	1.245	.247	.797	.386	1.261	.255	.823	.391	.30
.32	1.191	.239	.720	.395	1.206	.247	.743	.401	1.221	.255	.767	.405	1 237	.263	.792	.411	1.252	.271	.818	.416	.32
.34	1.183	.254	.715	.418	1.198	.262	.738	.425	1.212	.270	.762	.430	1.228	.279	.787	.435	1.243	.287	.812	440	.34
.36	1.174	.268	710	.442	1.189	.277	.733	.449	1.203	.285	.757	.454	1.219	.295	.782	.460	1.234	.303	.806	.466	.36
.38	1.165	.281	.704	.465	1.180	.291	.727	.472	1.193	.300	.752	.477	1 210	.310	776	.484	1.225	.319	.800	490	.38
.40	1 156	.295	.699	.489	1.171	.305	.721	.495	1.183	.315	.746	.500	1.200	.325	.770	.508	1 215	335	.791	.514	.40
.42	1.146	309	.693	.512	1.162	.319	.715	.518	1.173	.330	.739	.524	1 190	.340	.763	.533	1.204	.351	.787	.538	.42
.44	1.136	.323	.687	.535	1.152	.333	.709	.541	1.162	.345	.732	.547	1 180	.355	.756	.556	1.193	.367	.780	.562	.44
.46	1.125	.336	.680	.558	1.141	.347	.702	.564	1.151	.359	.725	.570	1.169	.370	.749	.580	1.182	.383	.772	.586	.46
.48	1.114	350	.673	.580	1.129	.361	695	.587	1.140	.373	.718	.593	1 158	.385	.741	603	1.171	.398	.764	609	.48
.50	1 102	.364	.666	.602	1.117	.375	.688	.609	1 129	.387	.710	.616	1.146	.399	.733	.625	1 159	413	.756	.632	.50
.52	1.090	.377	.658	.624	1.104	.389	.680	631	1 116	.401	.702	.638	1 133	.414	.725	.649	1.146	.428	.747	.655	.52
.54	1.077	.389	.650	.646	1.091	402	.672	.653	1.103	.415	694	.660	1.120	428	.716	.670	1.132	443	.738	.678	.54
.56	1 064	.402	642	.667	1.078	415	.664	.675	1.090	.429	685	.682	1.106	.443	.707	692	1 118	457	.729	700	.56
.58	1.050	.415	.634	.688	1.064	428	.655	.697	1.076	.443	676	.704	1.092	.457	.698	.714	1.104	.471	.720	722	.58
.60	1 036	.427	.626	.709	1.050	.441	.646	.718	1.061	.456	.667	.725	1 077	.471	.689	.735	1.093	.485	.711	744	.60
.62	1.019	440	.617	.729	1.035	.454	.637	.739	1.046	.469	.658	.746	1.062	.485	.680	.758	1.075	.499	701	.766	.62
.64	1.002	453	.608	.749	1 020	.467	.628	.759	1.031	.482	.649	.767	1 047	498	670	.779	1.059	.513	.691	.787	.64
.66	985	.465	.599	.769	1 005	.480	619	.779	1 016	.495	.639	788	1.031	.511	660	.800	1.043	.527	.681	808	.66
.68	978	.477	.590	789	.990	492	.609	.799	1 001	.509	.629	.808	1.015	.524	650	.820	1.027	.541	670	829	.68
.70	960	489	580	.809	.974	.504	599	.819	.985	.521	.619	828	999	.537	.639	.840	1 011	.555	.659	.850	.70
.72	943	501	.570	.828	.957	.516	589	.838	.968	.533	.609	.848	.982	.550	.628	.860	.991	.568	.648	870	.72
.74	926	512	560	.846	940	.528	.579	.857	.951	.545	.598	867	.965	.562	617	.880	.976	.581	.637	.890	.74
.76	909	523	550	864	923	.540	.568	.876	.933	.557	.587	.886	.947	574	.606	.899	.958	.594	.625	.909	.76
.78	892	534	.539	.882	905	.551	.557	.894	.915	.569	.576	.905	929	586	591	.918	.910	.606	613	.928	.78
.80	874	544	529	.900	887	562	546	.912	.897	.580	.564	923	.910	.598	.582	.936	.921	618	.601	947	.80
.82	856	554	517	917	869	573	.535	930	878	.591	.552	.911	891	610	.570	.954	.902	.630	.589	965	.82
.84	837	564	506	934	860	583	.523	.947	.859	.602	.540	958	.872	621	.558	971	.882	641	.576	.983	.84
.86	818	574	494	951	831	593	511	.964	.840	613	.528	.975	.852	.632	546	.988	.862	652	.563	1 000	.86
.88	799	584	483	967	812	603	499	980	820	.623	.516	.991	.832	.643	533	1 004	.842	663	.550	1.017	.88
.90	780	594	472	983	792	613	487	.996	.800	633	.503	1.007	.812	.654	.520	1.020	.821	.674	.536	1.034	.90
.92	760	603	460	998	771	623	.475	1 013	.780	.643	490	1 023	.791	.664	.507	1.036	.800	.685	.522	1.050	.92
.94	740	612	447	1 013	750	632	462	1.028	759	.653	.477	1.038	.770	.674	493	1.051	.779	695	.508	1.066	.94
.96	720	621	435	1.028	729	641	449	1 042	738	663	464	1.053	.749	.681	.479	1 066	758	.705	494	1.081	.96
.98	699	630	422	1.042	708	650	436	1.057	717	.672	.450	1.068	.727	.693	.465	1 081	.736	.715	480	1.096	.98
1.00	678	638	410	1.056	687	.659	423	1.070	.695	.681	.436	1.082	.705	702	.451	1.096	.714	.725	465	1 110	1.00

TABLE XII

Values of cosh (x + jy) = a + jb and sinh (x + jy) = c + jd

y	x = .80 a	b	c	d	x = .82 a	b	c	d	x = .84 a	b	c	d	x = .86 a	b	c	d	x = .88 a	b	c	d	y
0.00	1.337	.000	.888	.000	1.355	.000	.915	.000	1.374	.000	.942	.000	1.393	.000	.970	.000	1.413	.000	.998	.000	0.00
.02	1.337	.018	.888	.027	1.355	.018	.915	.027	1.374	.019	.942	.028	1.393	.019	.970	.028	1.413	.020	.998	.028	.02
.04	1.336	.035	.887	.053	1.354	.037	.914	.054	1.373	.038	.941	.055	1.392	.039	.969	.056	1.412	.040	.997	.057	.04
.06	1.335	.053	.886	.080	1.353	.055	.913	.081	1.372	.056	.940	.083	1.391	.058	.968	.084	1.411	.060	.996	.085	.06
.08	1.333	.071	.885	.107	1.351	.073	.912	.108	1.371	.076	.939	.110	1.390	.078	.967	.112	1.410	.080	.995	.113	.08
.10	1.331	.089	.884	.134	1.349	.091	.910	.136	1.369	.094	.937	.137	1.388	.097	.965	.139	1.408	.100	.993	.141	.10
.12	1.328	.106	.882	.160	1.346	.110	.908	.163	1.366	.113	.935	.165	1.385	.116	.963	.167	1.405	.120	.991	.170	.12
.14	1.324	.124	.880	.187	1.342	.128	.906	.190	1.362	.132	.933	.193	1.381	.136	.961	.195	1.401	.140	.988	.198	.14
.16	1.320	.141	.877	.212	1.338	.146	.903	.216	1.358	.150	.930	.219	1.377	.155	.958	.222	1.397	.159	.985	.225	.16
.18	1.316	.159	.874	.239	1.334	.164	.900	.243	1.353	.169	.927	.246	1.373	.173	.954	.250	1.392	.179	.982	.253	.18
.20	1.311	.176	.870	.266	1.329	.182	.896	.270	1.348	.187	.923	.274	1.368	.193	.950	.278	1.387	.199	.978	.282	.20
.22	1.306	.193	.867	.292	1.323	.199	.893	.296	1.342	.205	.920	.300	1.362	.211	.946	.304	1.380	.218	.974	.309	.22
.24	1.300	.211	.863	.318	1.317	.218	.889	.323	1.336	.224	.916	.328	1.355	.231	.942	.332	1.373	.238	.969	.337	.24
.26	1.293	.228	.859	.344	1.310	.235	.885	.349	1.329	.242	.911	.354	1.348	.249	.937	.359	1.366	.257	.964	.364	.26
.28	1.286	.246	.854	.370	1.302	.253	.880	.376	1.321	.261	.906	.381	1.340	.269	.932	.386	1.358	.276	.959	.392	.28
.30	1.278	.262	.848	.395	1.294	.271	.874	.401	1.312	.279	.900	.407	1.331	.287	.926	.413	1.350	.295	.953	.419	.30
.32	1.270	.279	.843	.421	1.286	.288	.869	.427	1.303	.297	.894	.434	1.322	.305	.920	.440	1.341	.314	.947	.446	.32
.34	1.261	.296	.837	.446	1.277	.306	.863	.453	1.295	.314	.888	.460	1.313	.324	.914	.466	1.331	.333	.941	.473	.34
.36	1.252	.313	.831	.472	1.268	.323	.857	.479	1.286	.333	.881	.486	1.303	.342	.908	.483	1.321	.352	.934	.500	.36
.38	1.242	.330	.825	.496	1.258	.339	.850	.504	1.276	.349	.874	.510	1.293	.360	.901	.518	1.311	.370	.927	.525	.38
.40	1.232	.346	.818	.521	1.248	.356	.843	.528	1.265	.366	.867	.535	1.282	.377	.894	.543	1.301	.388	.919	.550	.40
.42	1.221	.362	.811	.545	1.237	.373	.836	.553	1.254	.384	.860	.562	1.272	.395	.886	.570	1.290	.407	.911	.577	.42
.44	1.210	.378	.803	.570	1.226	.390	.828	.578	1.243	.401	.852	.586	1.261	.413	.878	.595	1.279	.425	.903	.603	.44
.46	1.198	.394	.796	.594	1.214	.406	.820	.602	1.232	.418	.844	.610	1.249	.430	.869	.619	1.267	.443	.894	.628	.46
.48	1.186	.410	.787	.618	1.202	.423	.812	.627	1.220	.435	.836	.635	1.237	.447	.860	.645	1.255	.461	.885	.653	.48
.50	1.174	.426	.779	.641	1.189	.439	.803	.650	1.207	.451	.827	.659	1.224	.464	.851	.668	1.242	.478	.876	.678	.50
.52	1.161	.441	.770	.664	1.176	.455	.794	.674	1.193	.467	.818	.684	1.210	.481	.841	.692	1.228	.496	.866	.703	.52
.54	1.147	.456	.761	.687	1.161	.471	.785	.697	1.179	.483	.808	.707	1.196	.498	.831	.716	1.214	.513	.856	.727	.54
.56	1.133	.471	.752	.710	1.147	.486	.775	.721	1.164	.499	.798	.731	1.181	.515	.821	.740	1.199	.530	.846	.751	.56
.58	1.119	.486	.743	.733	1.133	.501	.765	.744	1.149	.515	.788	.754	1.165	.530	.811	.763	1.184	.547	.834	.775	.58
.60	1.104	.501	.733	.755	1.118	.516	.755	.765	1.134	.531	.777	.776	1.150	.546	.800	.786	1.168	.563	.823	.799	.60
.62	1.089	.516	.723	.777	1.103	.531	.745	.789	1.118	.546	.766	.797	1.135	.562	.789	.809	1.151	.580	.812	.822	.62
.64	1.073	.531	.712	.799	1.088	.546	.735	.810	1.102	.561	.756	.819	1.119	.578	.778	.832	1.134	.596	.800	.845	.64
.66	1.057	.545	.701	.820	1.072	.561	.724	.832	1.085	.576	.744	.841	1.102	.594	.766	.854	1.117	.612	.788	.867	.66
.68	1.040	.559	.690	.841	1.055	.576	.712	.853	1.068	.591	.732	.863	1.085	.609	.754	.876	1.099	.628	.776	.889	.68
.70	1.023	.572	.679	.862	1.037	.589	.700	.874	1.051	.606	.720	.885	1.067	.624	.742	.898	1.081	.643	.763	.911	.70
.72	1.006	.585	.667	.882	1.020	.603	.688	.894	1.033	.621	.708	.906	1.049	.639	.730	.919	1.063	.658	.750	.932	.72
.74	.988	.598	.656	.902	1.003	.617	.676	.914	1.015	.635	.696	.927	1.031	.654	.717	.940	1.045	.673	.736	.953	.74
.76	.970	.611	.643	.921	.985	.630	.664	.934	.997	.649	.683	.947	1.012	.668	.704	.961	1.026	.688	.724	.973	.76
.78	.951	.624	.631	.940	.966	.643	.651	.954	.978	.663	.670	.967	.993	.682	.690	.981	1.007	.702	.710	.993	.78
.80	.932	.637	.619	.959	.946	.656	.638	.973	.959	.676	.657	.987	.973	.696	.676	1.001	.987	.716	.696	1.013	.80
.82	.913	.649	.606	.978	.926	.669	.625	.991	.939	.689	.644	1.006	.953	.709	.662	1.020	.966	.730	.681	1.032	.82
.84	.893	.661	.593	.996	.906	.681	.611	1.009	.918	.702	.630	1.024	.933	.722	.648	1.039	.945	.743	.666	1.051	.84
.86	.873	.673	.580	1.014	.885	.693	.597	1.027	.897	.714	.616	1.042	.912	.735	.633	1.057	.924	.757	.651	1.070	.86
.88	.852	.685	.566	1.031	.864	.705	.583	1.044	.876	.726	.601	1.060	.890	.747	.618	1.075	.903	.769	.636	1.088	.88
.90	.831	.696	.552	1.048	.843	.717	.569	1.061	.855	.738	.586	1.077	.868	.759	.603	1.092	.881	.781	.621	1.106	.90
.92	.810	.707	.538	1.064	.821	.728	.554	1.078	.833	.749	.571	1.094	.846	.771	.588	1.109	.859	.794	.605	1.124	.92
.94	.789	.717	.524	1.080	.799	.739	.539	1.094	.811	.760	.556	1.110	.824	.783	.572	1.125	.836	.806	.589	1.141	.94
.96	.767	.727	.510	1.096	.777	.750	.524	1.110	.789	.771	.541	1.126	.801	.794	.556	1.141	.813	.817	.573	1.158	.96
.98	.745	.737	.495	1.110	.755	.760	.509	1.125	.766	.782	.525	1.141	.778	.805	.540	1.157	.789	.828	.556	1.174	.98
1.00	.723	.747	.480	1.125	.733	.770	.494	1.140	.743	.792	.509	1.156	.754	.816	.521	1.173	.765	.839	.539	1.190	1.00

TABLE XIII

Values of cosh $(x + jy) = a + jb$ and sinh $(x + jy) = c + jd$

y	x = .90 a	b	c	d	x = .92 a	b	c	d	x = .94 a	b	c	d	x = .96 a	b	c	d	x = .98 a	b	c	d	y
0.00	1.433	.000	1.026	.000	1.464	.000	1.066	.000	1.476	.000	1.086	.000	1.497	.000	1.114	.000	1.620	.000	1.146	.000	0.00
.02	1.433	.021	1.026	.029	1.464	.021	1.066	.029	1.476	.022	1.086	.030	1.497	.022	1.114	.030	1.519	.023	1.144	.030	.02
.04	1.432	.041	1.026	.067	1.453	.042	1.064	.068	1.474	.043	1.084	.059	1.496	.045	1.113	.060	1.618	.046	1.144	.061	.04
.06	1.431	.062	1.024	.086	1.462	.063	1.063	.087	1.473	.066	1.083	.089	1.496	.067	1.112	.090	1.617	.069	1.143	.091	.06
.08	1.429	.082	1.023	.116	1.460	.084	1.062	.116	1.471	.087	1.081	.118	1.493	.089	1.111	.120	1.616	.092	1.142	.122	.08
.10	1.426	.102	1.021	.143	1.447	.106	1.060	.146	1.469	.108	1.079	.147	1.490	.111	1.109	.160	1.612	.114	1.139	.152	.10
.12	1.422	.123	1.019	.172	1.443	.127	1.048	.176	1.466	.130	1.077	.177	1.486	.134	1.107	.180	1.608	.137	1.137	.182	.12
.14	1.418	.144	1.017	.201	1.439	.148	1.046	.204	1.462	.152	1.076	.206	1.482	.166	1.105	.210	1.504	.160	1.134	.213	.14
.16	1.414	.163	1.014	.228	1.436	.168	1.042	.232	1.467	.172	1.072	.234	1.477	.177	1.102	.238	1.600	.182	1.131	.242	.16
.18	1.409	.184	1.010	.266	1.430	.189	1.038	.261	1.462	.194	1.068	.264	1.472	.200	1.098	.268	1.496	.206	1.127	.272	.18
.20	1.404	.204	1.006	.286	1.425	.210	1.034	.290	1.446	.216	1.063	.294	1.466	.222	1.092	.298	1.489	.228	1.122	.303	.20
.22	1.398	.224	1.002	.313	1.419	.230	1.030	.317	1.439	.236	1.068	.322	1.459	.243	1.087	.326	1.482	.250	1.117	.332	.22
.24	1.392	.244	.997	.342	1.413	.251	1.026	.346	1.432	.268	1.063	.361	1.462	.266	1.082	.356	1.475	.273	1.112	.362	.24
.26	1.386	.264	.992	.369	1.406	.271	1.020	.374	1.426	.279	1.048	.380	1.446	.287	1.076	.385	1.467	.294	1.106	.391	.26
.28	1.377	.284	.987	.398	1.398	.292	1.014	.403	1.418	.300	1.042	.409	1.437	.309	1.070	.416	1.469	.317	1.100	.421	.28
.30	1.369	.303	.981	.424	1.390	.312	1.008	.431	1.410	.321	1.036	.436	1.429	.330	1.064	.443	1.451	.339	1.093	.460	.30
.32	1.360	.322	.974	.451	1.381	.333	1.002	.468	1.402	.346	1.029	.466	1.420	.361	1.057	.472	1.442	.361	1.086	.479	.32
.34	1.361	.342	.967	.478	1.372	.362	.996	.486	1.393	.362	1.022	.494	1.411	.372	1.050	.600	1.432	.383	1.079	.608	.34
.36	1.341	.362	.960	.506	1.362	.373	.988	.514	1.382	.383	1.016	.621	1.401	.393	1.042	.629	1.422	.406	1.071	.636	.36
.38	1.331	.381	.963	.632	1.362	.391	.980	.540	1.371	.402	1.007	.648	1.390	.414	1.034	.556	1.411	.425	1.063	.664	.38
.40	1.320	.400	.946	.668	1.341	.410	.972	.666	1.369	.422	.999	.674	1.378	.434	1.026	.683	1.399	.446	1.064	.691	.40
.42	1.309	.419	.937	.684	1.329	.431	.964	.692	1.347	.442	.990	.601	1.366	.465	1.017	.610	1.386	.467	1.046	.620	.42
.44	1.297	.438	.929	.610	1.317	.460	.966	.618	1.335	.462	.981	.628	1.363	.476	1.008	.637	1.373	.488	1.036	.648	.44
.46	1.285	.456	.920	.636	1.304	.469	.946	.644	1.322	.481	.972	.654	1.340	.496	.999	.664	1.360	.609	1.026	.676	.46
.48	1.272	.474	.911	.662	1.290	.487	.936	.670	1.308	.600	.962	.680	1.327	.516	.989	.691	1.347	.529	1.016	.703	.48
.50	1.258	.492	.901	.687	1.276	.505	.927	.696	1.294	.619	.952	.706	1.313	.534	.979	.717	1.333	.549	1.005	.728	.50
.52	1.244	.510	.891	.712	1.262	.623	.916	.721	1.279	.638	.941	.732	1.298	.553	.968	.743	1.318	.669	.994	.756	.52
.54	1.229	.628	.881	.737	1.247	.641	.906	.746	1.260	.667	.930	.768	1.282	.672	.966	.769	1.303	.689	.982	.781	.54
.56	1.214	.646	.870	.761	1.232	.669	.894	.771	1.249	.676	.919	.783	1.266	.691	.944	.796	1.287	.608	.970	.807	.56
.58	1.199	.663	.869	.786	1.216	.677	.883	.796	1.233	.694	.907	.808	1.260	.610	.932	.820	1.270	.627	.958	.833	.58
.60	1.183	.680	.847	.809	1.200	.696	.871	.821	1.217	.612	.895	.833	1.233	.629	.920	.846	1.263	.646	.946	.858	.60
.62	1.166	.597	.835	.833	1.184	.613	.869	.845	1.200	.630	.883	.867	1 216	.647	.908	.869	1.235	.665	.932	.883	.62
.64	1.149	.614	.823	.856	1.167	.630	.847	.868	1.182	.648	.870	.891	1.199	.665	.895	.893	1.217	.684	.919	.908	.64
.66	1.132	.630	.811	.879	1.149	.647	.834	.891	1.164	.666	.867	.914	1.181	.683	.882	.917	1.199	.702	.906	.932	.66
.68	1.114	.646	.798	.901	1.131	.664	.821	.914	1.146	.682	.844	.937	1.162	.701	.868	.941	1.180	.720	.891	.966	.68
.70	1.096	.661	.785	.923	1.112	.680	.808	.937	1.128	.698	.830	.950	1.143	.718	.864	.964	1.161	.738	.876	.979	.70
.72	1.078	.676	.772	.946	1.093	.696	.794	.969	1.109	.714	.816	.972	1.124	.735	.839	.987	1.142	.755	.861	1.002	.72
.74	1.059	.691	.758	.966	1.073	.712	.780	.981	1.090	.730	.802	.994	1.106	.752	.824	1.009	1.122	.772	.846	1.025	.74
.76	1.039	.706	.744	.987	1.053	.727	.766	1.002	1.070	.746	.787	1.016	1.085	.768	.809	1.031	1.102	.789	.830	1.047	.76
.78	1.019	.721	.730	1.008	1.033	.742	.761	1.023	1.060	.762	.772	1.037	1.066	.784	.793	1.062	1.081	.805	.814	1.069	.78
.80	.998	.736	.715	1.028	1.013	.757	.736	1.044	1.029	.778	.766	1.059	1.044	.800	.777	1.073	1.060	.821	.798	1.090	.80
.82	.977	.750	.700	1.048	.992	.772	.721	1.064	1.008	.793	.740	1.078	1.022	.815	.761	1.094	1.038	.837	.781	1.111	.82
.84	.956	.764	.685	1.067	.971	.786	.706	1.083	.986	.808	.724	1.099	1.000	.830	.745	1.114	1.016	.852	.764	1.131	.84
.86	.936	.778	.670	1.086	.950	.800	.689	1.102	.964	.822	.708	1.118	.978	.846	.728	1.134	.993	.867	.747	1.151	.86
.88	.913	.791	.654	1.105	.928	.813	.673	1.121	.941	.836	.692	1.137	.956	.859	.711	1.163	.970	.882	.730	1.171	.88
.90	.891	.804	.638	1.123	.906	.826	.666	1.139	.918	.849	.676	1.156	.932	.873	.694	1.172	.946	.897	.712	1.190	.90
.92	.868	.817	.622	1.140	.883	.839	.639	1.157	.895	.862	.658	1.174	.908	.887	.676	1.190	.922	.911	.694	1.209	.92
.94	.845	.829	.606	1.157	.860	.852	.622	1.176	.871	.875	.641	1.191	.884	.900	.658	1.208	.897	.924	.676	1.227	.94
.96	.822	.841	.589	1.174	.836	.864	.605	1.192	.847	.888	.623	1.208	.859	.913	.640	1.225	.872	.937	.656	1.245	.96
.98	.798	.863	.572	1.190	.811	.876	.588	1.208	.822	.900	.606	1.225	.834	.925	.621	1.242	.847	.950	.637	1.262	.98
1.00	.774	.864	.565	1.206	.786	.888	.670	1.224	.797	.912	.586	1.241	.809	.937	.602	1.258	.821	.963	.618	1.278	1.00

GENERAL ELECTRIC REVIEW

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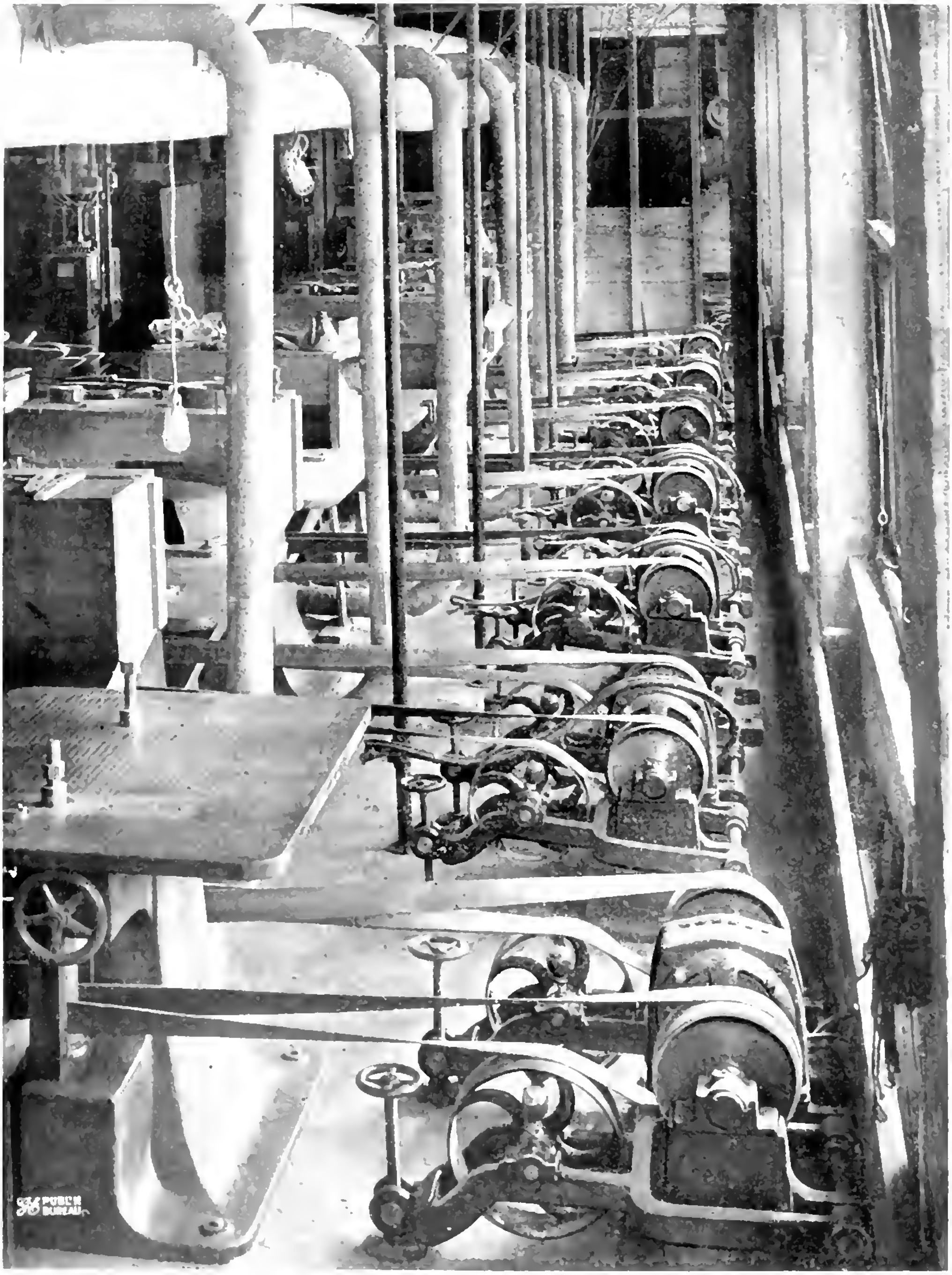


Group of Two Spindle Shapers Driven by 5 H.P. Induction Motors

Heywood Bros. & Wakefield Company, Gardner, Mass.

See page 251

GENERAL ELECTRIC REVIEW

THE 1200 VOLT RAILROAD

The transportation facilities of a country are an accurate criterion of that country's condition; no form of public improvement is more far-reaching in its effects than are the improvements in these facilities. For this reason, the use of electricity for transportation is probably of more importance to the public at large than any other application of this form of energy.

In the building of an electric road or the electrification of a steam road, one of the first matters that requires consideration is the choice of the system to be employed. At the present time this choice is practically confined to the 600 volt and the 1200 volt (or higher) systems with the direct current, and the single-phase (15 or 25 cycle) and the three-phase systems with the alternating current. In any case any one of these would be entirely operative, and each has its specific advantages. The selection is therefore a matter calling for the highest engineering ability; the ability to weigh the several advantages and disadvantages of the different systems, considered in relation to the conditions of the specific case in mind, and to select that one which, all things considered, best meets the requirements. For, while data from existing roads are not lacking, the local conditions under which the roads operate have so important a bearing upon the matter as to largely modify any conclusions that might be drawn from such information. Thus, it is difficult or impossible to compare the different systems by means of the data taken from different roads, the local conditions always being dissimilar.

On account of the increasing importance of the subject, authoritative articles that help to determine which of the various systems is best adapted to particular fields are of much interest.

In the REVIEW for June, 1909, an article by Mr. G. H. Hill was published, comparing the 1200 volt direct and the single-phase alternating current systems, and showing the advantages of the former for a certain class of interurban service. At that time, it was pointed out that, whereas the chief claim of the single-phase system for recognition is the low first cost of the distributing system, this saving is obtained at the expense of much complication of the motor car equipments, oil switches being necessary to control the circuits, a heavy transformer to supply the low potential, and an additional winding being required on the motors to make commutation possible. Both the first cost and the maintenance charges for these equipments are therefore considerably greater than the corresponding items for the 1200 volt system. Again, on account of inductive drop in track and line and the starting characteristics of the single-phase alternating current motor, a much higher potential is demanded than in the case of the 1200 volt system, for the same operating results.

Mr. Hill summarizes the situation as follows: "All things considered, the average interurban road will cost less to install, will be operated for a less amount, and will give a more reliable and satisfactory service when equipped with 1200 volts direct current than it will with an alternating current system of 6600 or 11000 volts."

In the present issue of the REVIEW we print a paper on The 1200 Volt Railroad, which was read by Mr. Charles E. Eveleth before the Philadelphia section of the A.I.E.E., and which compares the 1200 and 600 volt direct current systems. Mr. Eveleth indicates clearly the service for which the 1200 volt system is particularly adapted. He shows that the adoption of this system not only largely decreases the first cost, through a material saving in sub-stations and secondary distribution conductors, but also greatly reduces the operating expenses, as it calls for fewer operators, and also decreases the power [illegible]nsumption, the improvement in load factor effecting a corresponding increase in efficiency.

Another important consideration is the fact that the motors may be run two in series on the 1200-volt trolleys, and two in multiple on 600-volt trolleys. Thus the speed on the lower voltage can be equal to that on the high, and the economy resulting from 1200-volt operation may be secured without in any way interfering with existing 600-volt systems in cities or elsewhere, over which it may be desired to run the cars.

The many advantages of the 1200-volt system, and the fact that despite its recent [illegible] it has been adopted by over a dozen different roads that are in operation or under construction, indicate that its adoption will be [illegible]. Even in Europe, which has generally been considered the stronghold of the single-phase system, there are nearly as many [illegible] operating at [illegible] volts and over as there are single-phase systems.

ELECTRIC HAULAGE IN COAL MINES

Although electric haulage for coal mines was introduced as long ago as 1887, its employment to any considerable extent is a matter of comparatively recent date. Until [illegible]

[illegible]

fact, as soon as it became evident that the employment of electricity was not accompanied by risk of accident, its rapid adoption was inevitable, on account of its obvious advantages.

In his article entitled Electricity in the Mines of the Davis Coal and Coke Company, in this issue of the REVIEW, Mr. R. Neil Williams shows that these advantages are both numerous and important. He states that with the exception of gravity, which, under certain conditions, is, of course, the cheapest power, but the use of which is circumscribed by many limitations, electricity as a motive power is without a competitor.

The high mortality among horses and mules in mining work militates seriously against their employment; the electric mining locomotive, on the contrary, is exceedingly durable—the first one that was manufactured in the United States being still in active daily operation. Again, the mining locomotive is capable of much longer hauls at higher rates of speed, the result being that, on an average, one of these will accomplish as much work as 15 horses, and in so doing will require the services of one man instead of 15 boys.

In his article Mr. Williams describes the various applications of electricity to the different processes of the mine and plant. Several electrical systems are used and the reasons for their adoption are explained.

The development of the mining locomotive has called for much thought on the part of designing engineers and today there are many different types, suitable for every variety of service and for use on a large number of different gauges, varying from 17 to $56\frac{1}{2}$ inches. Some of these are simply intended for direct haulage, while others are in addition provided with hoisting drums for drawing out cars from the rooms. The REVIEW for August, 1908, contains an article by Mr. C. W. Larson describing a number of different types.

THE SINGLE-PHASE INDUCTION MOTOR

PART II

BY PROFS. J. H. MORECROFT AND M. ARENDT

COLUMBIA UNIVERSITY

Characteristic Curves

The preceding torque equation, while valuable in that it indicates the general characteristics of single-phase induction motors, is not readily applied to the detail study of any specific machine. The working curves are most accurately determined by actual test. They may, however, be derived with moderate accuracy by means of a circle diagram somewhat similar to that utilized in connection with the study of the polyphase motor.

The particular diagram described herein (Fig. 7) is that developed by A. S. McAllister, and its construction is as follows:*

Let the vertical line OE (Fig. 7) represent the line voltage. Draw at their proper phase positions and scale values the no-load as well as the locked currents OM and OF respectively.

MN and IF represent the energy components of the corresponding currents and are therefore directly proportional to the respective inputs. Through M draw a line MK perpendicular to OE, join M and F; draw also a line perpendicular to the middle of MF intersecting MK at X. With X as a center and either XM or XF as a radius describe the circular arc MPF, this being the locus of the primary current. The distance IG represents the added primary or stator loss existing with the rotor locked, its length = (added primary copper loss ÷ total locked watts) $\times HF$. Draw the line GM. With this construction completed the performance of the motor may be determined by inspection.

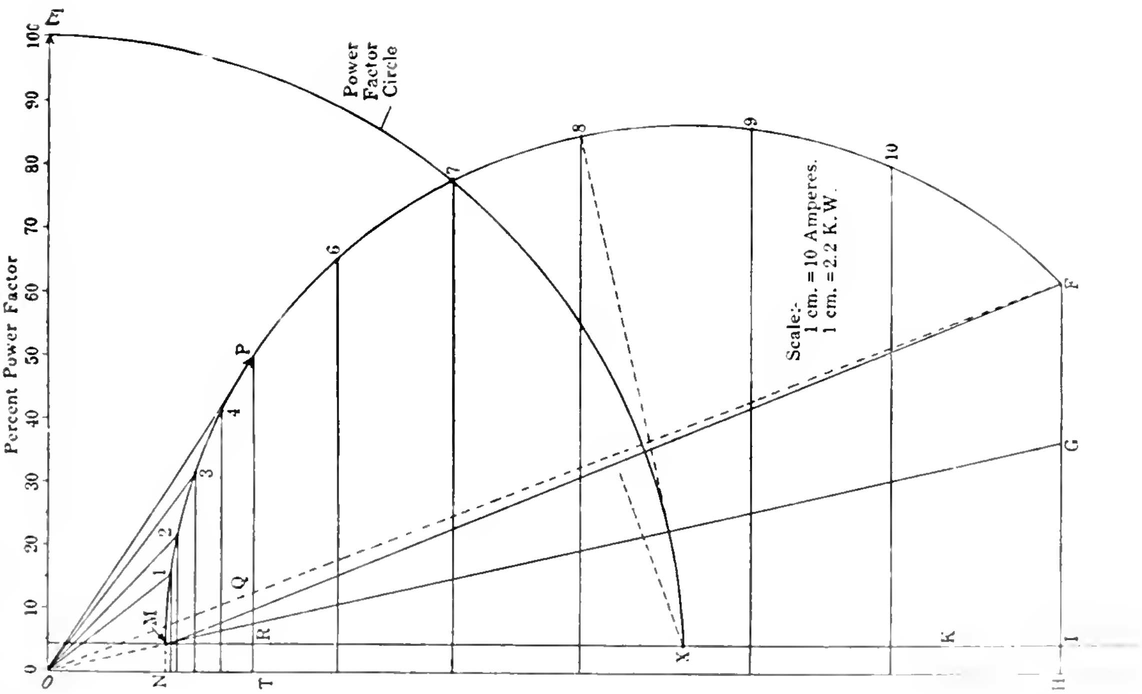


Fig. 7. McAllister Circle Diagram for a 10 H.P. Single-Phase Induction Motor

* Alternating Current Motors, A. S. McAllister, pages 115-119. McGraw Co., New York, 1909.

For example, the factors determining the performance of the motor with a current P are as follows:

OP to scale represents the primary current.
$\cos POE$ is the power factor of current OP.
PT represents the watts input at current OP.
MN represents the watts input at no load.
TQ represents the watts loss at current OP.
TR represents the total primary loss at current OP.
QR represents the added secondary copper loss.
QP represents the watts output at current OP.
$QP \div PT$ represents the efficiency of the motor at current OP.
$100 (PQ \div PR)$ represents the per cent. slip.
$7.05 (QP \div$ r.p.m.) represents the torque at current OP.

The field set up through the motion of the rotor varies as the speed ω, consequently the torque T for a given rotor input W' will be proportional to the product of $\omega W'$, or

$$T = K_1 \omega W'. \qquad (19)$$

The torque, however, is also proportional to the secondary output W'' divided by the speed ω, or

$$T = K_2 (W'' \div \omega)$$

whence

$$\omega = K (W'' \div W')^{\frac{1}{2}}. \qquad (20)$$

The secondary input, from the circle diagram, is proportional to PR; the output is similarly represented by PQ; consequently $(PQ \div PR)^{\frac{1}{2}}$ corresponds to the rotor speed as above stated.

The diagram shown in Fig. 7 has been applied to the determination of the characteristic curves of a standard 220 volt, 60 cycle, 4 pole, 10 horsepower single-phase induction motor. The fundamental data employed in the construction of this diagram were derived by test, and are as follows: Stator resistance .301 ohm, current with motor running free 19 amperes, corresponding input 1 kw., and power factor 24 per cent. The current with rotor at standstill is 170 amperes, input 13.4 kw., power factor 36 per cent. Line potential in both instances is 220 volts.

The values derived from the diagram are given in Table I and presented in the form of curves in Fig. 8.

Comparison of these characteristic curves of the single-phase induction motor with those of the standard polyphase induction motor brings out the fact that the former has zero torque, not only at synchronous speed but also at standstill, whereas the latter has a starting torque in excess of that developed at rated load.

Table II gives characteristics of operation attained by standard single-phase induction motors.

Comparison of the values in this table with the characteristics of polyphase induction motors shows that in general the power factor, efficiency and pull-out torque are higher for polyphase than for single-phase motors, while the speed regulation of the single-phase machine is better. This latter feature of the single-phase induction motor is accounted for by Dr. C. P. Steinmetz as follows.*

"Since in the single-phase motor one primary and a multiplicity of secondary circuits exist, all secondary circuits are to be considered as corresponding to the same primary circuit. Thus the joint impedance of all secondary circuits must be used as the secondary impedance, at least at or near synchronous speed. Thus, if the armature has a quarter-phase winding of impedance Z_1 per circuit, the resultant secondary impedance is $\frac{Z_1}{2}$; if it contains a three-phase winding of impedance Z_1 per circuit, the resultant secondary impedance is $\frac{Z_1}{3}$.

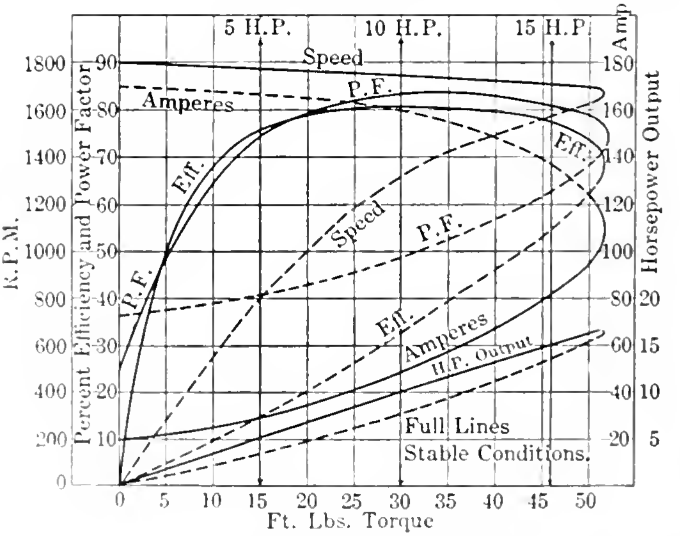


Fig. 8 Characteristic Curves of 4 Pole, 10 H.P., 220 Volt, 60 Cycle, Single Phase Induction Motor

In consequence thereof, the resultant impedance of a single-phase motor is less in comparison with the primary impedance than in the polyphase motor. Since the drop in speed under load depends upon

*Elements of Electrical Engineering, page 284 the secondary resistance, the decrease in speed in the case of the single-phase motor is generally less than that in the polyphase motor."

Methods of Starting

As already shown, the simple single-phase induction motor cannot exert any starting torque. In practice, however, except in the smallest sizes which may be started by hand), the conditions of service which this motor is to meet require a starting torque as high as 150 per cent. of the rated value; consequently some device to produce this feature must be connected with or incorporated into the machine. The methods of accomplishing this result may be grouped into two general classes. The first is technically known as ***phase-splitting*** and the second as the ***repulsion-motor*** method.

TABLE I

CHARACTERISTICS OF A 220-VOLT, 60-CYCLE, 10 HORSE-POWER, SINGLE-PHASE INDUCTION MOTOR

Point	Amp	% P F	Kw Input	H P Output	% Eff	R P M	Ft Lb Torque
M	19	21	1	0	0	1800	0
1	25	65	3.56	3.4	70	1782	10
2	30	75	4.95	5.03	76	1772	15
3	40	81	7.15	7.65	80	1760	23
P	50	83	9.24	10	81	1745	30
5	60	85	11.2	12	80	1738	36
6	80	81	14.2	14.75	78	1715	45
7	100	78	17.2	16.5	72	1690	51
8	119	70	18.7	16	64	1640	51
9	110	61	18.8	13.1	52	1550	44.5
10	155	51	17.6	8.8	37.5	1400	33.0
F	170	36	13.4	0	0	0	0

TABLE II

DATA OF STANDARD SINGLE-PHASE INDUCTION MOTORS—110 TO 440 VOLTS

H.P.	Poles	Per cent Slip	Pull-out Torque*	PER CENT. POWER FACTOR LOAD				PER CENT. EFFICIENCY LOAD			
				½	¾	Rtd.	1¼	½	¾	Rtd.	1¼
½	4	6	1.5	46	58	66	68	53	60	63	60
1	4	4	1.6	55	59	73	75	60	63	68	62
2	4	2.5	1.8	56	65	77	76	71	75	78	77
5	4	2.5	1.8	78	83	86	86	71	76	77	76
10	4	2.5	1.8	75	81	84	83	75	79	80	79
20	6	2	1.9	78	80	86	87	85	88	86	85
30	8	2	1.9	68	80	85	84	77	81	83	82
50	4	2.3	2.0	91	94	93	91	82	84	86	86

*Pull-out torque in terms of rated load torque.

Split-phase Starting

Two-phase currents may be obtained on a single-phase circuit by dividing it into two branches, one of which is inductive and the other non-inductive. If supplied with two-phase currents, even though these be less than 90 degrees apart, an induction motor is self-starting; thus when synchronous speed is approximated, the phase-splitting device may be cut out and the machine will continue to operate. There are many other ways to obtain such two-phase currents. The two parts of the circuit may be in series, one being shunted by inductance or capacity (Fig. 9). They may also be put into inductive relation to each other to produce a phase difference.*

Motors employing the above starting methods are provided with two stator windings, a *working* winding and a *starting* winding. The two windings are displaced from each other by about ninety electrical degrees, just as in the ordinary two-phase motor. The working winding, however, is of more

*U.S. Patent No. 401,520, April 16, 1889, to Nikola Tesla.

turns, being spread over a larger surface, and is of heavier wire than the starting winding, because it remains in circuit as long as the motor operates, whereas the starting coils are only in use momentarily.

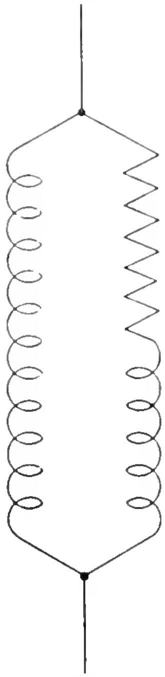


Fig. 9 Split Phase Circuit, using Resistance and Inductance

The method illustrated in Fig. 10 has been developed by Brown, Boveri and Co. of Baden, Switzerland. At starting, the two windings are placed in series across the supply lines, the starting winding *S* being shunted by the condenser. The current consequently lags more in that winding, the difference in phase between the currents in *R* and S being sufficient to set up an elliptically formed rotating field. The starting winding and its condenser are cut out and the working winding placed directly across the line by means of the double-throw switch *T*, when the motor has approximately attained synchronous speed. This method is slightly modified when machines of over 5 h.p. capacity are to be started. The two windings in such instances are placed in parallel, as shown in Fig. 11. By this means the working coil circuit is not broken and the flash occurring upon cutting out the auxiliary winding is eliminated.

An excellent method for starting single-phase motors has been developed by the General Electric Company under patents granted to Dr. C. P. Steinmetz, the connections for which are shown in Fig. 12.* Two terminals of the stator winding, which is substantially of standard three-phase construction, are connected directly to the supply lines. The third terminal is also connected to either one of the mains through an auto-transformer, the order depending upon the direction of rotation desired. The ends of this compensator are placed across a condenser. This combination is technically known as a *condenser-compensator*, and is employed because a condenser of given volt-ampere capacity is more economically constructed for high than for low voltage. The starting winding can be cut out by opening the switch at *S* after the motor is up to speed. It may, however, be advantageous to keep the starting coil in circuit, if of sufficient current capacity for continuous service, because the increased power factor at light loads thus obtained more than compensates for the losses occuring in the transformer.

The use of external phase-splitting apparatus may, however, be dispensed with if the two stator windings are arranged to have different time constants. This is accomplished by having the auxiliary winding of larger self-inductance than the main coil. Heyland devised a very successful motor of this type, utilizing the scheme suggested in the Tesla

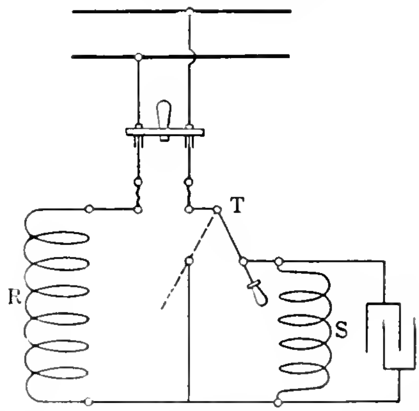


Fig. 10 Connections for Starting Small Single-Phase Induction Motors

patent cited above. The working winding *P* is distributed in a series of semi-closed slots. The starting coils *S* are short-circuited upon themselves and placed in closed ducts, the result being a highly inductive secondary circuit, the general arrangement of which is

* U. S. Patent Nos. 602,920 and 602,921, April 26, 1898.

illustrated in Fig. 13. The current induced in the secondary winding lags almost 90 degrees with respect to the primary current, producing a field component similar to that

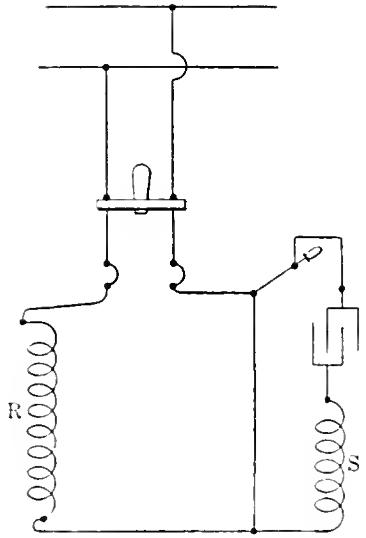


Fig. 11. Phase Splitting Method Devised by Brown, Boveri & Co. for Use with Large Motors

caused by the second phase of a two-phase current. The starting torque thus produced is large, though the power factor of the machine is necessarily low, and therefore the starting coil should be cut out as soon as the machine has come up to speed.*

The rotor windings employed in connection with any or all of the preceding methods for starting may be of the standard squirrel-cage or slip-ring type.

Repulsion Motor Starting

A very interesting type of self-starting single-phase induction motor is one that is provided with an armature of the ordinary direct current drum type, having a disk commutator with radial bars.† The brushes bearing upon the commutator are displaced about 45 degrees from the corresponding neutral zones and short-circuited upon each other. The stator winding is connected to the supply lines, and at starting the machine speeds up as a repulsion motor. In the annular space between the armature core and the shaft are two governor weights *w* (Fig. 14) which are forced outward, further and further, by centrifugal force as the machine accelerates. When synchronous speed is nearly attained, the force acting upon these weights is sufficient to push the heavy copper ring *R*, against the

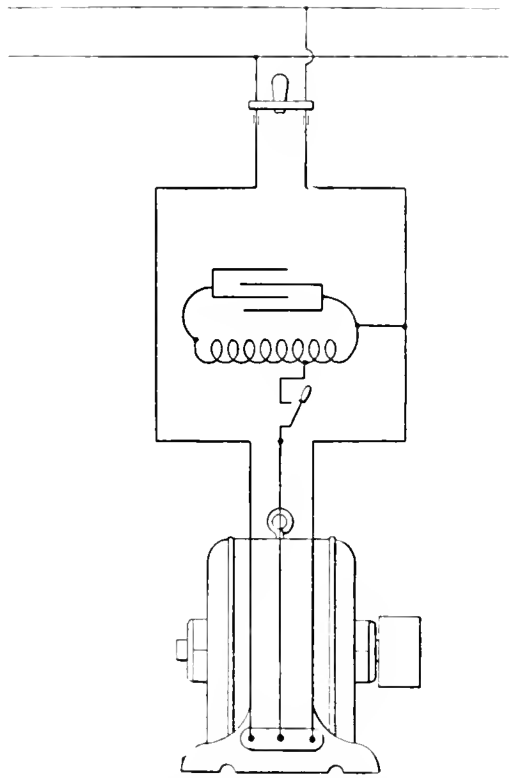


Fig. 12. General Electric Company Condenser Compensator Method of Starting Single-Phase Motors

action of spring *S*, into contact with the inner cylindrical surface of the commutator

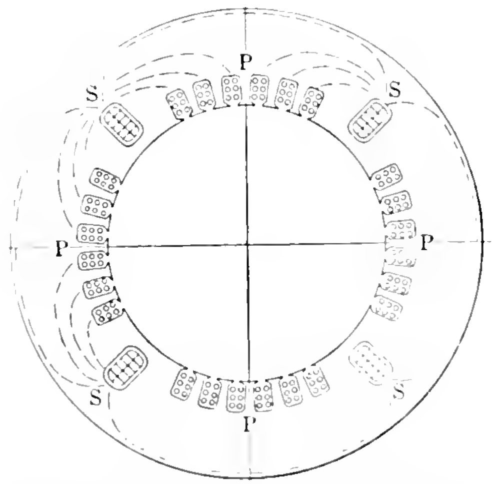


Fig. 13. Arrangement of Working and Auxiliary Stator Coils, Heyland Self Starting Single Phase Induction Motor

*Electrical Engineer, Vol. XXXVI, page 306, London, 1895

†U. S. Patent No. 543,836, Dec. 4, 1894

bars *G*, thus completely short-circuiting the armature winding. Simultaneously with this action the sleeve *P* is forced to the left sufficiently to lift the brushes *B* from the commutator. This series of automatic actions transforms the machine from a repulsion to a single-phase induction motor, having in the latter form what is substantially a squirrel-cage armature winding. The starting torque thus obtained may be readily adjusted to about twice the normal value, without an excessive current being required.

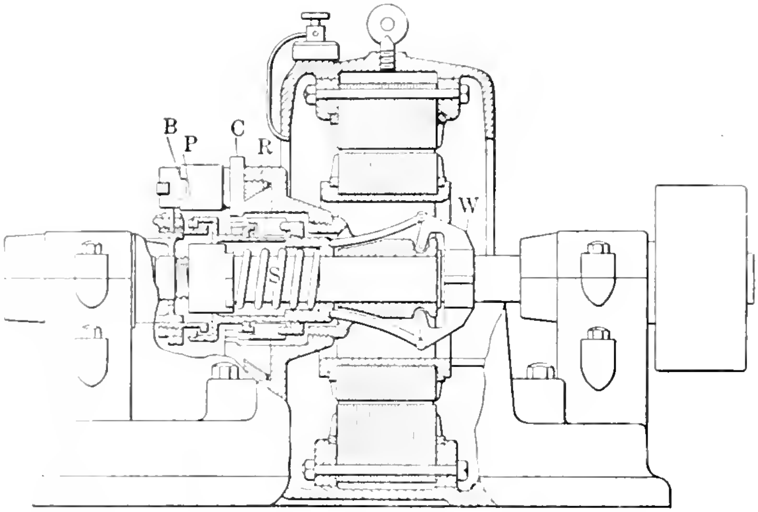


Fig. 14 General Arrangement of Wagner Motor, Showing Automatic Short Circuiting Devices

A very interesting feature of this motor, and one equally pertinent to repulsion motors, is the relation between torque and thickness of rotor brushes. The series of curves shown in Fig. 15 were determined from the tests of a 5 h.p., 220 volt Wagner motor. Curve *A* shows the speed torque relation on accelerating with normal brush thickness, this being substantially that of a commutator bar. Curve *B* represents the relations existing with a brush of twice normal thickness, etc. It is apparent from these curves that the normal thickness of brush gives the highest starting and synchronous speed torques. Further study of Fig. 15 indicates that use of a brush thinner than normal might tend to produce starting and synchronous speed torques of greater value than occur with normal brush thickness. Practical questions, however, as regard mechanical strength limit the reduction of brush thickness.

Single-phase induction motors, in addition to being provided with one or another of the preceding means for developing starting torque, require, when above moderate size (3 or 5 h.p.), the introduction of starting compensators, or the use of wound rotors with slip-ring control. This precaution is necessary as the inrush of current otherwise occurring would be considerable and likely to react upon the line, producing voltage fluctuations.

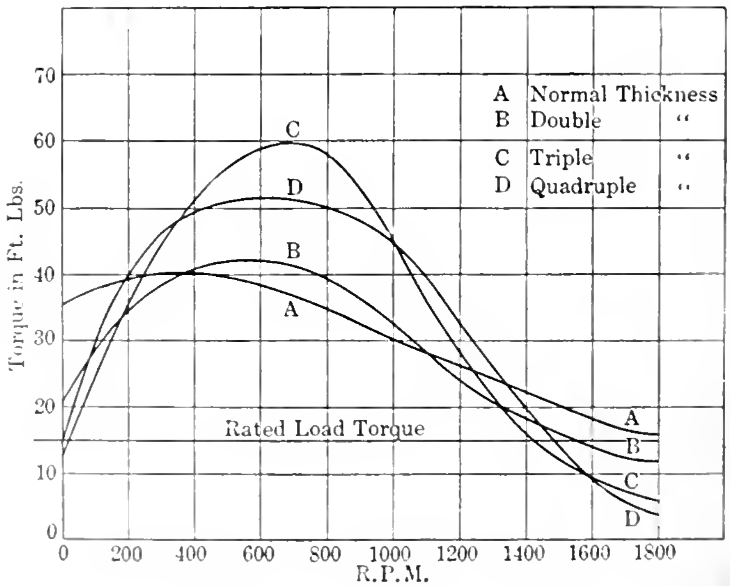


Fig. 15. Speed Torque Curve with Various Brush Thicknesses

HIGH SPEED MOTORS FOR WOOD WORKING MACHINERY

By John Liston

The specialization to which the construction of modern wood working machinery has been subjected in order to obtain results commensurate with the improvement in the mechanical equipment of other industries, has tended to concentrate the attention of practical operators of wood working machinery on the various factors entering into the power costs of production.

The rapidly extending use of motors in practically every industry indicates that the superiority of the electric drive as compared with mechanical drive for application to all forms of machinery is now generally acknowledged, and a discussion of the relative merits of the two methods in the present case is unnecessary.

The system of motor drive adopted, however, directly affects the percentage of the initial power which is actually applied at the machine, as well as the speed of operation, the cost of installation and the amount of floor space required. The problems to be met by the manufacturers of wood working machinery and those specializing in electric motor applications, will, in the future, deal largely with the question of obtaining the highest possible efficiencies for each given set

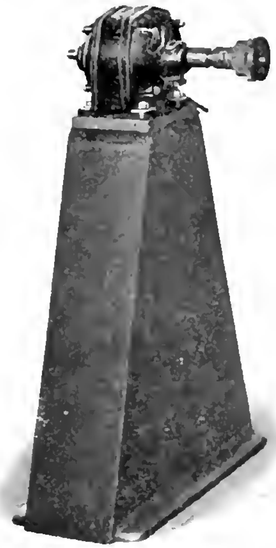


Fig 2. 3 4 H P. Induction Motor with Spindle Chuck Mounted on Motor Shaft

of operating conditions represented by the varying demands peculiar to the industry.

The relative values of group and individual drive must be determined in every instance by a careful analysis of the requirements of the installation, and while there are many successful examples of economical group drive, it is now the concensus of competent opinion that in a large majority of cases the highest efficiency, both for the machinery to be driven and for the electrical equipment, can be best obtained by the application of separate motors to each unit. This is especially true where the operation of the machines is intermittent, as in this case the cost of current, if obtained from an outside

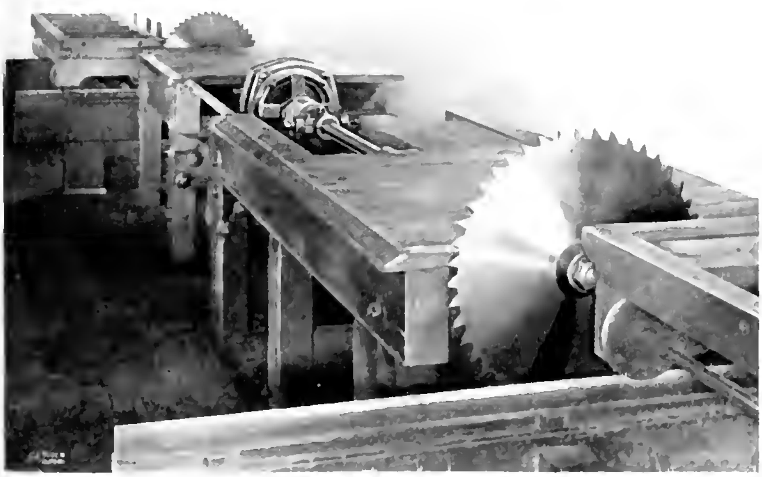


Fig. 1. 7 1 2 H.P. Induction Motor Direct Coupled to Two 20 in. Circular Cross Cut Saws

source, is entailed only during the actual operation of the machine, so that by the use of instruments the actual cost of the current

Fig. 3. 1 H P. Induction Motor with Dowel Cutting Saw Mounted on Motor Shaft

consumed by each machine or group of machines can be accurately determined.

If, on the other hand, the plant utilizing motor drive is provided with an isolated generating outfit, the size of the prime mover and generator, as well as the power factor in the case of alternating current plants, will be appreciably affected by the choice of group or individual drive. In the latter case, each machine can be equipped with a motor which will most nearly meet the exact requirements in regard to the maximum desirable speed and the amount of power delivered at the driving shaft.

Where the operation of the various units is intermittent, the individual drive system will, in practically every case, permit the successful operation of a plant when equipped with a much smaller generating outfit than would be required with motors driving the machinery in groups, even if there is considerable variation in the length of time that the units are in service; for, in the latter case, power is wasted through the unavoidable operation of shafting and belting which, during varying periods, performs no useful work.

There is perhaps no industry in which the electric motor has been so successfully applied as in that of wood working. This is due to the fact that the average wood working machine operates at relatively high speed, and therefore lends itself readily to the most economical application of the electric motor; *i.e.*, by direct connection to the driving shaft of the machine.

In designing motor drive for wood working plants, there should be active co-operation between the manufacturers of wood working machinery, the practical operator, and the designing electrical engineer, to the end that each individual machine may be constructed and operated as a compact, self-contained unit capable of positive and ready control by the class of labor generally found in wood working plants.

In order to obtain the high speeds required for the application of individual motors to wood working machinery, practice has in many instances included the use of short belts between the motor pulley and the driving shaft of the machine. It was with the object of eliminating this characteristic feature of mechanical drive that the General Electric Company developed its line of high speed motors designed for coupling direct to the driving shaft.

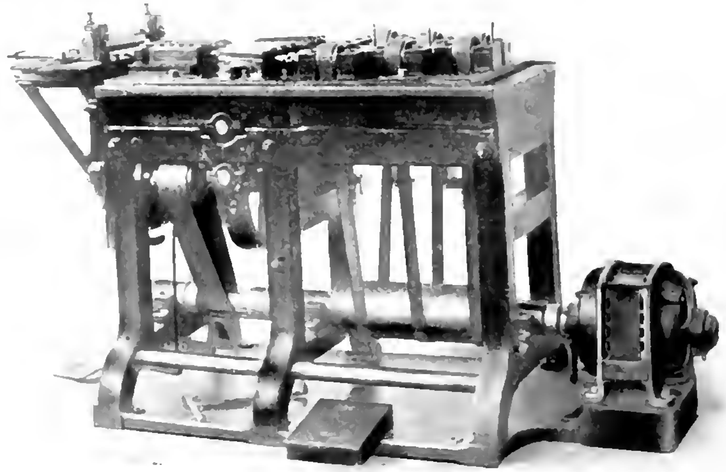


Fig. 4 5 H.P. Induction Motor Direct Connected to Driving Shaft of 6-Spindle Automatic Dowel Boring Machine

As a large majority of the operations carried on in wood working plants demand constant speed, and as the characteristics of the induction motor render it especially suitable for constant speed work, it was decided to adopt the three-phase induction motor as a standard type for this service in those places where alternating current is available.

This motor is compactly and strongly constructed, its rotating element being as simple in form as the ordinary hanger bearing; and, as it has no commutator, its operation does not involve any fire risk and the motor may therefore be safely installed in wood working plants without being enclosed. No special foundations are required and the motors may be mounted on the floor, wall or ceiling, or on the framework or headstock of the wood working machines.

The use of high speed motors in wood working plants is not merely a question of power efficiency, but one of economy in the cost of equipment, and for this reason should receive the careful consideration of all persons interested in increasing the volume and lowering the cost of production in this industry. By the adoption of high speed motors,

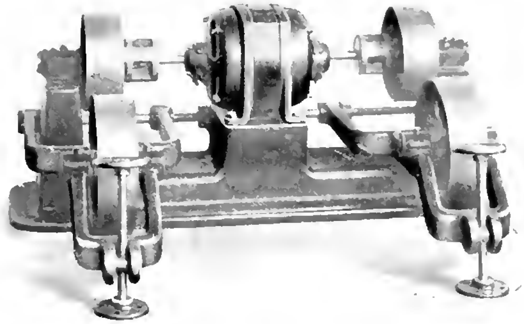


Fig. 6. Special Countershaft Device with Motor Base and Belt Tighteners Used for Driving Two-Spindle Shapers shown in Fig. 5

the size, weight and cost of motors of a given horse-power are greatly reduced as compared with the same capacity in motors of lower speed.

The accompanying illustrations show some very successful adaptations of high speed motors of small and medium size to wood working machinery, and indicate the results which may be obtained by considering each unit in a wood working plant as a separate problem, to be worked out with the idea of obtaining the highest possible efficiency for each manufacturing operation.

These machines are installed in the plant of Heywood Brothers & Wakefield Company, at Gardner, Mass., which is the largest chair factory in the world. This factory has been partially equipped with motor drive for a number of years, during which time the electrical outfit has been constantly added to, as its superiority to the previously existing drive was demonstrated.

The plant is equipped with a 600 volt, three-phase, 60 cycle, engine driven generator, and at the present time 107 motors are installed, about 80 per cent. of these being of General Electric manufacture. The equipment includes examples of belt connected group drive, and belt connected and direct connected individual drive. There are also some high speed motors direct coupled to overhead and floor shafting, from which small groups of machines, practically in continuous operation, are driven.

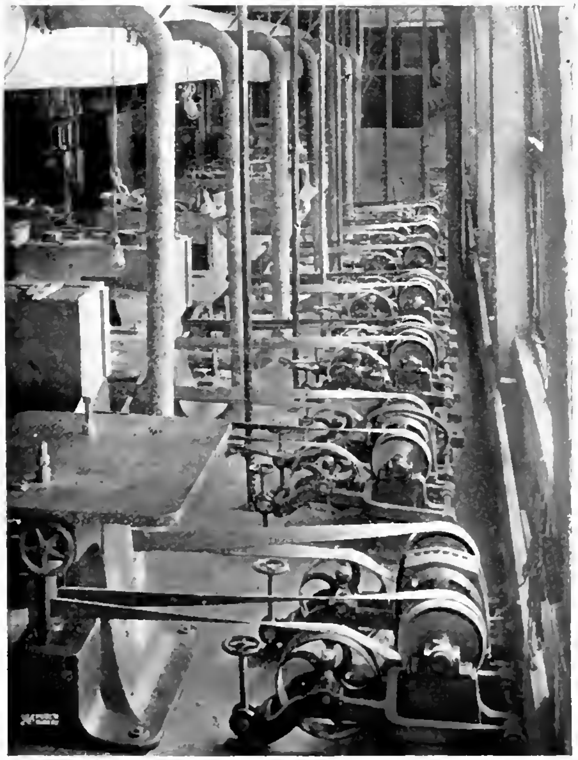


Fig. 5. Seven Two-Spindle Shapers, Motor Driven Through Special Countershaft by 5 H.P. Induction Motors

Many of the wood working machines in this plant are of original design, and most of those illustrated herewith were either designed throughout or were equipped with special features under the direct supervision of the Heywood Brothers & Wakefield Company's engineers. The motors installed in this plant are all of small or medium size, ranging in capacity from 1/2 h.p. to 35 h.p., with initial speeds varying from 540 r.p.m. to 3600 r.p.m.

While accurate figures in regard to the saving in power which has been effected by the adoption of motor drive in this plant are not available, a competent estimate indicates that the operating expense for a given amount of production has been reduced by more than 30 per cent.

A careful consideration of the following instances of the direct application of high speed motors will give a comprehensive idea of the possibilities of this method of drive for wood working machinery:

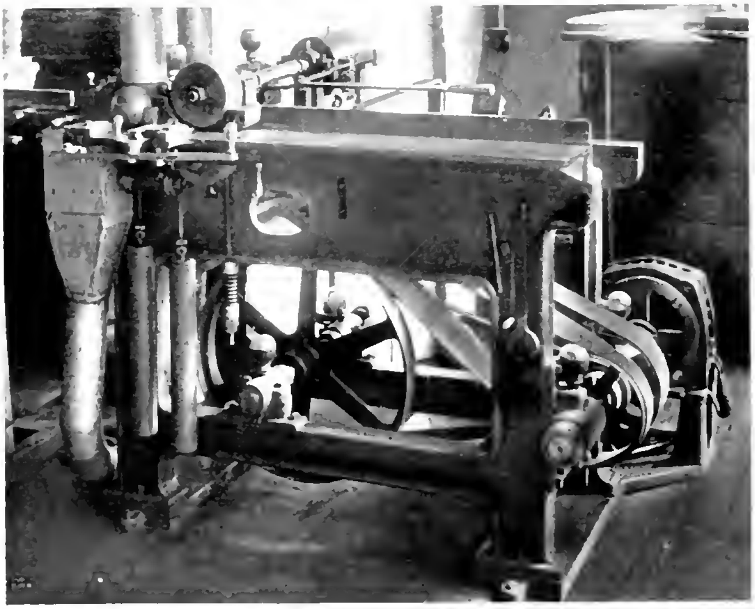


Fig. 7. 5 H.P. Induction Motor Driving Spline Cutting Machine

Fig. 1 shows a 7 1/2 h.p. motor which drives two 20 inch circular saws at 1800 r.p.m., the motor being mounted between the saws and direct coupled to the saw shafts. These saws are used for cutting up large stock, and the shafting is therefore relatively long. Both the motor and the saw bearings are mounted on a common cast iron bed-plate, thereby avoiding any tendency to distortion of the shaft. In addition to the equipment shown, there is another double saw set of a similar type but larger size, and two single saws, all utilizing direct coupled motors.

The illustration, Fig. 2, suggests one of the benefits of individual motor drive; *i.e.*, the location of auxiliary machinery where it will be most effective in insuring the continuity of progressive operations. Each unit may be placed wherever desired and connected to the feeder wires without regard to the location of the rest of the machinery. Fig 2 shows a small cutting chuck for chucking 3/4 in. chair

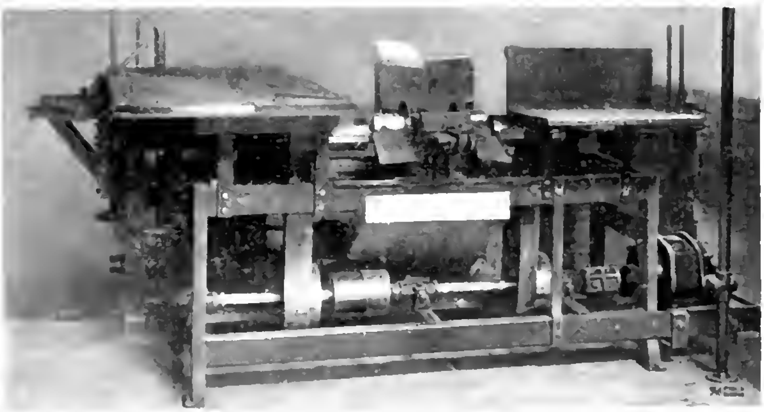


Fig 8. 7 1/2 H.P. Induction Motor Direct Connected to Driving Shaft of Frame Machine, and Belt Connected to a Four Spindle Dowel Boring Machine

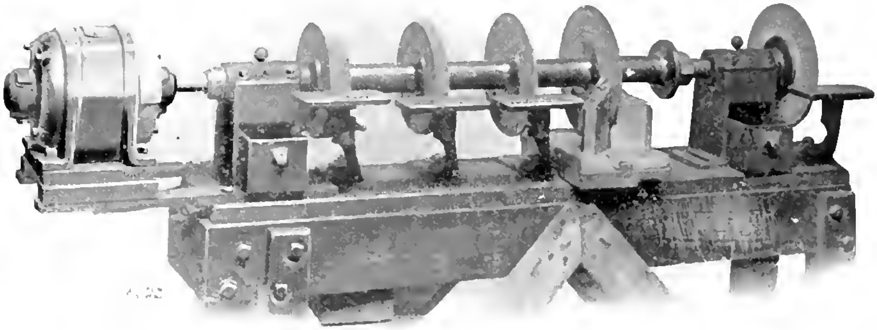


Fig. 9. 1 H P. Induction Motor Driving Six-Wheel Grinding Set

spindles, mounted on the shaft of a ¾ h.p. motor which operates at 3600 r.p.m.; while

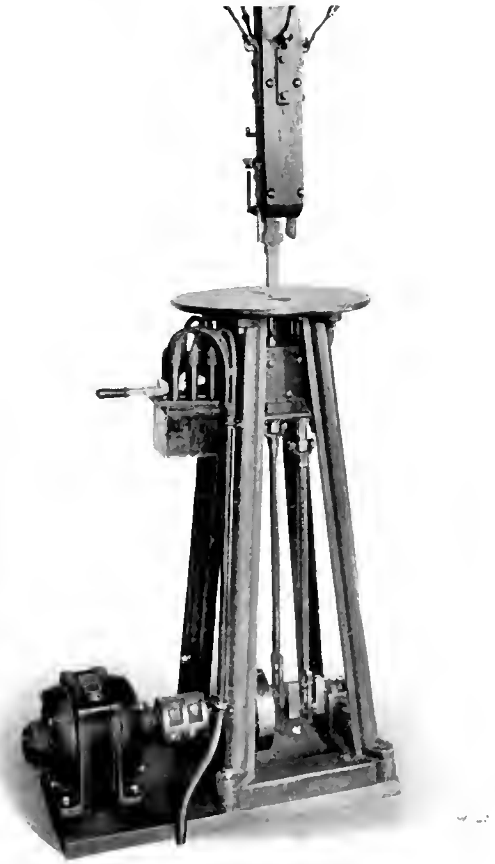


Fig. 10. 3 H.P. Induction Motor Direct Connected to Driving Shaft of Jig Saw

Fig. 3 shows a circular saw, mounted on the shaft of a 1 h.p. motor and used for cutting dowels, also operating at 3600 r.p.m.

An example of the special machines designed and built by the wood working company's engineers is shown in Fig. 4. This consists of a special six-spindle automatic dowel boring machine with a 5 h.p., 1800 r.p.m. motor direct connected to the driving shaft, which is equipped with a broad pulley from which belts are run to the small driving pulleys for the individual drills. The proper spacing of the six drills, which are located in a horizontal row at the top of the machine, is effected through universal joints.

For shaping and moulding chair seat frames, ten two-spindle vertical shaft shapers are used, each double shaper being driven by a 5 h.p., 1800 r.p.m. motor, and provided with a specially designed countershaft device in which the motor and the driving pulleys are mounted on a common cast iron bed-plate. These driving pulleys are direct coupled to the motor shaft, the coupling and pulley being made in halves, thus insuring a simple, compact and strong driving mechanism. A group of seven of these shapers is shown in Fig. 5, while the motor driven countershaft is shown separately in Fig. 6.

That this factory has an enormous output is indicated by the fact that it has facilities for the production of 6000 chairs of one type per day. For cane seated chairs a very large number of splines are required, and as the ordinary machine for this work cuts only one spline at a time, it was decided to increase the production of this detail part by constructing the machine shown in Fig. 7, which is driven by a 5 h.p., 1800 r.p.m. motor, and cuts ten splines in one operation.

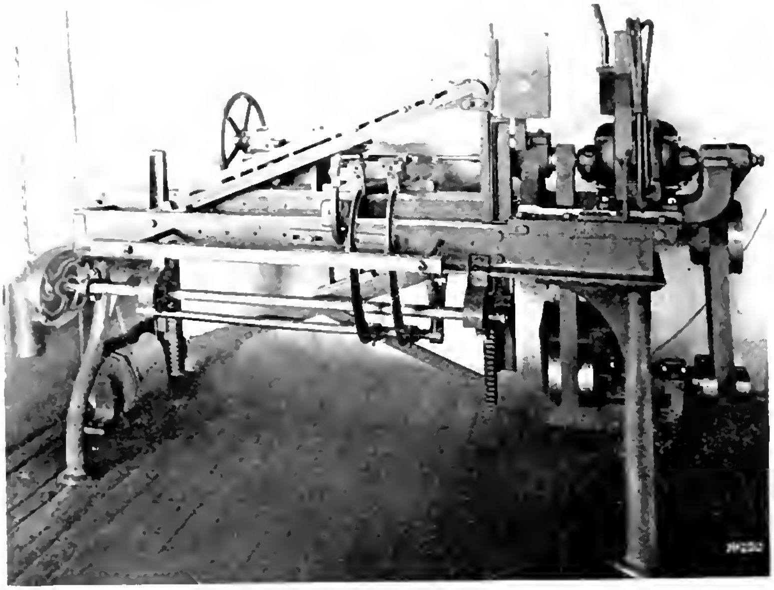


Fig. 11. 3 H P Induction Motor mounted on Head Stock of Back Knife Gauge Lathe

An instance of two interconnected machines involving two consecutive manufacturing operations and driven by a single motor is shown in Fig. 8. This set consists of a frame cutting machine and a four-spindle dowel boring machine; the former being utilized for cutting wood for seat frames to the proper size and angle, and the latter for boring the holes for the dowels. A $7\frac{1}{2}$ h.p., 1800 r.p.m. motor is direct connected to the driving shaft of the framing machine, which is in turn belt connected to that of the dowel boring machine.

For grinding tools a compact grinding set arranged for holding six wheels and direct driven by a 1 h.p. motor at 1800 r.p.m. is shown in Fig. 9, while Fig. 10 shows an auxiliary device consisting of a small jig saw driven by a $\frac{3}{4}$ h.p., 1200 r.p.m. motor, direct connected to the crank shaft. There is a similar jig saw installed in the plant and equipped with a small self-contained centrifugal blower, which is also operated by the driving motor, thereby rendering this particular unit independent of the air exhaust system of the factory and avoiding the expense of running an air conduit to the machine.

The light weight of the high speed induction motor makes it possible, in many cases, to mount the motor directly on the machine when there is no driving shaft to which it may be coupled. An example of this is shown in Fig 11, which illustrates a back-knife lathe used for shaping chair spindles and having a 3 h.p., 3600 r.p.m. motor mounted on the headstock.

The compactness and strength of the mounting which has been adopted as a standard for motor driven circular saws is well illustrated in Fig. 12, which shows a 1 h.p., 3600 r.p.m. motor direct connected to two 12 in. circular cross cut saws, used for trimming seat frames. The general

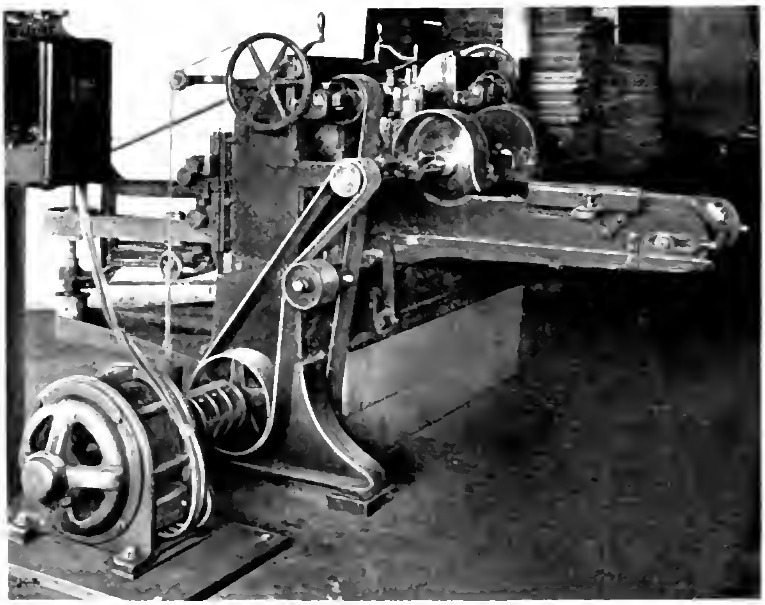


Fig 13. 10 H P. Induction Motor Driving Double End Tenoning Machine

LIST OF MOTORS

Group	No. Motors	H.P.	R.P.M.
Group A	1	.75	3600
	1	3	3600
	1	1	3600
Group B	1	3	1800
	3	5	1200
	2	5	1800
	3	7.5	1800
	2	10	900
	2	10	1200
	3	15	1200
	2	20	900
	3	20	1200
	1	5	570
	1	5	1730
	4	10	1145
	2	15	1145
	3	20	1150
	1	30	1150
Group C	3	5	1800
	1	7.5	1800
	2	10	1200
	1	15	1200
	1	20	900
	2	25	1200
	1	3	1730
	1	10	1145
	1	15	1145
	1	20	1150
	1	25	870
	1	7.5	1200
Group D	2	.75	1200
	1	1	1800
	1	2	3600
	3	3	3600
	1	4	900
	2	5	1800
	1	5	3600
	6	7.5	720
	1	7.5	900
	2	7.5	1800
	2	10	900
	1	25	600
Group E	1	1	3600
	1	2	1800
	2	3	1800
	1	5	1200
	13	5	1800
	1	5.5	900
	1	7.5	1200
	6	7.5	1800
	2	3	1730
	1	7.5	1145
	1	10	1145
	1	15	1145
	1	.2	3400

Group A. Operating tool directly connected to rotor shaft; as for example, a saw or chuck on the extended end of the rotor shaft.

Group B. Shaft driving a group of machines belted to the shaft of the motor.

Group C. Shaft driving a group of machines coupled to the shaft of the motor.

Group D. Driving shaft of the machine direct coupled to the shaft of the motor.

Group E. Driving shaft of the machine belted to the shaft of the motor.

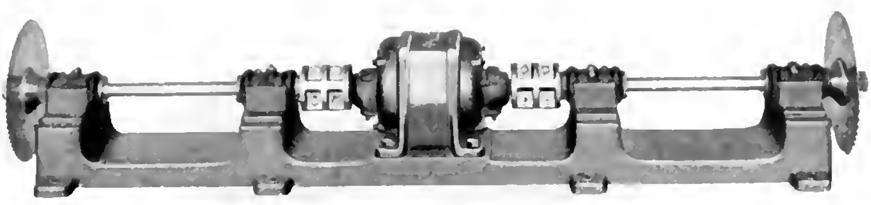


Fig. 1.. 1 H.P. Induction Motor Direct Coupled to Two 12 in. Cross Cut Trim Saws

arrangement of the saws and motors in this instance is similar to that in the installation

Fig. 14. 10 H.P. Induction Motor Direct Connected to Driving Shaft of Four-Sided Moulder

shown in Fig. 1. The convenience of a compact set mounted on a rigid bed-plate will be readily appreciated by those who have had to line up machinery of this character with motor shafting when installing motors and saws provided with separate bases.

In addition to the set illustrated, there are two 3 h.p. sets and one 5 h.p. set, the latter being used for cutting up stock for the gauge lathes. All of these saws operate at 3600 r.p.m.

In the above description, we have considered only those motors having speeds of 1200, 1800 and 3600 r.p.m. There are, in addition to these, some good examples of direct drive utilizing motors of somewhat larger capacity and lower speed. These are considered below.

A centrifugal blower for supplying the exhaust system of the factory employs a 25 h.p., 600 r.p.m. motor for driving, the complete set being mounted on a platform suspended from the ceiling beams, thereby rendering the space beneath the set available for storage.

In Fig. 13 a double end tenoner, used principally for the manufacture of school furniture, is shown. This machine cuts stock to length, and makes groove and tongue, tenon and special joints. It is driven by a 10 h.p. motor operating at 900 r.p.m., the motor being securely mounted on a flat iron bed-plate having sufficient surface to avoid disturbance of the shaft alignment. A motor of similar capacity and speed is direct connected to the driving shaft of a four-sided moulder, as shown in Fig. 14.

Six rip band saws are used for cutting stock all of them being provided with direct motor drive. One of these saws, a 42 in. No. 1, is shown in Fig. 15 and is direct connected to a $7\frac{1}{2}$ h.p., 720 r.p.m. motor with belt connection from the driving shaft to the feed mechanism.

The applications above described illustrate some of the unusual features of the Heywood Brothers & Wakefield Co.'s installation, which are due to the initiative of their engineers; the extent to which motor drive has been adopted in this factory being graphically shown by the tabulation on page 257, which gives the capacity and speed of all the motors in service and the methods of connection used.

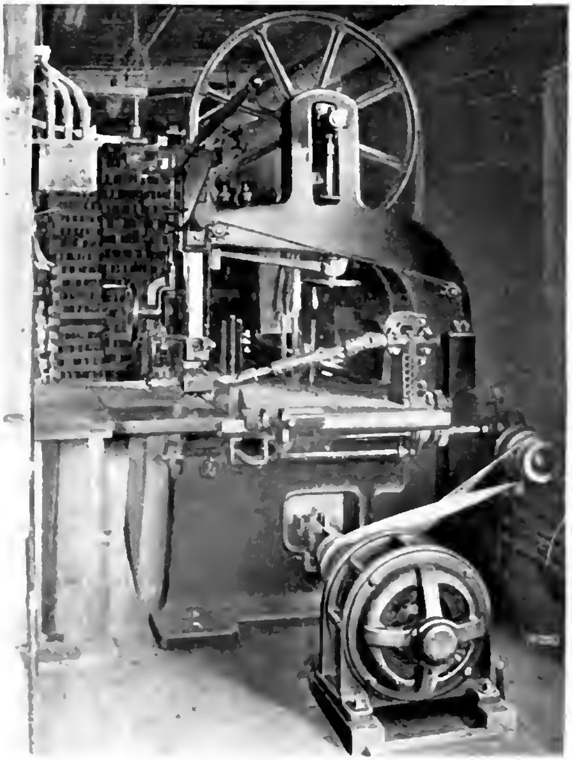


Fig. 15. $7\frac{1}{2}$ H.P. Induction Motor Direct Connected to Driving Shaft of 42 in. No. 1 Self Feed Band Rip Saw

COMMERCIAL ELECTRICAL TESTING

Part VIII

By E. F. Collins

INDUCTION MOTORS

The test usually made upon induction motors for checking guarantees and determining characteristics for engineering information are given under the following headings. Wherever these tests differ from those employed for other alternating current motors they are described in detail.

The preliminary tests made on induction motors include the measuring of the air gap, bearing and end play, slip and resistance, as well as the tests for starting, running light, excitation and static impedance.

Special measuring scales are used for taking induction motor air gap and considerable care should be exercised in making this measurement both with the rotor in a given position and in different positions.

Bearing play is taken by measuring the gap at the top, bottom and on each side. With the rotor in the same relative position to the stator, that is, without turning the rotor, the motor is turned over in all four positions of the quadrant and the same measurements of air gap taken. Any defects in the bearings which will affect the air gap of the machine are thus disclosed.

A starting test on Form K motors is made by switching the machine onto the line at a low voltage and then increasing the voltage until the motor starts, the current and voltage at this point being recorded. The starting current should not exceed 200 per cent. normal current. This test is occasionally made with a compensator.

With all the internal resistance in the rotor circuit, full line voltage should be impressed on Form L motors and the starting current recorded. This current should not exceed normal current.

Form M motors are started at full line voltage with all the external resistance in the rotor circuit, and the starting current is recorded, which should not exceed normal value. Sometimes the collector rings on Form M motors are short circuited and the starting test made at reduced voltage, as in the case of Form K motors.

Slip is usually measured at full load and running light by means of the slip indicator. During this test, constant speed must be held on the driving alternator, and constant voltage on the motor.

To take slip by the lamp method, an arc lamp is connected in the circuit from which the motor is running. On the end of the motor shaft a disk is placed which has as many white and black sectors as there are

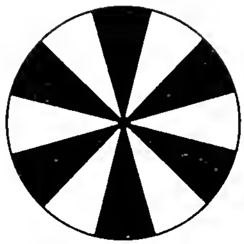


Fig. 37. Slip Disk

poles in the motor. (See Fig. 37, which is used for a six-pole motor.) As the lamp is running from an alternating current source, the current wave passes through zero twice in each complete cycle. At the zero instant, the light given out by the lamp is a minimum.

Consider a six-pole 60 cycle motor running at 1200 r.p.m., that is to say, at 20 revolutions per second; then $20 \times 6 = 120$ black sectors passing a stationary point on the circumference of the disk in one second. As the frequency is 60, the number of maximum illuminations will be 120. At each maximum illumination, therefore, the black strips will always occupy the same positions. However, the slip which always occurs in an induction motor will cause the black strip to lag by a small angle behind the position occupied at the previous illumination. These successive differences in position appear as a sector rotating backwards, which can be followed by the eye. The slip, that is, the difference between the actual speed and the synchronous speed of the motor per minute, can thus be counted.

The resistance of the stator should be measured cold and hot.

Running light is taken by applying normal voltage to the stator and reading the amperes input to the motor. Static impedance is taken by blocking the rotor and applying such a voltage to the stator as will give about full load current, reading the current in each leg, together with the voltage between each of the legs. If the motor is of the Form L type, impedance is taken with the resistance all in and then all out, always holding the same voltage across the stator. This practice has been found to give the best results. End play should be tested both with and without voltage on the stator, and on all motors particular care should be taken to see that the rotor is in perfect balance.

When cutting out the internal resistance, the starting switch of Form L motors should be watched closely for sparking or any other defects. The brushes must make good contact on the resistances in all positions and the switch must not work too easily, otherwise the resistance may be cut out too rapidly.

On Form M motors, the brushes must fit the collector rings perfectly, as a successful test on this type of motor depends considerably on a good fit. The voltage ratio should be taken on Form M motors by impressing normal voltage on the stator and measuring the voltage between the rings of the rotor on open circuit. Volts and amperes stator, and volts between rotor rings should be read and recorded.

Two speeds on a motor can be obtained by changing the connections on the stator by means of a switch and connection board, these changes altering the number of effective poles. The rotor must have the correct number and ratio of slots in the stator and rotor, otherwise dead points may occur at certain starting positions, or again the motor may operate at subsynchronous speeds. These machines are usually run at the lower speed during test.

Excitation

The tests for excitation and impedance are important, and the following precautions must be observed in all cases. The calculation of the characteristic curves of induction motors depends entirely on test results, and great care must therefore be taken to obtain accurate measurements.

The motor should be located so that all the conditions affecting its operation during test remain unchanged throughout the run. A solid foundation is necessary to prevent vibration at full speed, and the table must not be near any source of stray field. The driving alternator should be at least 3/4 the kw. capacity of the motor. The transformers and other apparatus must be connected so that the alternator will work under normal conditions, since satisfactory wattmeter readings cannot be obtained if the alternator is run too low on the saturation curve. Transformers, when used, must be well balanced and not forced beyond their voltage range, otherwise unsatisfactory results may be obtained.

The table must be adapted for wattmeters by providing a special wattmeter switch connected on two of the three phases, as shown in Fig. 38. A and B are the terminals for the current leads to the wattmeters, X and Z being the short circuiting switches. Calling the phases 1-2-3, then phase 1 is on the current coil of wattmeter R, connected at A, and the pressure coil is connected across 1 and 2. Likewise with the other meter S, the current coil of which is on phase 3 at B, with its pressure coil between 2 and 3. If the voltage is too high for direct use on wattmeters, multipliers (non-inductive coils of known resistance) or potential transformers must be connected between the meter and the volt lines at the table.

On motors of less than 20 h.p. the lines to the primaries of the potential transformers must be attached to the generator side of the lines coming to the top of the dynamometer

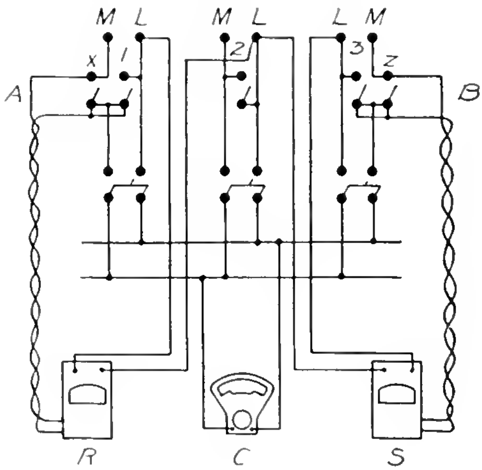


Fig 38. Wattmeter Connections for Excitation

board. If placed on the motor side of top of the board, or on the motor terminal block, the excitation current of the potential transformer passes through the wattmeters. Although this current is small, with a small motor it may be an appreciable percentage of the excitation current. Hence an error is caused and an abrupt break made in the excitation curves every time the ratio of the potential transformer is changed. On large motors the excitation current of the potential transformer is so small in comparison with the motor current that the incidental errors are negligible. The above does not apply to multipliers because they are non-inductive.

On large motors the volt leads should always be attached at the terminal block in order to eliminate the line drop in switches and leads from the table to the motor. The current leads to the wattmeters should be twisted together throughout their length and come direct from the terminal to the meter without loops or sharp turns. All connections must be kept tight and clean.

The air gap should be taken before the test is started. On voltages above 500 volts all instruments must have any static charge thereon discharged and a small fuse connected between the current terminal and the nearest volt terminal of the wattmeter. Do not ground the secondaries of the transformer.

As soon as the machine is wired and ready to start, the switches on the dynamometer board should be closed. (Always see that the wattmeter switches are closed whenever a change in the field current is made.) The exciter field switch is then closed and the voltage brought up slowly until the motor starts and reaches normal speed. The machine should then be inspected to see that it is operating normally and the amperes and volts in the different phases read and any unbalancing corrected or its cause discovered.

The end play of the motor should be tested next, since the rotor must always run centrally in the frame. A slight pressure against one side will change the friction watts and give an incorrect value to the core loss. Small motors should be run about one hour and a half and large ones two hours and a half or more, to obtain constant friction before starting tests. If the wattmeter needle goes off the scale in a negative direction when connected in circuit, the current leads on the current terminals should be interchanged. On a two-phase circuit, with a machine under load, both wattmeters should read positive.

For running light readings on a three-phase machine the sign of the meter must be determined, since one reads negative on the upper part of the curve. With both meters reading positive, one of the phases containing the current coil of the wattmeter should be opened and the other meter observed. If the needle drops off the scale below zero the meter reads negatively. If the needle drops to some value above zero the reading is positive. This process must be repeated for determining the readings of the other wattmeter.

The alternator speed must be held constant during the test and about 130 per cent. normal volts used for the first reading; volts amperes, watts and speed of generator and motor being read and recorded. The volts should then be decreased in steps so as to obtain about 20-25 points on the curve, down to 10 or 15 per cent. of normal volts. Here the conditions are no longer stable. The meter with the negative sign will read less than the other, and its readings will fall off more rapidly, becoming less and less until zero is reached and its sign changes. When it becomes positive, the current leads must be interchanged.

After the volts have been reduced from the starting point of curve to normal, three single-phase wattmeter readings, one above, one below and one at normal voltage, should be taken on the two legs to check the results. Check readings should also be taken with a different voltmeter and ammeter.

The single-phase excitation amperes are theoretically 1.73 times the three-phase and twice the two-phase values; that is, the kv-a. has equal values for the motor, whether single-phase or polyphase. Practically, the single-phase amperes are from 1.6 to 1.7 times the three-phase, instead of 1.73 times. The same ratio holds for quarter-phase. The watts excitation is the same for polyphase or single-phase, so far as core loss is concerned. The increase in watts single-phase over the watts polyphase is equal to the polyphase C^2R. For instance, if the three-phase excitation requires 1000 watts and the C^2R three-phase is 100 watts, the single-phase excitation will be 1100 watts.

Before shutting down, a curve should be plotted with volts as abscissæ and the algebraic sum of the watts as ordinates.

Wattmeter work is somewhat uncertain, and accurate results can only be obtained under good conditions. An endless belt on the driving alternator is necessary, a laced belt making the wattmeter needle swing with a steady beat corresponding to the striking of lacing on the generator pulley. Any belts running near the table must have their static charges drawn off by a grounded wire and the cases of all transformers should be connected together and grounded. Wattmeters must be carefully handled on high voltages, since all three phases of the alternator are connected on the table and contact between

TABLE XVI—Excitation on a 100 H.P., 2080 V., 6-Pole, 60 Cycle, 3-Phase Induction Motor

Volts	Amps.	Watts +	Watts	Total Watts
2510	11.5	18300	12150	6150
2370	10.4	15500	9900	5600
2175	9.5	12900	8000	4900
2105	9.2	12090	7380	4710
2075	8.8	11470	6920	4550
2020	8.6	10870	6370	4500
1830	7.7	9060	5060	4000
1610	6.76	6950	3450	3500
1440	6.03	5740	2670	3070
2160	15.4	5150	—	
2070	14.6	4750	—	
2000	14.2	4550	—	
2070	14.6	—	4950	
2200	15.85	—	5140	
2235	15.9	—	5540	
1366	5.78	5440	2310	3130
1185	5.08	4390	1540	2850
988	4.3	3185	685	2500
816	3.75	2550	178	2372
585	3.35	1670	+380	2050
485	3.25	1370	530	1900
292	3.6	1200	644	1844
241	1.85	1210	673	1883
176	5.8	974	500	1474

two of the instruments short circuits one of the phases.

The two important points on an excitation curve are the watts at normal voltage and friction watts. These points determine the percentage core loss for the motor. Several readings, only a few volts apart, should be taken on each side of normal voltage and the volts and amperes in the different phases at two or three other points in the curve should be carefully read and recorded as a check on the balance of the motor. As the lowest point of the curve, or friction reading is approached, many readings should be taken. This portion is the most difficult part of the curve to locate, especially in the case of large motors, as in many instances "hunting" begins at a low voltage. A reading taken when the motor is accelerating is of greater value than the steady reading.

Hunting usually makes the meter needle swing with a slow beat, the range of the beat varying with the size of motor and degree of hunting. Bad cases of hunting are not numerous and reliable readings can generally be secured between beats. To test successfully, the speed of the driving generator must be kept constant and no reading taken until the speed is properly adjusted. The tachometer used must be carefully checked.

The excitation tests on all forms of induction motors are the same.

The Form M motor is provided with collector rings for the external resistance. These must be short circuited at the brush-holder terminal and the brushes carefully sandpapered until they fit the rings accurately.

Calculation of Excitation Test on Induction Motors

All readings must be corrected for the instrument constants and ratios used. Special care should be taken to use the proper signs for the wattmeter readings. Table XVI shows the form used in calculating an excitation test, and Fig. 39 the method of plotting it. The friction and windage watts

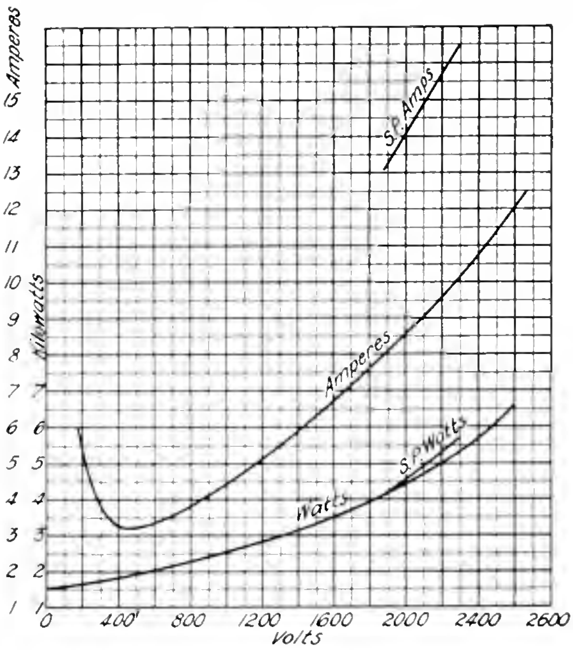


Fig. 39. Excitation Curve on a 100 H.P., 2080 Volt, 1200 R.P.M., 60 Cycle, 3-Phase Induction Motor

are obtained from the excitation curve by producing the watt curve to zero volts.

Impedance

The Form K motor has a symmetrical bar winding in the rotor and therefore the impedance is the same for any position of the stator relative to the rotor.

In Forms L, M and P, which have wound rotors, a position curve is first taken.

Two-thirds of the distance between two consecutive poles on a three-phase motor and one-half that distance on a quarter-phase motor are marked off on the bearing bracket, this space being divided into about eight parts. A pointer should be attached to the motor shaft or pulley so that its outer end will pass over the division marks; it is then set on mark 1 and the rotor blocked so that it cannot move from that position. The switches are next closed and the impressed voltage increased gradually until about normal current is obtained. Volts and amperes should be read and recorded on all three phases to make sure that no unbalancing occurs. Holding the same volts as for position 1, the pointer is moved to mark 2, and the amperes read; this procedure being repeated on each of the succeeding marks and a curve plotted, giving amperes and pointer position. The motor is then blocked in the position which gives an average value of the current. Form K induction motors are blocked in any position.

The current is then increased until 150 per cent. normal current is obtained, and the amperes, volts and watts are read. The sign of the wattmeter must be determined in the same way as at the beginning of the excitation test. About six or eight readings should be taken between zero and 150 per cent. normal current, but the current should not be held on the motor longer than necessary to secure a reading. After each reading the exciter field should be opened, until ready for the next reading, otherwise the motor will get too hot. As soon as the readings are taken,

TABLE XVII—Impedance on a 100 H.P., 2880 V., 6-Pole, 60 Cycle, 3-Phase Induction Motor

Volts	Amps.	Watts +	Watts —	Total Watts
146	11.9	1230	445	785
188	15	1870	660	1210
220	18	2825	1080	1745
263	21.5	4060	1485	2575
301	24	5260	1930	3330
355	28.5	7255	2845	4410
384	30.7	8360	3190	5170
410	33	9450	3710	5740
455	36	11680	4450	7230
297	20.6	—	1460	
272	19.1	—	1190	
322	22.2	—	1680	
273	19	1255	—	
297	20.5	1500	—	
322	22.2	1720	—	

curves should be plotted with volts as abscissæ, and amperes and the algebraic sum of the watts as ordinates. The ampere curve should be a straight line, though sometimes the top portion curves upward very slightly.

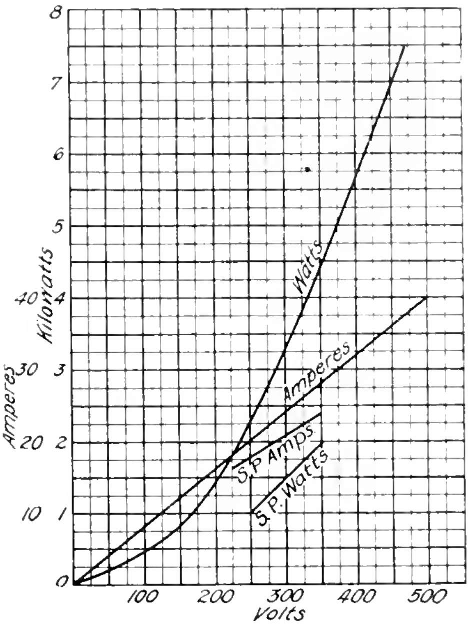


Fig. 40. Impedance Curve on a 100 H.P., 2080 Volt, 1200 R.P.M., 60 Cycle, 3-Phase Induction Motor

Single-phase check readings should be taken, one above, one below and one at normal amperes, on the two phases containing wattmeters.

The single-phase impedance current should be 86.5 per cent. of the three-phase (line) values. The single-phase impedance watts should be approximately half of the three-phase watts. In a quarter-phase motor single-phase impedance is the impedance of one of the two phases.

On Form M motors, when taking impedance, the collector rings should be short circuited either by metal brushes or by metal strips, as the contact resistance varies with carbon brushes. The ratios between the primary and secondary voltage should be taken with the secondary open circuited.

Calculation of Impedance Test on Induction Motors

Table XVII shows the form used in calculating an impedance test, and Fig. 40 the method of plotting it.

(To be Continued)

HYPERBOLIC FUNCTIONS AND THEIR APPLICATION TO TRANSMISSION LINE PROBLEMS

Part III

By W. E. Miller

Transmission Line Characteristic Curves

To illustrate how the volts, amperes and power factors vary along a transmission line, the electrical conditions being determined at the receiving end, various curves have been plotted for a line 400 miles long operating at 60 cycles and using three No. 0000 hard drawn stranded copper wires triangularly spaced 10 ft. apart. In all cases the volts received are assumed constant at 60,000 volts between wire and neutral, *i.e.*, 104,000 volts between wires.

Fig. 10 shows the variation of the volts along the line with unity power factor at the slightly greater than that at the generator end. When the received current is 179 amperes, the generator current has the same value.

The volts at no load, Fig. 10, rise from the generator towards the receiving end. With a current of 102 amperes receiving end at unity power factor, the generator and received volts become equal, a maximum voltage occuring about halfway along the line. When the received current is greater than 102 amperes, the voltage drops along the line from the generator towards the receiving end.

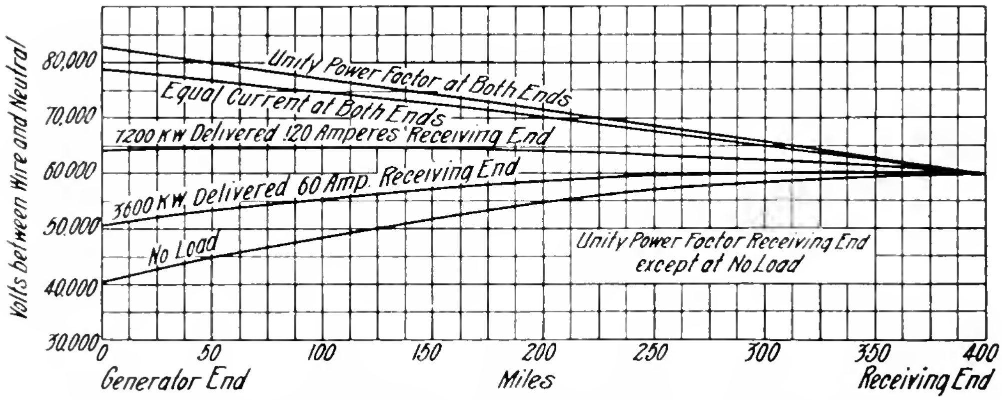


Fig. 10. Variation of Volts along 400 Mile Three-Phase Line, Using Three No. 0000 B.&S. Wires 10 ft. apart, Operating at 60 Cycles, 104,000 Volts between Wires at Receiving End. Unity Power Factor at Receiving End, and conditions as stated on curves

receiving end for the following cases: 3600 kw. and 7200 kw. delivered per phase—equal current values at the generating and receiving ends—unity power factor maintained at both ends. Fig. 11 shows how the current varied along the line in the above cases.

It should be noted that when 3600 kw. is delivered the current at the generating end is more than double that at the receiving end: when, however, the power delivered is doubled, the generator current is only increased 20 amperes. To maintain unity power factor at both ends, the current at the receiving end must be 197 amperes, which is

ERRATA. Table XIII, page 17 of "Review" supplement, column a, x [illegible], y [illegible], should read 1.359 not 1.3[illegible]

Equation numbers on page 223 of May "Review" should read 30, 31, 32 and 33 in place of 23, 24, 25 and 26 respectively

Fig. 12 shows the variation of volts and current along the same line when 120 amperes are delivered at .90 leading and lagging power factors respectively. With a leading power factor at the receiving end, the current at the generator end is very much larger than that at the receiving end, whereas the volts rise slightly towards the receiving end. Thus a leading power factor at the receiving end means a high transmission loss along the line. On the other hand, when the power factor is .90 lagging at the receiving end, the current is nearly equal at both ends, being minimum half way, and the transmission efficiency is nearly maximum. The volts in this case drop slightly from the generating end towards the receiving end.

Curves C and A, Fig. 13, illustrate the variation of the power factor along the line for the two cases just mentioned. When the power factor is .90 leading at the receiving end, it has a considerable variation occurs. The transmission efficiency in this case is 85 per cent., whereas, with the power factor leading at the receiving end, the efficiency is only 74 per cent.,

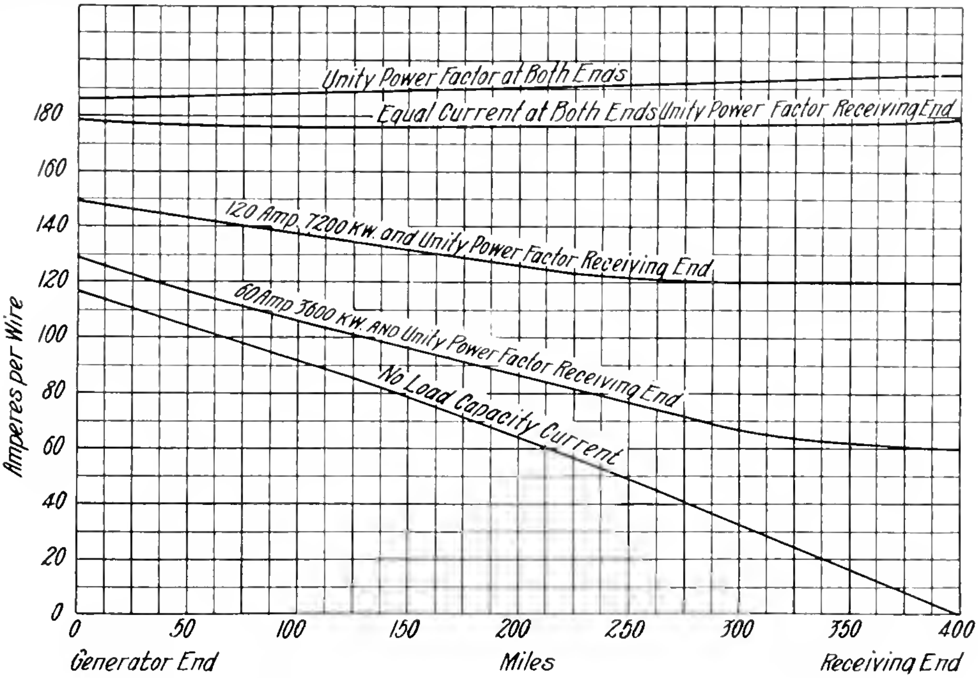


Fig. 11. Variation of Current along 400 Mile Three-Phase Line, Using Three No. 0000 Wires 10 ft. apart, Operating at 60 Cycles, 104,000 Volts between Wires at Receiving End Unity Power Factor at Receiving End, and conditions as stated on curves

minimum value about 280 miles from the generating end, rising to .94 leading at the latter end. Thus, only a small variation of the same kw. being delivered in both cases.

Curve B, Fig. 13, shows the variation of power factor when 7200 kw. at unity power

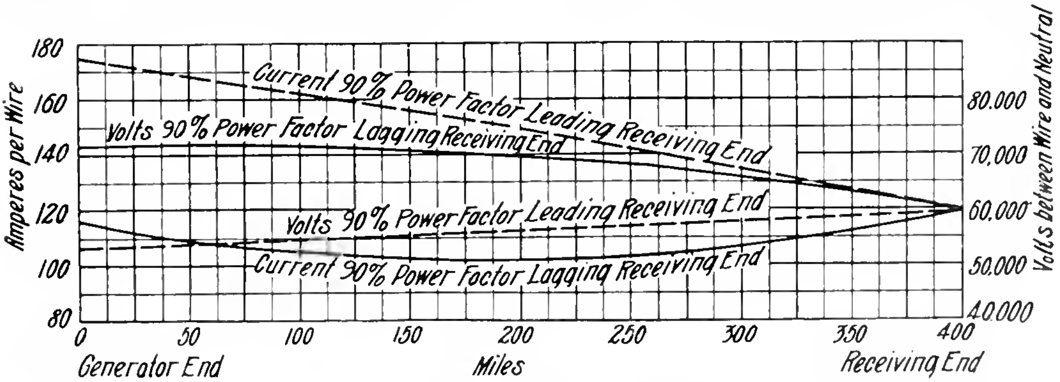


Fig. 12. Variation of Amperes and Volts along 400 Mile Three-Phase Line, Using Three No. 0000 B &S Wires 10 ft. apart, Operating at 60 Cycles, 104,000 Volts between Wires at Receiving End Power Factor Receiving End .90 Leading and Lagging

power factor occurs along the line. When, however, the power factor is .90 lagging at the receiving end, it is .90 leading at the generator end and unity halfway along the line, that is, factor are delivered and Curve D shows the variation of power factor when 3600 kw. are delivered. In the latter case, the power factor is only .68 leading at the generator end.

Curve E shows the variation of power factor with no load at the receiving end, the line

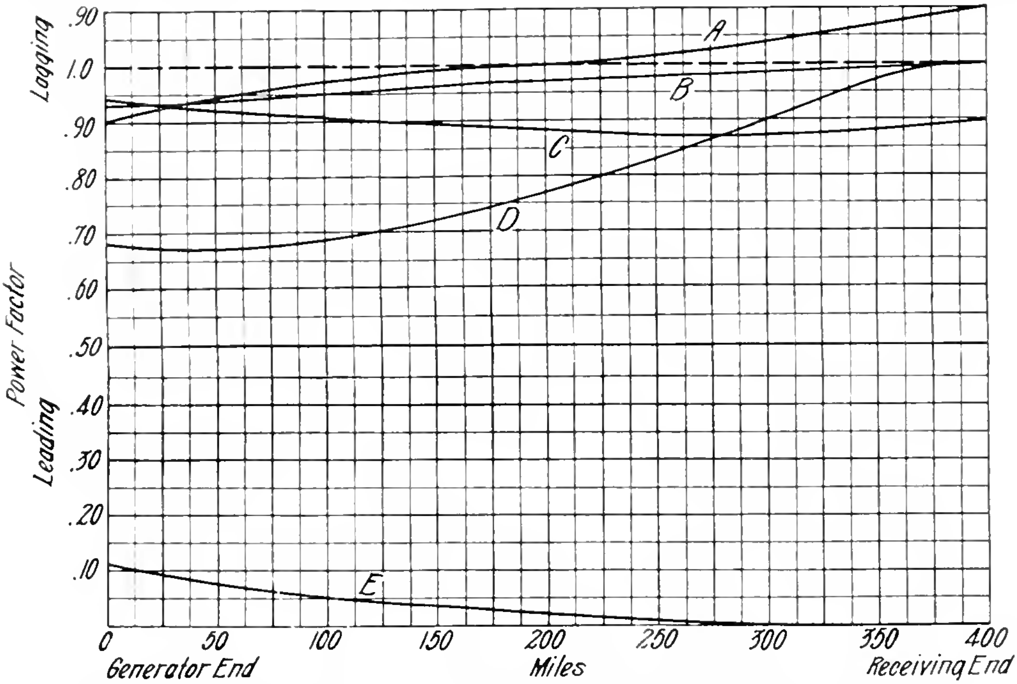


Fig. 13 Variation of Power Factor along 400 Mile Three-Phase Line, Using Three No. 0000 B.& S. Wires 10 ft. apart, Operating at 60 Cycles, 104,000 Volts between Wires at Receiving End. Curve A, 120 Amperes Delivered at .90 Power Factor Lagging. Curve C at .90 Power Factor Leading. Curve B, 7,200 Kw. Delivered and Curve D, 3,600 Kw. Delivered at Unity Power Factor Receiving End Curve E No Load Delivered

loss being 510 kw. per phase and the power factor .115 leading at the generator end.

Transmission Efficiency

It is of some interest to discover what power factor should be maintained at the receiving end for a given voltage and load delivered to obtain maximum transmission efficiency. Unlike transmission by direct current, the efficiency does not necessarily increase with decrease of load delivered. In fact, for every transmission line, there is one particular load delivered for which the transmission efficiency is an absolute maximum for that line. This load in the case of long lines may represent a considerable amount of power; the load current at receiving end must have a fairly large value at a small lagging power factor to give equal current at both ends.

Maximum efficiency for a given load delivered occurs when the currents at each end are equal, this condition being always obtainable by varying the power factor at the receiving end.

Curve C, Fig. 14, shows how the current varies with the power factor at the receiving end for 7200 kw. delivered; this curve being, of course, immediately obtained from the relation between k.v.a. and kw. delivered, the voltage at the receiving end being held

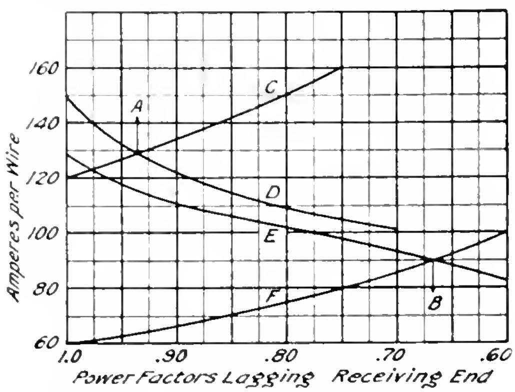


Fig. 14. Curve C Gives Values of Received Current for Various Power Factors at Receiving End, and Curve D Values of the Generated Current for the Same Power Factors, with 7,200 Kw. Delivered. Curve F and E Represent Values of Received and Generated Current for Various Power Factors, with 3,600 Kw. Delivered. Three-Phase Line 400 Miles Long, Using Three No. 0000 Wires 10 ft. apart, Operating at 60 Cycles, 104,000 Volts between Wires, Receiving End.

constant at 60,000 volts between wire and neutral. Curve D is obtained by calculations from the transmission line equations and connects the generator amperes with various power factors at the receiving end for the given load and voltage delivered. The intersection point of Curves C and D determines the receiving end power factor at which the currents at each end become equal, *i.e.*, at 128 amperes. On Fig. 15, curves have been plotted connecting volts at the generator end with the power factor at both the receiving and generator ends. These curves were calculated from the transmission line equations, the conditions being 7,200 kw. delivered at 60,000 volts.

The intersection point A occurs at a power factor .935 lagging (receiving end) (see Fig. 14), the corresponding volts at the generator end being 72,500 volts at a power factor .935 leading (see Fig. 15). Hence, the maximum transmission efficiency obtainable with this line, for 7200 kw. delivered per phase, is

$$\frac{7200 \times 1000}{72{,}500 \times 128 \times .935} = .80.$$

The curves E and F have also been drawn for 3600 kw. per phase delivered, point B being the intersection of the ampere curves drawn for the generator and receiving ends. This point corresponds to 89 amperes at .67 power factor lagging (receiving end), the generator volts being 66,500 and the power factor at the generator end .695 leading.

The transmission efficiency in this case is, therefore,

$$\frac{3600 \times 1000}{66{,}500 \times 89 \times .695} = .875.$$

Thus, to obtain maximum efficiency for this line when delivering 3,600 kw. per phase or a total of 10,800 kw., a low lagging power factor must be maintained at the receiving end, *i.e.*, .67. With twice the delivered power, *i.e.*, a total of 21,600 kw., the power factor at the receiving end must be .935 lagging and the load need only be slightly inductive to obtain this value. It follows, therefore, that the condition for maximum efficiency can be obtained for fairly high loads along transmission lines, but when light loads are in consideration, the highest efficiency is impracticable.

Note on Capacity Calculations

As it is generally easier to calculate the self induction between wires or between wire and neutral than the capacity, the following method for obtaining the value of the capacity from the value of the self induction is sometimes useful. It is based on the fact that the expression $\frac{1}{\sqrt{LC}}$ represents (in the case of commercial transmission lines) the velocity of light in miles per second when L is expressed in henrys per mile and C in farads per mile. In using this formula L should be calculated, neglecting that part of the self induction due to the flux within the wires. Then $C = \frac{1}{v^2 L} = \frac{2.87 \times 10^{-11}}{L}$ (31)

This method was used for calculating the capacity between wire and neutral for three-phase lines when the wires lie equally spaced in a plane, and are transposed to balance the phases.

(To be Continued)

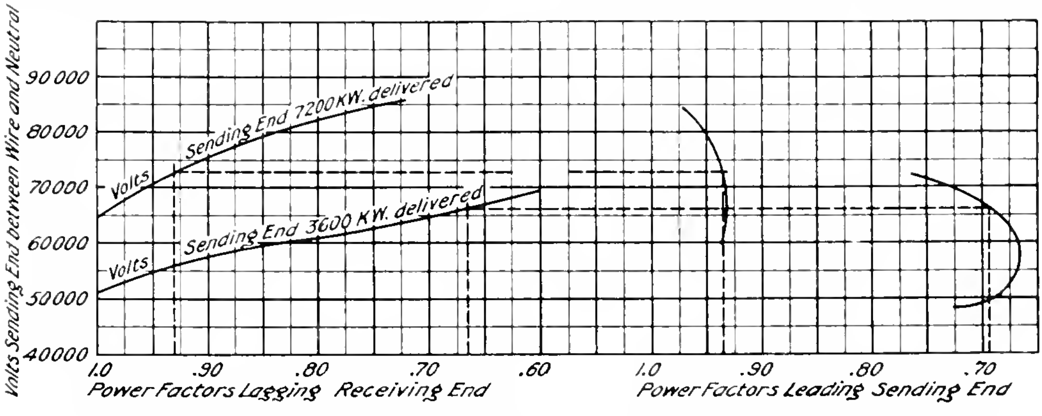


Fig. 15. Values of Volts at Sending End for Different Power Factors at Receiving and Sending Ends. 7,200 Kw. and 3,600 Kw. per Phase Delivered. 400 Mile Three-Phase Line, Using Three No. 0000 B.&S. Wires 10 ft. apart, Operating at 60 Cycles, 104,000 Volts between Wires, Receiving End

ELECTRICITY IN THE MINES OF THE DAVIS COAL AND COKE CO.

By R. Neil Williams

Consulting Engineer

The causes which have led to the general adoption of electricity as a motive power in mining work are mostly obvious. The only logical competitor of electricity is gravity, which is, of course, the cheapest power as long as its use does not involve too much loss of time, or its inflexibility necessitate an expenditure for labor of a sum sufficiently great to offset the saving in investment and that effected by the elimination of the fuel bill. Where conditions do not permit of making use of gravity, either horses, mules or electric locomotives must be employed; advantages being much in favor of the latter, especially when the thinner seams of coal are exploited. The horse as a factor in coal-mining became of minor importance with the advent of electric haulage in 1887. The mortality of horses used in mining work is extremely high, while the first mining locomotive built in the United States, for the Lykens Valley Coal Co., is still hauling coal in everyday service. This feature is accentuated by the necessity of using very small horses in mining work and of their working in the dark and in bad air.

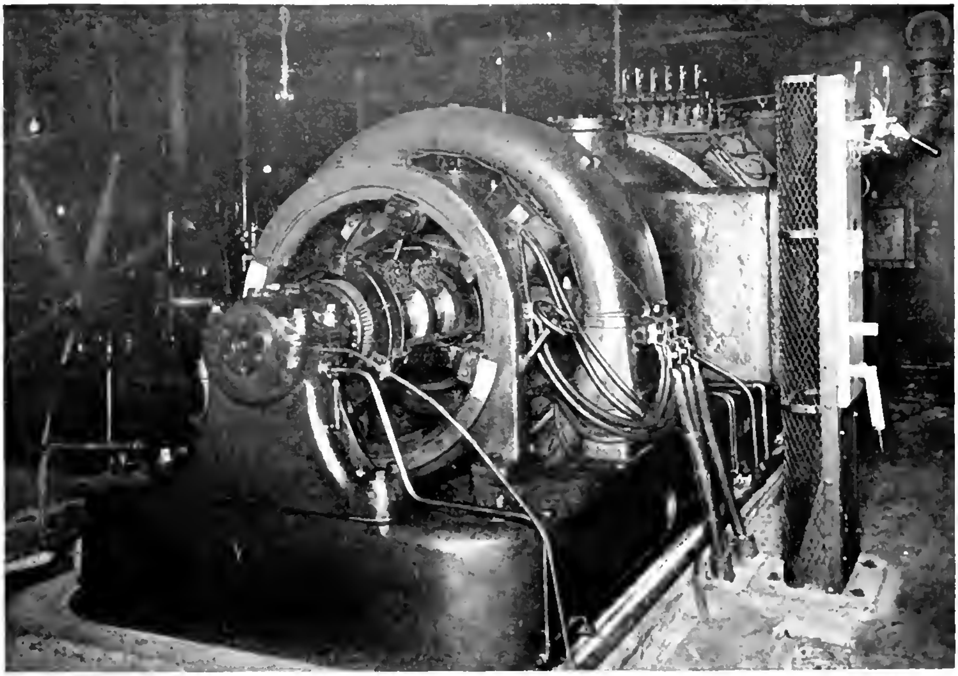
The economic advantage of electric operation becomes evident from an inspection of the pay roll, for with electric locomotives longer trips can be made at higher rates of speed, with the result that one locomotive will do the work of fifteen horses on the average. This means the employment of one good man instead of fifteen boys, and the expenditure of $2.50 to $3.00 for power instead of $7.50 for feed.

Power Plant of Davis Coal and Coke Co., West Virginia Central Junction

The advantages of electricity as a source of power in coal mines where the electric installation has been properly made and is wisely managed are exemplified in the equipment of the Davis Coal and Coke Co., which operates bituminous mines in West Virginia along the lines of the Western Maryland Railroad Company. At the present time this company owns 160,000 acres of coal land and operates mines at West Virginia Central Junction, Elk Garden, Harrison (Harrison being included in the Elk Garden district), Henry, Thomas, Coketon and Weaver; these places being situated, in the order named, along the West Virginia C. & P. Division of the Western Maryland Railroad, which begins just above Piedmont, W. Va., at the junction of this railroad and the B. & O. In the Fairmount region the company also owns 30,000 acres of coal lands, which, however, are not being worked.

It is interesting to follow the development of this company through the various stages of its growth and to note how systematically the various managements have worked to a well thought out plan of electric operation. While the use of electric power in the first place was made imperative by the nature of the working, its advantages in other directions than those which compelled its adoption became apparent and led to the introduction of electricity for other purposes.

Realizing that the distances over which it would be necessary to transmit electrical energy were, in many cases, already too great for the economical use of direct current, and that as the operation in the mines extended all these distances must necessarily become greater, it was decided to use alternating current wherever possible. The greater economy of alternating current for long distance transmission was not, however, the only consideration which was influential in the adoption of this policy. The alternating current system is very much more flexible than any direct current system, and is adapted readily to any distance of transmission by means of the simple alternating current transformer. Furthermore, the induction motor is admirably suited for use in coal mines, particularly for driving pumps and fans which run continuously. As it requires no brushes or other devices for making electrical connection with the secondary circuit, the rotor revolves very freely and there is no friction other than that of the bearings. This arrangement requires a minimum of attention and ensures absolutely no sparking. A motor of this type will operate for long periods of time with no further attention than an occasional inspection of the oil gauges and air gap.



500 Kw., 600 Volt, Curtis Turbine Generator Set at Thomas, W. Va.

For haulage and hoisting purposes, the direct current series motor was adopted, due to its characteristic of maximum torque at starting. Owing to the long distances to which direct current had to be transmitted, it was decided to generate it at a potential of 600 volts. The objection which might be raised to this high potential, due to the danger to men and animals, where the latter are still used for gathering, is more imaginary than real, owing to the fact that the current is turned off while the shifts are changing. In fact, there has been no loss of human life from electric shocks in the company's entire history, and only a few instances in which animals have come into contact with live wires and were electrocuted. In these cases, the accident was due to the slowness of the drivers in getting back into the workings.

The electrical development has been consistently carried out throughout all of the various workings with 600 volts direct current for haulage and three-phase alternating current, at a frequency of 60 cycles, for all other purposes, with the exception of the lighting of the various mining towns. For this purpose, single-phase alternating current is used, constant current tub transformers being employed for the lighting of streets.

This policy of buying uniform apparatus for all mines, even to standardizing the make of machinery, has resulted in an almost entire absence of an electrical junk pile. It is a case of the pitcher going to the well till it is broken, and but for the advent of greatly improved steam motive power in the form of the Curtis steam turbine, there would have been very little noticeable depreciation in any of the apparatus. As it is, the increase of power required by the rapid developments in the last year or two has made it necessary to operate the older reciprocating steam units in multiple with the steam turbines; but it is hoped that in a short time it will be able to discontinue some of the less efficient steam engines and use the corresponding alternating current generators as synchronous condensers to improve the power factor of the general system.

150 Kw., 600 Volt Engine Driven Direct Current Generator

The importance of the work being done by the induction motors in mine ventilation and pumping is so great that these motors must of necessity be selected amply large for the duty. Stinting in this respect would be poor policy, but naturally the result of having partially loaded motors continuously in operation results in a very poor power factor for the whole system. The main objection to low power factor in mining work is not the necessity of providing transmission lines large enough to carry the excess idle current, but chiefly one of station economy. A unit consisting of steam driver and electric generator designed to deliver an output of, say, 100 kilowatts at 100 per cent. power factor can only be called on for 55 kilowatts at 55 per cent. power factor, and not even for this unless the fields and armature have been specially designed for such operation. Even assuming this to be the case, the steam end of the unit would be operating at but little more than half load, and consequently with very poor efficiency. It is, therefore, desirable to bring up the general power factor as near as possible to 100 per cent. by means of units independent of the generators. Rotary condensers, or synchronous motors, operating as motors, are suitable for this purpose, whether running idle or with load. It is not always possible to provide a suitable load for a synchronous motor in the interior of the mine itself, as this type of machine will not operate with the small amount of attention required by an induction motor, and is more susceptible to fluctuations in the supply of electric energy. However, there is no reason why fans outside the mines and not too far from the power station or repair shops, where expert attention is available, should not be driven by synchronous motors. If the motor runs idle, the improvement in power factor is gained at the expense of an amount of energy representing the losses in the motor.

In the following history of the Davis Coal and Coke Co. and its development, the electrical equipment will be discussed in conjunction with the description of the various workings.

In 1884 some prospectors in the employ of H. G. Davis & Bro. discovered the Davis vein of coal near Thomas, W. Va. This was the beginning of the present company and of operations at Thomas. In 1886 H. G. Davis & Bro. and S. B. Elkins formed a partnership for the purpose of opening the Davis coal at a point about a mile south of Thomas, at what is now known as Coketon, W. Va. In 1887 the first coke ovens were built and experiments made as to the coking qualities of the coal, which was found to be indeed an excellent coking, steaming and smithing product. In 1888 the Davis Coal and Coke Company was incorporated with an authorized capital stock of $250,000, which in 1893 was increased to $3,000,000 to enable the company to acquire controlling interests in several other mines operating on the line of the W. Va. Central Railway. From this time on, until the taking over of the road by the Goulds as the coal operating department of the Western Maryland Railroad, the development of the company from a technical point of view has been systematic and comprehensive.

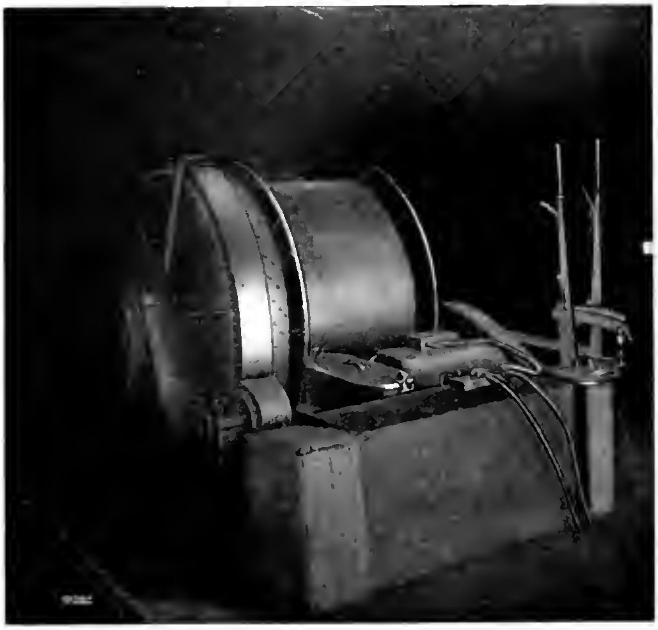
Taking the various operations in geographical rather than historical order, we will begin with the mines nearest to Tidewater. At West Virginia Central Junction there are four operations, two in what is known as the Bayard formation, which carries the Bakerton seam of coal and is locally known as the "four foot;" and the "three foot" coal, operated elsewhere as the upper Freeport seam. These mines are operated by the General Electric system of rope haulage. As the mines are on the extreme eastern outcrop, the pitches are very heavy and haulages are located at the extreme end of the headings on the inside of the mines. Empties are hauled in with the rope and the loaded cars dropped out by gravity, dragging the rope behind them. The loaded cars are controlled by brakes on the hoisting drums, which are operated by 550 volt direct current motors. The Bakerton seam is at the very top of the Bayard formation and, since the north branch of the Potomac river cuts the valley deep at this point, the above two mines are opened very high on the hillside and require inclined planes 2100 feet in length to reach the railroad track. Mine No. 19 is operated at the base of these planes, on the lower Kittanning seam, known locally as the "six foot." This mine also requires rope haulage, which is placed on the inside of the mine as in the case of the two mines above referred to, Nos. 50 and 51. The power station for this group is equipped with a 150 kw. General Electric generator driven by a Buckeye engine. These three mines, together with number 17 on the opposite side of the river in Maryland, which uses endless rope haulage, constitute the West Virginia Central Division, under the direction of Mr. O. Tibbets, Superintendent.

The next group of mines, located at Elk


Hoisting Drum Operated by Direct Current Motor

Garden, are principally in the Pittsburg formation. These mines are Nos. 6 and 9 in the Pittsburg formation; No. 10 in the upper Sewickly, which is known locally as gas coal; No. 20 in the upper Freeport seam on a line with the railroad; and No. 14 four miles west of No. 20 on Abrams creek, producing a very high grade coal. With the exception of No. 6, which has a gravity rope haulage, this group is not provided with mechanical haulage other than steam trams. Mr. Robert Grant is superintendent of the Elk Garden district with headquarters at Elk Garden.

At Henry, about 8 miles east of Thomas, is located one of the later and, consequently, one of the more modern of the company's operations. The complete Bayard and Savage formations are accessible from this plant, the upper Freeport and the lower Kittanning being in good workable condition. It is operated by shafts 1 and 2 tapping the upper Freeport at a depth of 250 feet and the lower Kittanning at 150 feet. Tipples and hoisting towers are built of steel, while the power house, engine houses, blacksmith shop and all buildings in connection with the mine are of brick. The plant is equipped with electric haulage throughout and the coal is mined with compressed air punching machines. The power house contains two 24"x26"x30" Ingersoll air compressors, one belted 150 kw. alternating current generator, one 250 kw., 600 volt direct current generator for haulage purposes, and a synchronous motor direct current generator set, which acts as connecting link between the two generating units, permitting either one or the other to be shut down. This set can be operated from either end so as to provide direct or alternating current. On the main roads of this mine the hauling is done with one 13 ton and one 10 ton locomotive (the latter of General Electric manufacture), while the coal is gathered with two General Electric gathering locomotives of 4½ tons each. In portions of the mine the coal is still gathered by mule haulage. Mr. W. J. Christopher is superintendent of this division.



Hoisting Drum Operated by Direct Current Motor

The next operation is at Thomas, where the upper Freeport coal is mined by drift mines at tipple height above the railroad. No. 23 mine has been operated for a number of years and has become quite extensive in its workings; it is, however, still a good mine, producing 1200 tons of coal per day from a seam 8½ ft. thick, and is free from any noxious gases. Mine No. 25 is directly opposite mine No. 23, with a drift opening slightly to the dip in the same seam of coal. Mine No. 24 is in this same group, and is worked from a shaft 200 ft. deep penetrating to the Davis seam of lower Kittanning. The seam is divided horizontally by a rock, the portion above the rock being 8 ft. thick and that below 3 ft. thick. The rock serves the purpose of a pavement and, therefore, the coal below it is not worked to any extent in this mine. The coal is of an exceptionally good quality, running less than 1 per cent. in sulphur and seldom over 6 per cent. in ash, making No. 1 coke equal to the Connelsville. This group of mines is operated entirely by electric haulage and all pumps are driven by alternating current motors.

The 114 coke ovens at this plant are served by electrically operated coke larries, the electrical equipment of which is of General Electric manufacture. The results obtained with these larries, which run along the top of the ovens where the heat is at times excessive and where the fumes from the ovens would be injurious to horses or mules, have been excellent. It has also been found that they are much quicker in operation, for the control is so much better that, when about to discharge into the oven, they can be moved backward or forward an inch at a time. They are used either independently or with trailers and offer a flexibility not otherwise obtainable.

The electric equipment of the larries has given virtually no trouble at all. On the other hand, as the workings in these mines have become more and more extensive, trouble has been experienced with the haulage locomotives, as the length of hauls is very great and some steep grades are necessary. The capacity of the trolley line was increased by the addition of copper in order to reduce the drop in voltage resulting when heavy loads were started up at the working face, far back in the mine, and the track bonding was also overhauled and rails put in condition; but the troubles did not disappear entirely until a 500 kw., 600 volt direct current steam turbo-generator was installed in the Thomas power house. This turbine has demonstrated the particular suitability of this type of prime mover for handling the enormous fluctuations in load which occur in mining work. The normal current of this machine at full load is 833 amperes, but the unit is continually called upon to handle variations from 0 to 1450 amperes, which recur sometimes at intervals of a minute or less, when a train is picking up cars at the far end of the mine. The installation of prime movers possessing sufficient steadiness to stand up to this severe requirement has resulted in the entire disappearance of the former frequent burnouts of motor armatures.

The electrical apparatus in the power house at Thomas comprises two 100 kw., single-phase alternators with tub transformers for town and house lighting; one 200 kw., three-phase, 60 cycle alternator for supplying power to motors operating endless belts in the breaker and those operating the pumps, of which there are four 5 in. suction 4 in. discharge, one 3 in. suction 2½ in. discharge, one 6 in. suction 5 in. discharge, and one 10 in. suction with 8 in. discharge. All of these motors are designed for operation at 550 volts. The direct current equipment consists of one 204 kw., 600 volt and one 136 kw., 600 volt General Electric generator. The 500 kw. Curtis turbine provides current for eight 13 ton and one 20 ton General Electric locomotives, and the coke larries.

Mr. L. S. McDowell is superintendent of this division.

In the Coketon division, one mile west of Thomas, mines Nos. 35, 36 and 37 are operated in the lower Kittanning seam. This coal comes to the surface at a good height for tipples with drift openings. Nos. 24 and 26 are operated in the same group on the upper Freeport seam. The mines at Coketon are all equipped for electric operation throughout. Five 14 ton, two 13 ton and two 10 ton locomotives, as well as four 4½ ton gathering locomotives and two electrically operated coke larries, are supplied with current from two 250 kw., 600 volt generators of the belted type. A 100 kw. Curtis turbine direct current generator and a 300 kw. Curtis turbine alternator supply current to this mine. There is also an older General Electric Form "D" alternator which has seen hard service for many years and can now be used either as additional power, running in multiple with the turbines, or, by simply dropping off the belt and starting from the turbines as a motor, can be used as a rotary condenser for improving the power factor of the system. At Coketon there are two pumps of 10 in. suction 8 in. discharge, two of 6 in. suction 5 in. discharge, and two of 5 in. suction 4 in. discharge. The fans at Coketon are also electrically driven. Mines Nos. 35 and 36 are connected with mine No. 34 at Thomas, and No. 35 is therefore ventilated by a split from No. 34, while No. 36 is ventilated by a 15 foot Crawford and McCrimmon fan driven by a variable speed induction motor. Mine No. 26 is ventilated by a similar unit.

Practically the entire output of these mines is used for the manufacture of coke, the remainder being shipped West for smithing purposes. There are 500 ovens here and all are charged electrically. The coal that is shipped West for smithing purposes is loaded in box cars with box car loaders driven by alternating current motors.

The power house is further equipped with two Norwalk air compressors for the coal punching machines. Mr. M. L. Garvey is superintendent.

The next group of mines at Weaver, Randolph County, consists of Nos. 1, 2 and 3 in the lower Kittanning bed, which here shows up 9 feet thick and provides an excellent coking coal. The three mines are operated by gravity rope haulage and have 235 coke ovens. Mr. W. W. Brewer is superintendent of this section.

The main office of the operating department is located at Thomas, W. Va., where Mr. Lee Ott, the general superintendent, resides. Mr. Ott has been with the company for many years and has, therefore, seen the company expand territorially and make great progress along technical lines. The former of these is a simple process, but to guide an undertaking of this magnitude in such technical channels, that all the best and most improved inventions and developments in the engineering world can be made available and used without accumulating a huge scrap heap at a large expense, is an achievement which requires unusual foresight and judgment.

THE 1200-VOLT RAILROAD—A STUDY OF ITS VALUE FOR INTERURBAN RAILWAYS*

By Charles E. Eveleth

The various 1200-volt interurban railways have now been operating a sufficient length of time to prove that there are no material objections to the use of this voltage on passenger cars. The nature of such minor difficulties as have been experienced have been such that their correction has required only detail changes of design which have been readily made. The important items of reliability and low cost of upkeep have met all expectations.

A single statement regarding the motors may explain the reason for this successful performance. On the Pittsburg, Harmony, Butler & Newcastle line, where the service is unusually severe on account of unusual grades and curves, a considerable number of the brushes originally shipped in the motor brush-holders are still in service, though many motors have now run over 150,000 car miles, and the wear on the commutators is hardly perceptible. It can be stated from the performance of the 1200-volt system that nothing is jeopardized by the adoption of this system, and such economies as are possible by its use can generally be obtained without offsetting disadvantages.

We may therefore assume that the 1200-volt system has "found itself" and a new system is thereby made available for consideration when studying the requirements of new railroads or extensions to existing systems. If desired, the cars may be run at equal efficiency over tracks equipped for 600 volts.

This being the case, the question naturally arises, what gains may be expected from the use of this higher voltage?

The primary object of any railway is to pay dividends and these are limited by the amount of receipts which must be expended for two items fixed charges and operation. The most inflexible item is fixed charges. This works twenty-four hours a day whether business is good or bad and never gives up any ground once gained. Its only vulnerable point is the first cost of the railway. The 1200-volt system now offers a practical way of reducing the first cost of electrification through the material saving in substations and secondary distribution conductors. This gain becomes a permanent asset of the railroad making a definite decrease in the fixed charges at a place which cannot be reached in any way except by raising the voltage.

The other item is cost of operation. This item may be controlled to a certain extent by the personal ability of the manager, but having once selected the type and size of cars and the voltage of the system it is practically impossible for him to materially change the cost of getting power to his cars, which depends upon the distribution efficiency of his system and the cost of substation operation. The 1200-volt system decreases the cost of getting power to the cars in two ways: first, reducing the number of substations, and second, increasing the substation efficiency by improving the load factor. This latter result may seem unreasonable at first thought until one considers upon what grounds substation units are selected. They are not selected on the basis of heating, for it is probable that there are few interurban stations in this country running with 50 per cent. average load factor, and the average is certainly below 30 per cent. for the ordinary interurban conditions. It is generally necessary for the station unit to commutate within its overload guarantees, the maximum starting current of at least two trains starting simultaneously. As the running current of a train is about one-third of the starting current, and there are considerable periods during coasting and stops when the train is taking no current, and, furthermore, there are generally times when no trains are on the section fed by an individual substation, the low load factor can readily be accounted for. If then the units are selected for peak conditions the capacity of each station will remain constant, independent of the number of stations. It is evident when decreasing the number of substations, that is, increasing the track mileage fed by each station, that the average load will be greater and the substation load factor and efficiency improved. The total substation cost and operation will be decreased practically in proportion to the reduction in the number of stations. These advantages are net advantages since they are, in the 1200-volt system, obtained without being offset by extraordinary car equipment maintenance.

* A paper presented before the Philadelphia Section of the American Institute of Electrical Engineers, on January 10, 1910

DESCRIPTION OF RAILROADS

	A	B	C	D
Length of road, miles, all single track	100	100	100	100
Time between trains each direction, minutes	60	60	60	60
Cars per train	3	1	1	1
Seating capacity per car	65	60	50	40
Distance between stops, miles	5	2	1	0.5
Schedule speed, miles per hour	45	35	25	15
Maximum speeds, miles per hour	60	48	38	28
Car-miles per day	9000	3000	3000	3000

Any railway is complex, but there are certain fundamental differences, namely, track mileage, size of trains units and schedule speeds, which have a definite influence on the cost of electrification. In order to obtain an idea of the advantages which may be expected with the use of 1200 volts as contrasted with 600 volts, let us consider some concrete applications to different classes of conditions from which we may be able to draw some general conclusions. (Table above.)

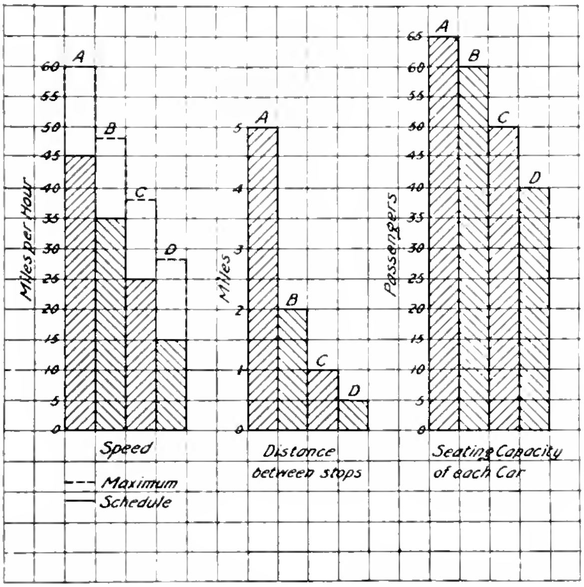


Fig. 1. Interurban Railway Systems. Single Track. Length of Road 100 Miles. Cars Every Hour in Each Direction.

In making these comparisons conservative values have been used, such as low substation cost, high cost of 1200-volt car maintenance, etc., so that the results will be conservative and the advantage rather less than might actually be achieved.

It will be seen that the roads vary greatly in conditions, from the heavy railroad conditions of *A*, through heavy interurban *B*, light interurban *C*, and very light traffic *D*. In fact, the cars of *D* will be no heavier than many city cars. (See also Fig. 1).

Cars. Based upon the requirements, the data in the table below may be considered reasonable for the cars:

It will be noticed that the power consumption which is "at the train" is slightly more for the 1200-volt cars on account of the greater weight of their equipments.

In the first table on following page, 10 per cent. greater maintenance is allowed for the upkeep of the 1200-volt electrical equipment. As a matter of fact, up to the present time no noticeable increase has been observed.

Substations. In selecting the size of synchronous converter units for the stations, they are in this case based on a maximum momentary demand of two cars starting simultaneously, except in the case of system *A*

CARS—GENERAL DATA

	A		B		C		D	
	1200 Volt	600 Volt	1200 Volt	600 Volt	1200 Volt	600 Volt	1200 Volt	600 Volt
Number	60	60	15	15	17	17	20	20
Cost each	$15,000	$13,000	$11,000	$10,000	$8,000	$7,000	$5,000	$4,500
Weight, tons	46.5	45	36	35	27	26	18	17
Amperes starting	1200	2200	280	520	200	370	120	220
Amperes run	300	574	94	174	66	124	40	74
Kw-hr. per train mile	11.16	10.8	2.88	2.80	1.89	1.82	1.08	1.02
Car-miles per day per car	150	150	200	200	176	176	150	150

where the size is based on the demand of one train starting and one train running. In each case a reasonable margin is allowed for occasional additional service.

The number of substations is dependent upon the maximum economical spacing, considered in conjunction with the cost of feeder copper and the allowable line drop with the assumed conditions of load. In each case it will be found that the addition of another substation to the number given in the data will not save its equivalent in cost of feeder copper. This brings up the question as to what may be considered equivalent feeder copper. The table below gives these equivalents:

The actual amount should be somewhat greater than these values, for with the addition of a substation there is a reduction in load factor on each substation, lowering the distribution efficiency. A curve is given (Fig. 2) to show the change in substation efficiency with change in the load factor on individual synchronous converters. This curve is for a station having 150 kw. to 300 kw. unit. For the larger machines the curve would be about two per cent. higher.

It will be seen that the investment in feeder copper which must be saved to justify an additional substation will be approximately $2\frac{1}{2}$ times the cost of the substation.

An examination of the diagram (Fig. 3),

CARS—COST OF MAINTENANCE
Cents per Car-Mile

	A		B		C		D	
	1200 Volt	600 Volt	1200 Volt	600 Volt	1200 Volt	600 Volt	1200 Volt	600 Volt
Mechanical	1.25	1.25	1.00	1.00	.90	.90	.75	.75
Electrical	.99	.90	.77	.70	.60	.55	.55	.50
Total	2.24	2.15	1.77	1.70	1.50	1.45	1.30	1.25
Yearly cost	$73,500	$70,500	$19,400	$18,600	$16,400	$17,000	$14,300	$13,700

	A		B		C		D	
	1200 Volt	600 Volt	1200 Volt	600 Volt	1200 Volt	600 Volt	1200 Volt	600 Volt
Number of substations	6	14	4	9	3	6	3	5
Est. momentary demand, kw.	1440	1320	448	416	370	300	250	200
Number of units	2	2	2	2	2	2	2	2
Size of each unit	1,000	1,000	300	300	200	200	150	150
Cost of station, each	$60,000	$56,000	$26,400	$24,000	$20,200	$18,400	$17,100	$15,600

EQUIVALENT FEEDER COPPER TO REPLACE ONE SUBSTATION

	A		B		C		D	
	1200 Volt	600 Volt	1200 Volt	600 Volt	1200 Volt	600 Volt	1200 Volt	600 Volt
Annual cost of labor and material	$2,500	$2,500	$1,900	$1,900	$1,800	$1,800	$1,700	$1,700
Fixed charges								
Interest . . . 5%								
Depreciation . . . 3%								
Taxes and insurance . . . 3%								
Total . . . 11%	6,600	6,160	2,904	2,640	2,222	2,024	1,881	1,716
Total	$9,100	$8,760	$4,804	$4,540	$4,022	$3,824	$3,581	$3,416
For feeder copper the interest, etc., will be approx. $8\frac{1}{4}$ per cent. Investment in feeder copper equivalent to each substa. will be	$110,000	106,000	$58,300	$55,000	$38,800	$46,400	$43,400	$41,400

showing the "location of substations" will give a fairly comprehensive view of the railroad layout and the location of the cars at any hour.

Primary Distribution. This in each case will be the same for either system, except that the total length of the 600-volt transmission line will be slightly longer on account of the greater distance between the terminal stations. A flat price of $3,500 per mile of transmission line is taken for system *A*, and $1,000 per mile for systems *B*, *C* and *D*.

It will make practically no difference where the power is fed to the high tension system. For the sake of simplicity it is assumed that power is purchased and delivered to the power house step-up transformers at one cent. per kw-hr.

Secondary Distribution. Track. For railroad *A*, 85 lb. rail is assumed. This has a resistance per mile, including bonding, of approximately 0.033 ohm. The other roads use 70 lb. rail having a resistance per mile of 0.04 ohm. A third-rail equivalent to a 1,000,000-cir-mil. feeder is assumed for *A*, and No. 0000 trolley wire for the other roads. The values used in obtaining the feeder copper necessary are based on a momentary maximum emergency drop of 250 volts for the 600-volt systems and 500 volts for the 1200-volt systems.

This will give an average secondary distribution efficiency of approximately 90 per cent.

In electrification material there is included under "first cost" and "fixed charges," (I and II) cars and car equipments, sub-

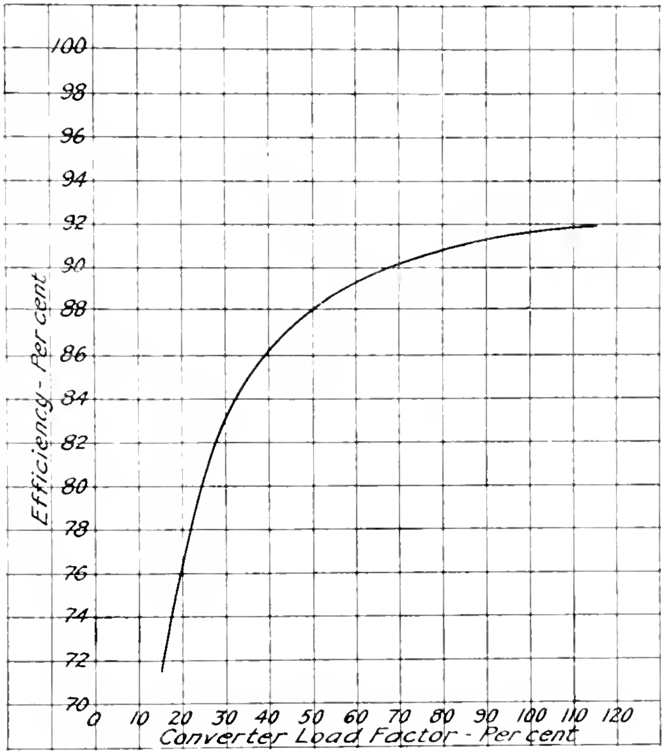


Fig. 2. Rotary Converter Sub-Station Efficiency Curve

FEEDER COPPER REQUIREMENTS

	A		B		C		D	
	1200 Volt	600 Volt	1200 Volt	600 Volt	1200 Volt	600 Volt	1200 Volt	600 Volt
Stub End Calculations:								
Trains starting and running	1-S	1-S	1-S	1-S	1-S–1-R	1-S	1-S	1-S
Total current, amperes	1200	2200	280	520	266	370	140	220
Length stub end miles,	4.5	1.85	8	28	10	45	10	5.5
Size copper required .	None	1,000,000	No. 000	No. 0000	No. 00	300,000	No. 0	No. 00
Between Substations:								
Trains starting and running midway	1-S	1-S	1-S–1-R	1-S	1-S 1-R	1-S	1-S 1-R	1-S
Amperes . .	1200	2200	374	520	266	370	160	220
Dist. between substations, miles . .	18.2	7.41	2.8	11.8	40	18.2	10	22.2
Size copper required .	None	1,000,000	No. 0	No. 0000	No. 00	300,000	No. 0	No. 00
Total cost of feeder installed		290,000	53,200	80,000	60,000	100,000	50,000	60,000

FEEDER COPPER—COST PER MILE INSTALLED

Size .	No. 0	No. 00	No. 000	No. 0000	300,000	1,000,000
Cost .	$500	$600	$700	$800	$1,000	$2,900

For track bonding $450 per mile has been taken for *A* and $400 per mile for *B*, *C* and *D*.

POWER CONSUMPTION

	A		B		C		D	
	1200 Volt	600 Volt	1200 Volt	600 Volt	1200 Volt	600 Volt	1200 Volt	600 Volt
Kw-hr. per day at car	$33,500	$32,400	$8,640	$8,400	$5,670	$5,470	$3,240	$3,060
Converter load factor	0.31	0.13	0.44	0.19	0.58	0.28	0.45	0.25
Efficiency (average								
Substation	0.836	0.69	0.87	0.76	0.89	0.823	0.873	0.803
Secondary distribution	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Transmission	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Step-up Transformers	0.98	0.98	0.97	0.97	0.97	0.97	0.97	0.97
Combined	0.722	0.595	0.745	0.632	0.761	0.705	0.748	0.688
Kw-hr. per day purchased	46,500	54,500	11,600	13,300	7,450	7,750	4,330	4,440
Cost per year at one cent. per kw-hr.	$169,000	$199,000	$42,400	$48,600	$27,200	$28,200	$15,800	$16,200

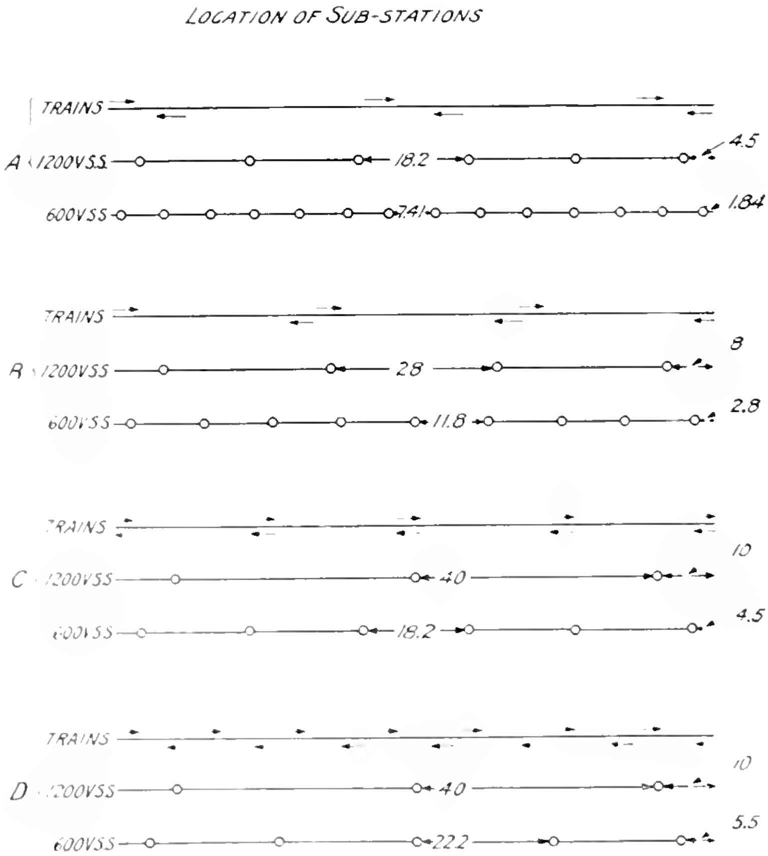


Fig. 3

stations complete, transmission line, trolley or third rail, low tension feeders and track bonding.

Under "operation and maintenance" (III) of electrification material there is included rolling stock, substations, trolley, feeders and track bonding, and cost of power; *i.e.*, all items which are affected by choice of system. Platform charges, general expenses, etc., common to both systems are not included.

SUMMARY OF COSTS—ELECTRIFICATION MATERIAL

	A		B		C		D	
	1200 Volt	600 Volt	1200 Volt	600 Volt	1200 Volt	600 Volt	1200 Volt	600 Volt
Cars	$960,000	$840,000	$172,500	$150,000	$136,000	$119,000	$100,000	$90,000
Substations	360,000	784,000	106,000	216,000	61,000	110,000	51,000	78,000
Transmission	318,000	340,000	81,000	91,000	80,000	91,000	80,000	88,000
Trolley *	625,000	600,000	160,000	160,000	160,000	150,000	160,000	150,000
Feeder	None	300,000	53,000	80,000	60,000	100,000	50,000	60,000
Bonding	43,000	43,000	40,000	40,000	40,000	40,000	40,000	40,000
	2,308000	2,909,000	615,500	730,000	537,000	610,000	481,000	506,000
Track, roadway, etc	2,500,000	2,500,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000
Total	$4,808,000	$5,409,000	$2,415,500	$2,530,000	$2,337,000	$2,410,000	$2,281,000	$2,506,000
Note:								
Substation buildings	45,000	105,000	20,000	45,000	14,000	29,000	14,000	23,000
Substation electric equipment	315,000	679,000	86,000	171,000	47,000	81,000	37,000	55,000
Cars and substations	1,320,000	1,624,000	278,500	386,000	197,000	229,000	151,000	69,000
Distribution materials	998,000	1,285,000	337,000	364,000	340,000	381,000	330,000	338,000

* Third rail used on A.

FIXED CHARGES—ELECTRIFICATION MATERIAL

	Life Years	Annuity 5 Per Cent.	A		B		C		D	
			1200 Volt	600 Volt	1200 Volt	600 Volt	1200 Volt	600 Volt	1200 Volt	600 Volt
Depreciation:										
Cars	15	46.34	$41,500	$39,000	$8,000	$7,000	$6,300	$5,500	$4,600	$4,200
Substation buildings	30	15.05	700	1,600	300	700	200	100	200	300
Substation apparatus	20	30.24	9,500	20,500	2,600	5,200	1,100	2,400	1,100	1,700
Transmission	20	30.24	9,600	10,300	2,500	2,800	2,100	2,700	2,100	2,700
Trolley	12	* 62.83	18,900	18,100	10,100	9,400	10,100	9,400	10,100	9,400
Feeders	20	30.24		9,100	1,600	2,400	1,800	3,000	1,500	1,800
Bonding	10	79.50	3,600	3,600	3,200	3,200	3,200	3,200	3,200	3,200
			86,800	102,200	28,300	30,700	25,400	26,600	23,100	23,300
Interest: 5 per cent. on total cost of electrification material			116,000	115,000	31,000	36,000	27,000	30,000	21,000	2 500
Taxes: $1\frac{1}{2}$ per cent. of total cost of electrification material			36,400	43,700	9,200	11,000	8,000	9,100	7,200	7,600
Insurance: $1\frac{1}{2}$ per cent. of cost of rolling stock and substations			19,800	24,200	4,200	5,500	2,000	[illegible]	[illegible]	2,500
Total fixed charges			$259,000	$315,100	$72,700	$83,200	$62,100	$69,100	$56,500	$58,100

* Third-rail depreciation based on 20 years life.

On examination of these results, which are based on conservative figures on account of the relative newness of the 1200-volt system, it is apparent that the higher voltage effects economies at points that can only be reached by a change more fundamental than is possible with the lower voltage.

The saving of $1\frac{1}{2}$ to 2 cents per car mile will permit a very material increase in dividends.

COST OF OPERATION AND MAINTENANCE

	A		B		C		D	
	1200 Volt	600 Volt	1200 Volt	600 Volt	1200 Volt	600 Volt	1200 Volt	600 Volt
Transmission	$9,000	$9,500	$3,000	$3,300	$2,800	$3,200	$2,800	$3,100
Trolley and feeders	15,000	15,000	9,000	9,000	9,000	9,000	9,000	9,000
Rolling stock	73,500	70,500	19,500	18,500	16,500	17,000	14,500	15,000
Substations	15,000	35,000	7,600	17,000	5,500	11,500	5,000	8,500
Cost of power	169,000	199,000	42,400	48,600	27,200	28,200	15,800	16,200
	281,500	329,000	81,500	97,100	61,000	68,400	47,100	50,800
Total operation and maintenance of items listed	282,000	329,000	82,000	97,000	61,000	68,000	47,000	51,000
Statistics indicate that the items listed on 600 volt roads constitute approximately 44 per cent of the total operating cost. Based upon this there should be added to each of the above	421,000	421,000	123,000	123,000	87,000	87,000	65,000	65,000
Total yearly cost of operation, and maintenance of 3,285,000 car-miles per year for *A* and 1,095,000 car-miles per year for *B*, *C* and *D*	$703,000	$750,000	$205,000	$220,000	$148,000	$155,000	$112,000	$116,000

COMPARISON OF SYSTEMS

	A		B		C		D	
	1200 Volt	600 Volt	1200 Volt	600 Volt	1200 Volt	600 Volt	1200 Volt	600 Volt
I. First Cost:								
Track, roadway, etc.	$2,500,000	$2,500,000	$1,800,000	$1,800,000	$1,800,000	$1,800,000	$1,800,000	$1,800,000
Electrification material								
Car equipments	960,000	840,000	172,500	150,000	136,000	119,000	100,000	90,000
Substations	360,000	784,000	106,000	216,000	61,000	110,000	51,000	78,000
Distribution	988,000	1,285,000	337,000	364,000	340,000	381,000	330,000	338,000
Total	$4,808,000	$5,409,000	$2,415,500	$2,530,000	$2,337,000	$2,410,000	$2,281,000	$2,303,000
In favor of 1200 volts	—	601,000	—	114,500	—	73,000	—	26,000
II. Fixed Charge:								
Track, roadway, etc., 7 per cent.	175,000	175,000	126,000	126,000	126,000	126,000	126,000	126,000
Electrification material	259,000	315,000	73,000	83,000	62,000	69,000	56,500	58,500
Total	$434,000	$490,000	$209,000	$209,000	$188,000	$195,000	$182,500	$184,500
In favor of 1200 volts		56,000	—	10,000	—	7,000	—	2,000
III. Operation and Maintenance.								
Miscellaneous	421,000	421,000	123,000	123,000	87,000	87,000	65,000	65,000
Electrical	282,000	329,000	82,000	97,000	61,000	68,000	47,000	31,000
Total	$703,000	$750,000	$205,000	$220,000	$148,000	$155,000	$112,000	$116,000
In favor of 1200 volts		47,000	—	15,000	—	7,000	—	4,000
IV. Annual Cost II + III	1,137,000	1,240,000	414,000	429,000	336,000	350,000	294,500	300,500
In favor of 1200 volts		103,000	—	2,500	—	14,000	—	6,000
V. Revenue:								
Additional receipts per car-mile necessary to pay additional cost of operation, etc., for 600 volts		3.1c.	—	2.28c.	—	1.28c.	—	0.55c.

NOTE.—3,285,000 car-miles per year for *A*.
1,095,000 car-miles per year for B, C and *D*.

It is further clear that the relative value of the higher voltage increases as the demand for power increases, and that below a certain size of equipment there would be practically no justification for the adoption of the higher voltage. Results are shown for convenience in graphical form in Fig. 4, as this indicates clearly how the economies change with the change in the system.

The place where the application of the 1200-volt system may be looked for in the immediate future is that field of interurban railroading where it has already made its successful start.

Conclusion. In conclusion it appears that a conservative estimate of the economy obtained by a 1200-volt system as compared with the 600-volt system in the elements of a railroad which are affected by the choice of system, that is, all of the electrification material, would place these savings approximately as follows:

1. First cost . . . . . 10 to 20 per cent.
2. Fixed charges . 10 to 18 per cent.
3. Operation and maintenance. . . . . 10 to 15 per cent.

Furthermore, experience has shown that

4. The 1200-volt system is just as reliable as the 600-volt system.
5. Substations may be operated from a system of any commercial frequency.
6. In specific cases the saving has been found materially greater than indicated in conclusions 1, 2 and 3, notably where the length of road is such that no substations are required for the 1200-volt system while substations are required for the 600-volt system. In some instances, the savings have been as great as 25 or 30 per cent. in the electrification material.

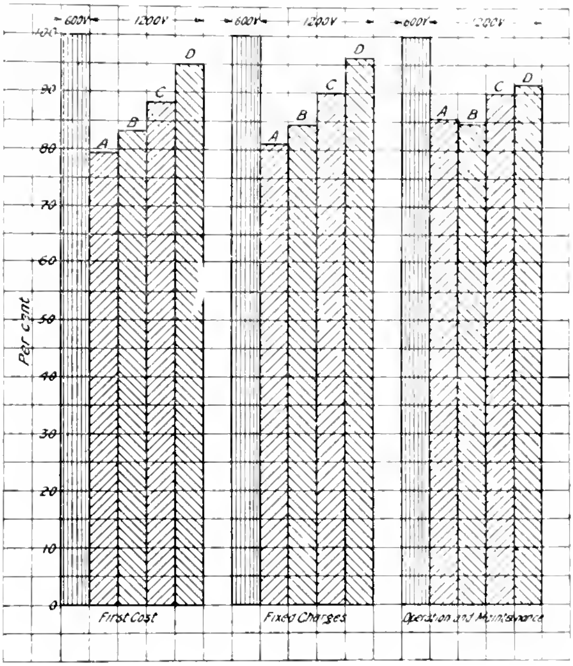


Fig. 4. Comparison of 600 Volt and 1200 Volt Railway Systems

COMPARISON OF SYSTEM

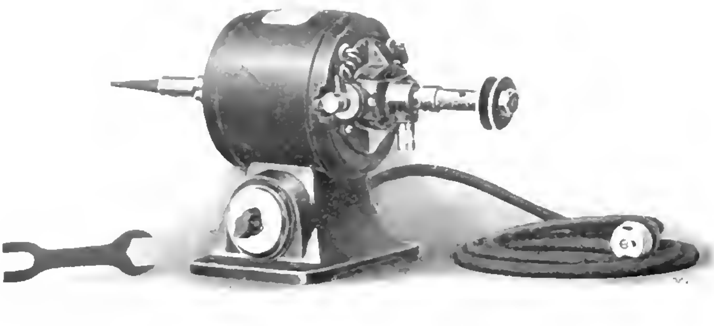
	600 Volt Per Cent.	A 1200 Volt Per Cent.	B 1200 Volt Per Cent.	C 1200 Volt Per Cent.	D 1200 Volt Per Cent.
I.—First Cost: All electrification material	100	79.4	85.5	88.0	95.0
II.—Fixed Charges: All electrification material	100	82.3	87.3	90.0	96.5
III.—Operation and Maintenance All electrification material .	100	85.8	84.5	89.9	92.0
IV.—Annual Cost II+III: All electrification material	100	84.0	86.0	90.0	94.0

SMALL BUFFING AND GRINDING MOTORS—DRAWN SHELL TYPE

By R. E. Barker

Small Motor Department—General Electric Company

In modern life many things are considered necessaries which only a generation ago were regarded as luxuries. It is evident to the student that this change in view is a natural one, going hand in hand with progress. Inventive genius is being constantly applied to the devising of new and improved mechanisms for lightening our tasks in the factory, shop and home by the replacement of hand work by power. It is now recognized that electric power has several advantages over all other forms, particularly for the smaller applications, of which buffing and grinding are good examples.



Small Power Motor Designed for the Use of Jewelers, Dentists, etc.

The art of polishing has been known from the most ancient times, but until the advent of power driven rotary wheels, a satisfactory polish could be accomplished only after a slow and laborious operation. The electric motor applied to this work offers a way of performing certain tasks satisfactorily and quickly which were often very poorly done by the earlier and slower methods.

Small buffing and grinding motors are offered in three distinct forms, each of which has a particular field of usefulness. For the light work of the ordinary household a motor with a simple extension shaft is found to be satisfactory. This machine is styled the "Domestic" buffing and grinding motor. It is developed from a standard small power motor and has a removable shaft extension substituted for the pulley. The extension is supplied with a rag wheel for buffing and an emery wheel for grinding, and these may be used interchangeably. The wheels are clamped between the nut and washer on the free end of the shaft extension.

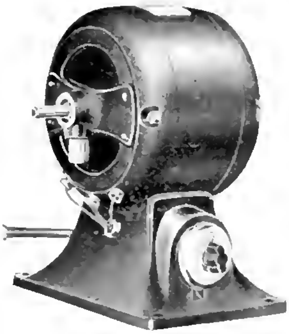
This little apparatus serves the double purpose of polishing silverware and grinding knives for the household, and when used intelligently does much better work and in a shorter time than is possible by the antiquated hand method. The expense of operation is very small — less than one cent per hour, at the average prevailing rate for current.

The use of buffing and grinding motors is not limited to the home, however; they have an important place in jewelers' shops, dentists' laboratories, machine and test rooms, and the like. For such applications, motors of larger size and greater capacity are demanded and two types of these are therefore offered, namely, the "Jeweler's" and the "Commercial."

The Jeweler's motor is particularly devised for the use of jewelers and dentists. It is made in four sizes ranging from 1/15 h.p. to 1/6 h.p., and is complete with all the accessory parts necessary to form a satisfactory outfit. The motor is mounted on a high base or

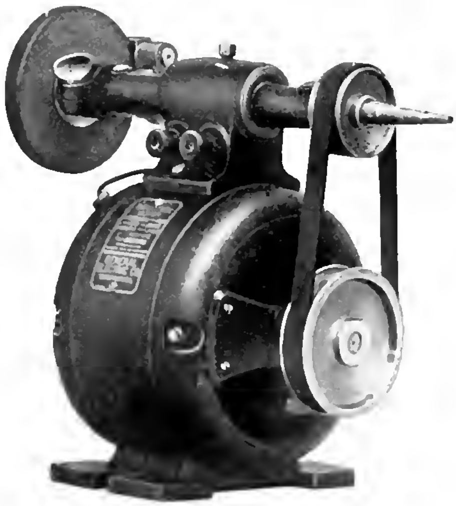
Small Power Motor for Domestic Purposes

pedestal casting, in which a controlling switch is conveniently placed. The leading in wires are combined in a flexible reinforced cord, fitted with a screw plug adapted to the usual screw base lamp socket. The motor armature or revolving part is made with a shaft extending from both ends of the frame. These ends are tapered to a standard dimension and are adapted to receive the two shaft extension. These, together with a combined wrench and removing tool, complete the outfit. One extension has a clamp nut and washers for taking grinding wheels, etc.; the other is taper-threaded to receive rag buffing wheels or wire scratch wheels with wooden hubs. All of these devices are well known to the jewelers and dentists.



Jeweler's Motor without Accessories

Both shaft extensions are held on the motor shaft by friction on the taper fit described above. When it is desired to change or remove them, this may be easily accomplished by the use of the removing tool furnished with each outfit, as shown in the illustration on following page. The tool is inserted over the shaft and between

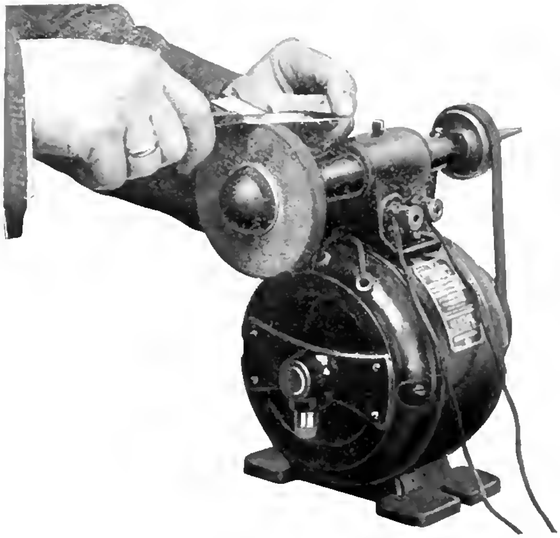


Small Power Motor for General Commercial Purposes

the motor-bearing hub and back of the shaft extension. Using the tool as a lever, a light pressure on its free end is sufficient to start the extension, which will then drop off the shaft. The jeweler's motors are used for a wide variety of purposes, each of which requires a different grade of buffing or grinding wheel. These additional accessories are not furnished, as it is thought better to leave it to the individual user to secure for himself such wheels as are best suited to his work.

The jeweler's motors are particularly suited to dentists, jewelers and such others as have small pieces of work to be handled. To provide for the larger requirements of silversmiths, manufacturing jewelers, etc., a third form of buffing and grinding motor known as the "Commercial" is offered.

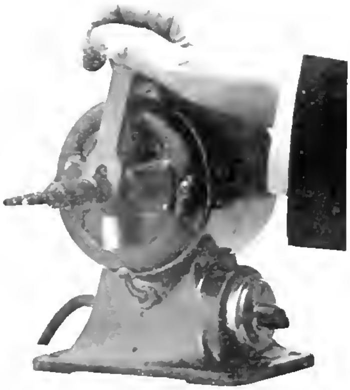
This machine is shown above. It consists of a small power motor of 1/10 h.p.



Showing Use of Commercial Motor for Grinding

or 1/6 h.p. capacity, on the top of which a cast iron bracket is fixed. The bracket carries a long counter-shaft support with a barrel shaped centre portion of enlarged diameter. The counter-shaft center is displaced with respect to the centre of the barrel for the purpose of providing an easy means of tightening the driving belt, which transmits power from the flanged pulley on the motor shaft to the counter-shaft above it. After the belt tension has been adjusted to the right amount, by turning the counter-shaft support in its eccentric bearing in the bracket, the square head set screw in the top of the bracket is tightened to lock the parts in place.

The shaft is furnished with one end tapered and threaded for rag wheels, etc., while the other has cheek plates and nut to clamp the four inch emery grinding wheel that forms a part of the outfit. On the end of the counter-shaft support an adjustable tool rest is fitted, by means of which the work may be held at the correct angle while being ground. This is an important improvement, for without a guide or rest considerable skill is required to secure the best results. It will be noted that the Commercial buffing and grinding motor has no parts above the center line of the countershaft which will interfere with the free swing of large work; for this reason it is especially desirable for silversmiths and manufacturing jewelers, etc. Large salvers, candelabra and the like can be buffed and polished without difficulty by the use of this motor.



Method of Removing Extension Shaft

All the buffing and grinding motors that have been described are totally enclosed and protected from the dust, metal chips, dirt, etc., which surround them while in use. They are all carefully planned to the classes of work for which they are intended. The motors may be obtained with the different windings that suit them for operation on the more common commercial lighting circuits, both alternating and direct current.

GEARS FOR MOTOR-DRIVEN TOOLS WITH SPECIAL REFERENCE TO CAMBRIC PINIONS

By John Riddell

With electrically driven machinery the means employed for transmitting the mechanical energy of the motor to the machine is a matter of first importance. In the early days of the electric motor, this subject was given little attention, belts and countershafts, etc., being considered entirely satisfactory. With the growth of electric drive, however, increasing attention has been given to this branch of the subject in the endeavor to lessen friction losses, reduce maintenance and attention, and conserve floorspace.

The last of these considerations, together with a desire to improve the appearance of motor-driven tools, has tended toward the evolution of the more modern design in which the tool and its driving motor appear as practically one machine.

When possible, direct connection is, of course, the simplest method of drive. For various reasons, however, this method is frequently inexpedient and in these cases, recourse must be had to belts, chains, gears or some similar means of drive.

In the case of machine tools, at least, the use of belting is generally precluded, as the proper utilization of floor space requires the motor to be so set that the pulley center would be too close for belt drive. For this work, therefore, chains or gears are generally employed.

Chains work fairly well where the sprockets are not in a vertical position and when the loads and speeds are not excessive, but these limitations, together with the fact that in most cases machine tools require something more positive, have made for the employment of gears.

The action of gears is, of course, dependent upon the material of which they are made; some of the more important varieties are as follows:

Steel Gears. These are usually very noisy and unless kept well lubricated are apt to cut and wear out quickly. Cast iron gears, on the other hand, generally give satisfaction, provided the load is not excessive and the back-lash, or shock, is not too great.

Brass for pinions is expensive and makes about as much noise as any other metal; it should be used only where greater toughness than can be had from cast iron is required, or where a pinion is to run with a steel gear for heavy work.

Rawhide has been used for many years and is often resorted to when other gears make too much noise. It is expensive, however, and shrinks badly in a dry, warm place. It will not stand moisture and, altogether, it is unsatisfactory for most work.

Fibre has also been used for reducing noise. The objection to it is that it is difficult to keep dry, as it absorbs moisture which causes it to swell and otherwise give trouble. This material seems also to deteriorate under the use of oil, which is a very serious drawback. It is not very strong, and while it is not so noisy as metal still the noise is sometimes objectionable.

In the above paragraph we have had spur gears in mind. Another style of gear is that known as the herring-bone type, its name being taken from the form of the teeth. This is a very expensive form to cut and assemble as both the gear and pinion are usually made in two pieces, which are later riveted together. When large quantities of these gears and pinions are made they are rough bored and faced where they join together. They are then assembled ten or a dozen halves on an arbor and cut right-handed. Another ten or a dozen are then placed on an arbor and cut left-handed. It will be readily seen that the slightest error between the different settings will result in inaccuracies, and it takes but a very slight error (sometimes only one or two thousandths of an inch) to cause trouble in the running of these gears.

The herring-bone pinions are cut in the same manner, but instead of using a gear cutter for this purpose, a milling machine may be employed.

As in the case of the gears, the machines must be set to cut both right- and left-handed, and errors are apt to creep in here as in the former case. If these errors happen to be in the opposite halves, so that the large halves of the gear and the pinion come together, trouble is apt to result. These gears do not allow of any end play in the revolving parts, as the angle of the teeth will not permit it without a corresponding shock to the opposite gear. This form of gear should be avoided except in very extreme cases, such as for heavy rolling mill machinery where very coarse pitches are used; where the rolling effect produced by the angle of the teeth will tend towards smoother running and give greater strength.

Most machine tools demand variable speeds, and the latest forms of variable speed drives require considerable gearing, which, if not properly made and installed, will cause more noise than is desirable. This noise can be entirely eliminated in any case fo which cambric pinions can be made; these, while noiseless, are also extremely durable and efficient.

CAMBRIC PINIONS

A brief description and history of this invention may be of interest.

A large punch and shear, driven by a motor through a train of gears and installed in a blacksmith shop, where the work is very heavy and rough, had been giving a great deal of trouble, both from noisy gears and from stripping of the gear teeth.

As originally fitted up, the train of driving gears consisted of a brass pinion on the motor shaft which drove through a cast iron cut gear on a countershaft, and this, in turn, through another pinion connecting with the main gear of the machine. The countershaft carried a heavy flywheel, which, when running, caused a backlash that several times stripped the teeth from the cast iron gear. The brass gear also soon lost its shape and gave trouble. After this experience a street railway gear and pinion were used, but they made an intolerable noise and had to be discontinued. It was at this stage that the inventor, looking for a substitute which would stand up, and having in mind rawhide and fibre, bethought him of having a muslin pinion made. This pinion was accordingly made, and was put on the punch over a year and a half ago; up to the present writing, it has not given a particle of trouble, neither does it show any appreciable signs of wear.

Since that experience, a great many other troublesome machines have been similarly equipped, until at present there are 700 of these cambric pinions in active service, and as yet not one has failed.

In making these pinions, the following process is followed. The muslin is cut out in discs which are assembled and pressed between two steel washers, the whole then being securely fastened with rivets or tap bolts, following the same method as that of making rawhide pinions. The blank is next turned to the proper diameter and the teeth cut in a gear cutter. The gear is then soaked in a good quality of machine oil.

These pinions can be made in various forms, of any reasonable size, and either with or without metallic centers. It is absolutely necessary, however, for the shrouding to extend to the full diameter of the gear.

With these pinions, the use of lubricants is unnecessary, as the oil which was absorbed by the muslin in the oil bath will keep the teeth of the pinion lubricated for an indefinite length of time. In the actual running of these gears they seem to take a metallic coating on the teeth, which tends to protect them from excessive wear from the teeth of the other gear.

In addition to these features, there is also a certain amount of flexibility which is beneficial, as in all commercial gears there is apt to be some slight inaccuracy in the spacing from tooth to tooth. When such gears are run with other metallic pinions there may be, and frequently is, an excessive strain brought on one tooth, which tends either to bend or break it. With the cloth pinion, however, the flexibility afforded by the material tends to distribute the strain over at least two or more teeth, depending on the size and number of teeth in contact; these will stand any reasonable amount of this bending, there being no fibres to crystalize as in the case of the metallic gears.

Some engineers, when the matter was first brought to their attention, were inclined to be a little skeptical, but the pinions have given and are giving a practical demonstration of their merits by running every day in the hardest kind of service. An inspection of some of these cases would, I think, satisfy anyone as to their worth.

ANNUAL REPORT OF THE GENERAL ELECTRIC COMPANY

The latest report of the General Electric Company gives the shareholders full information about the work of the year under review, the present financial position, and the prospects of the Company in the immediate future.

The address of the President summarizes the financial result in the statement that after paying all expenses, making ample allowance for losses and depreciation, and authorizing 88 per cent. of the expenditure on factory plants ($2,447,984) the net profits were $6,493,670.

Out of this $5,214,352 was paid to the shareholders in dividends—being 8 per cent. on $65,179,600 of capital; the balance $1,279,318 was added to the surplus, which now amounts to $17,318,318.

The total assets are $102,140,988, and bearing in mind the drastic manner in which they have been shrunk in past years, it is evident why this industrial occupies the high rank among others that it does.

In the previous year's report the President intimated that the capacity of the factories was then far in excess of existing demands for their product and sufficient to provide for a much greater output than had ever been reached in the history of the Company. In the present report he states that there is still a surplus of factory facilities which cannot be fully employed until the volume of orders received is considerably increased. This may be partly accounted for by the fact that the various departments are not all equally busy. In 1909, some $2,878,942 was expended upon factory plants, which added considerably to the factory facilities. While the President calls attention to the fact that there is still room and to spare for more orders, Vice-President Lovejoy shows in his report that $54,360,562 in orders were received in 1909 (11 mo's) against only $42,186,917 in 1908, and that for the last five months of 1909 they were being booked at the rate of nearly $70,000,000 per annum, a figure almost as large as in the record year of 1907.

In the reports of Vice President Rice and Vice President Lovejoy, we have a record of achievement in many directions. The total turnover in 1909 (11 mo's) was $51,656,631 against $44,540,676 for the previous year, evidence clear enough that there has been a substantial recovery from the depression of 1908 and that the Company has resumed its phenominal progress from the annual "billed amounts" of $12,000,000 in the "nineties" towards the predicted turnover of $100,000,000 in 1914. As the field for electrical apparatus and appliances increases, the immense number of separate machines and parts to be catalogued and listed enlarges. This in turn means larger stock and more warehouse accommodation at distributing centers.

New triumphs for the Curtis steam turbines and the G.E. high voltage direct current railway system are announced—the natural result of simplicity, economy, reliability and safety in operation. Included in the expenditure on patents during the year was a considerable sum for U. S. patents on foreign inventions relating to incandescent lamp filaments and processes of manufacture.

In consequence, immense strides have been made in the efficiency of metal filament lamps, the business in which grows apace. This is the more remarkable when it is considered that but few central stations have done more than advise their customers that these new Mazda lamps can be got by paying for them.

Vice President Rice mentions the engineering problems that have been solved and are being solved, and from his remarks it is apparent that the art is steadily progressing.

Apparatus for the economical transmission of current over very long distances is being constantly improved. Larger units at higher voltage, and the attendant devices to render their use safe and reliable afford a wide field for cultivation. Industrial power problems invite the highest skill of the electrical engineer, each successful solution leading to still greater triumphs.

The financial report which follows bears testimony to the magnitude of the transactions of the Company, and the care taken to have its accounts and records full and clear. The accuracy of the balance sheet is certified to by Marwick, Mitchell & Co., chartered accountants. Of this part of the report it may be said that every facility is at the command of the Company for the successful prosecution of its business.

Modern machine tools and machinery are employed throughout, and the physical condition of all the manufacturing plants is maintained at the highest point of excellence.

Large expenditures for these purposes, together with the purchase of raw materials and commodities at the lowest prices, can only be made with ample cash resources. The inventive genius of the Company's engineers, the enterprise of its commercial men, and the skillful administration of its financial affairs, command the business and warrant the confidence of the thousands of customers of the Company, who are now to be found in every quarter of the globe.

A comparison of accounts follows:

	1906	1907	1908	1909	1910 (Dec. 31 11 Mo.)
Net Profits	$7,319,161	$8,502,237	$6,948,682	$4,802,252	$6,493,670
Dividends and Interest	3,861,062	4,418,727	5,545,643	5,214,026	5,930,669
Balance	$3,548,099	$4,083,510	$1,403,039	* $411,773	$1,279,319
Sprague Account	...	..	...	...	...
Written off on account Stanley Company	759,654				
Patents written off	1,000,000	999,999			
Balance	$2,458,099	$3,083,501	$1,403,039	$411,773	$1,279,319
Previous surplus	9,569,196	12,027,295	15,110,796	16,513,836	$16,102,062
Stock Dividend					
Total Surplus	$12,027,295	$15,110,796	$16,513,836	$16,102,062	$17,381,381

* Loss.

We make further comparison:

	1906	1907	1908	1909	1910
Sales	$43,146,902	$60,071,882	$70,977,168	$44,540,675	$51,656,631
Royalties, dividends, etc.	798,539	417,586	1,010,961	703,942	1,260,847
Profits made by Security Holding Companies		675,000		750,000	
Profits on sales of Stocks and Bonds	173,390	329,702	9,778	35,912	478,019
Interest and Discount	300,782	114,660	487,079	1,137,938	706,552
Total	$44,419,613	$61,608,830	$72,484,986	$47,168,469	$54,102,049
Cost of Sales	37,025,347	53,106,594	65,898,334	42,366,216	47,608,379
Net Profits	$7,394,266	$8,502,236	$6,586,653	$4,802,252	$6,493,670

The balance sheets as of January 31 compare:

ASSETS	1906	1907	1908	1909	1910
Patents, etc.	$1,000,000	1	1	1	1
Factory Plants	8,000,000	9,000,000	12,900,600	13,900,000	14,330 958
Real Estate	359,014	347,489	541,900	85,124	118,063
Stocks and Bonds	19,104,539	20,086,790	18,000,089	21,922,189	22,329,663
Notes and Accounts Receivable	16,287,018	22,860,789	29,857,726	18,873,057	19,377,972
Advances to Affiliated Cos.		2,922,675			
Inventories	16,922,291	22,593,907	20,997,055	18,393,899	25,150,035
Work in Progress	2,496,206	3,853,321	1,276,294	607,276	462,223
Cash	6,356,094	3,910,709	12,250,720	22,233,671	17,623,466
Discounted Paper		666,608			
Copper Mining Investment			2,701,976	3,174,580	3,048,604
Total	$70,525,162	$86,245,289	$98,525,765	$99,189,800	$102,440,988

LIABILITIES	1906	1907	1908	1909	1910
Common Stock	$54,286,750	$64,353,550	$65,167,400	$65,178,800	$65,179,600
Debentures	2,102,000	2,102,000	14,974,750	14,963,000	14,962,000
Accrued Interest	2,253	1,924	108,791	107,623	83,664
Accounts Payable	2,106,864	4,010,411	1,179,517	2,836,834	3,530,750
Purchase Curtis Patents					
Endorsements		666,608			
Profit and Loss Surplus	12,027,295	15,110,796	16,513,836	16,102,062	17,381,381
Total	$70,525,162	$86,245,289	$98,525,765	$99,189,800	$102,440,988

Sales and orders received during last nine years compare:

Year ending January 31.	Amount Billed	Orders Received
1900	23,370,463	26,323,626
1901	28,783,275	27,969,541
1902	32,338,036	34,350,840
1903	36,685,598	39,944,454
1904	41,699,617	39,060,038
1905	39,231,328	35,994,807
1906	43,146,902	50,044,272
1907	60,071,882	60,483,659
1908	70,977,168	59,301,040
1909	44,540,676	42,186,917
1910	51,656,631	54,360,562

During the year there were received 270, 659 separate orders (not including contracts), an average of 902 per working day.

The following table shows approximately the floor space and the number of employes during the last eight years:

	Floor Space	Employes
1901	2,500,000	15,000
1902	3,000,000	15,000
1903	3,009,000	18,000
1904	3,700,000	17,000
1905	4,100,000	18,000
1906	4,350,000	22,500
1907	4,970,000	28,000
1908	6,460,000	20,000
1909	7,000,000	23,300
1910	7,180,000	30,000

The amount written off factory plants and equipment is substantially 82 per cent. of the cash expended thereon during the year.

The land area of all three plants is now about 521 acres.

GENERAL ELECTRIC REVIEW

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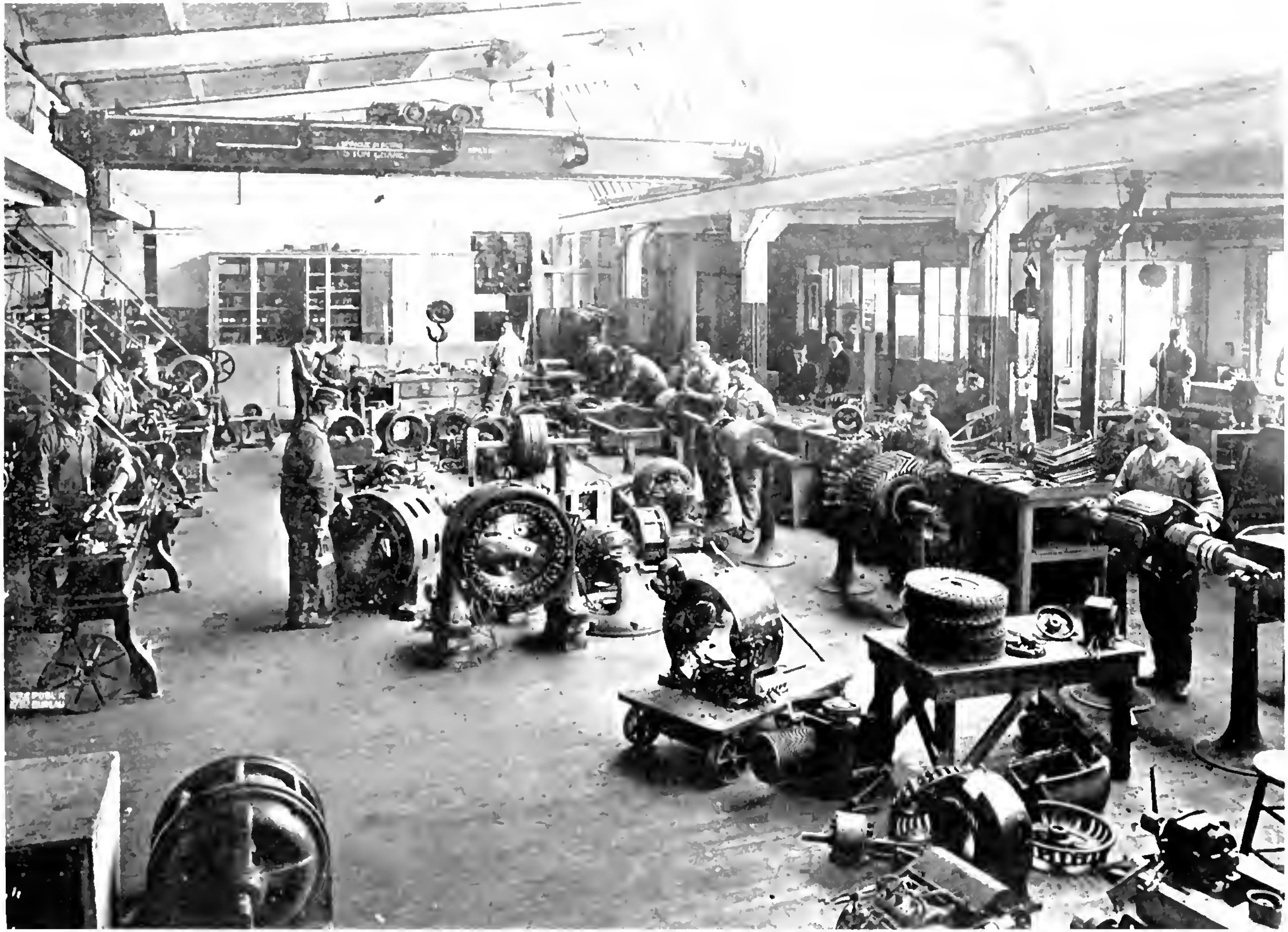


Armature Winding; General Motor and Armature Repairs. Repair Shop of the General Electric Company, Chicago

(See Page 297)

GENERAL ELECTRIC REVIEW

COMETS

The origin, behavior and composition of comets have long been matters of speculation amongst astronomers. Owing partly to the somewhat rare appearance of large comets and to the fact that refined spectroscopic methods have only been available recently, little is at present actually known about their composition or the causes underlying the formation of the tail, which is so marked a phenomenon attending many comets. Prof. Thomson's article in this issue of the REVIEW, which deals with the forces causing comets' tails and the possible source from which sufficient material is derived for their maintenance, is extremely opportune just now, since, historically speaking, the most noted comet has been visible for the last two months.

A great part of the article is very suggestive, especially that relating to the genesis of the new tail which occurs as the comet nears the sun, when it is subjected to maximum radiation. As the author points out, the matter composing the tail must be extremely attenuated and the mass of the nucleus very small. In no case has any perturbation of a planet been observed due to proximity of a comet, although the orbits of comets have been considerably altered by planets; hence only a higher limit can be set for the total mass, which is but a minute fraction of the earth's—certainly less than one-hundredth-thousandth part.

Astronomers divide comets into two groups: the parabolic and periodic. The former revolve in practically parabolic orbits; that is to say, their orbits are either very elongated ellipses, with periods measured in hundreds of years, or are slightly hyperbolic. These comet pass out into space far beyond the orbit of the furthest planet and acquire at perihelion, when their distance from the sun is minimum, a velocity which is practically that which would be acquired by a body falling from rest at infinity to a point at perihelion distance from the sun. It is interesting to note that this velocity is the same as that which the comet would acquire by falling from its position at perihelion to the sun's center under the uniform gravitational acceleration of the sun at the perihelion position. This velocity is the greater the nearer the comet passes to the sun's surface, its limiting value being approximately 380 miles per second. A few comets have been observed for which this velocity has been nearly attained, notably the great comets of 1843 and 1882. The former comet at perihelion passed within 100,000 miles of the sun's surface, traversing the inner part of the corona. So fast did it travel that 180 degrees of its orbit were completed in less than two and a quarter hours, the maximum velocity being slightly over 360 miles per second.

The great comet of 1882 passed nearly as close to the sun and its brilliance was sufficient for it to be visible for three consecutive days, its passage up to the sun's disc being clearly observed at Cape Town. The brightness then appeared equal to that of the sun itself, but on crossing the sun's limb the comet vanished; on emergence a few minutes later, it was again clearly seen and could be followed telescopically until 180,000,000 miles away. The paths and velocities of these comets were not affected by their close proximity to the sun at perihelion, proving that the matter contained in the sun's corona is extremely attenuated; no resistance to motion was perceptible.

Periodic comets, of which Halley's is an example, have paths of which the major axes are comparable to planetary distances. Jupiter, the largest planet in our system, has a family of his own, whose paths extend close to his orbit. Halley's comet, known to history from Chinese annals as early as 12 B.C., is a Neptune comet, its aphelion distance being slightly greater than Neptune's distance from the sun. In consequence of this fact, the comet's orbit has been somewhat disturbed when Neptune chanced to be at the right point of his path during the comet's aphelion; but since the plane of the comet makes an angle of about 18 deg. with the plane of the ecliptic, and the major axis a slightly less angle, Neptune can never have been sufficiently close to have attracted the comet strongly. So far observed, Halley's is the only periodic comet moving in a retrograde direction around the sun, all the others travelling in the same sense as the planets.

The perihelion distance of this comet is about 60,000,000 miles, and the aphelion distance about 3,000,000,000 miles, so that its path is highly elongated and gives a very different orbit from the relatively circular orbits of the planets. At aphelion it has a velocity of less than one mile per second, whereas the perihelion velocity is about 30 miles per second, these two velocities being inversely proportional to the comet's distance from the sun at these points.

Prof. Thomson's suggestion as to the possibility of a comet picking up material as it traverses its long journey through space removes a difficulty as to the source from which a comet draws the supplies necessary for tail formation. Many of the materials composing a comet's nucleus are still unknown, but a few have been recognized by spectroscopic analysis; *viz.*, carbon in the form of hydrocarbons, cyanogen, carbonic oxide, iron, sodium, and possibly hydrogen. Bright bands have also been observed in the spectrum of the nucleus, of unknown origin.

The light from comets' tails is probably electrical in origin and is closely analogous to the light obtained from a vacuum tube; it is not due to temperature radiation. At perihelion, a comet may absorb electrical radiations of high frequency from the sun, radiating them at lower frequency; that is to say, the light from the tail may be due to phosphorescence.

The repulsion of the particles forming the tail when passing around the sun is probably due to electrical forces, although reflected sunlight may be in part the cause. As, however, the matter forming the tail is bombarded by electrified particles from the sun, electrostatic repulsion between it and the electrified surface of the sun is very likely the reason for the motion of the tail. However this may be, the cause is still unsettled and much more observation and experiment is required before a true theory is discovered.

Comets' tails are usually curved and as many as three distinct tails emanate from some comets, those most strongly curved being formed of the heaviest material. Observation proves that the repulsive force, whatever its cause, overcomes the gravitational and, acting on the surface of the tail particles, is relatively the more important the lighter these particles are, since any gravitational action of the sun is exactly proportional to the mass of each particle and independent of its surface area.

W. E. Miller

STARTING RESISTANCE FOR SERIES MOTORS

The article by Mr. E. R. Carichoff and Prof. Harold Pender on the determination of resistance steps for the acceleration of series motors, which appears on another page of this issue, forms an interesting and entirely new solution of a problem of much importance. In general, the steps in the starting rheostat of series motors are few in number, and it is essential that their value be accurately determined, as otherwise wide variations in starting current must result and a gradual and even acceleration will be impossible. While the lack of smooth acceleration is undesirable in nearly all classes of electric drive, it is particularly so where the motors are used for traction purposes. Here the sudden and uneven acceleration of the car is, as we all know, exceedingly annoying.

While a number of attempts have been made to deduce a rigid mathematical solution of the problem of determining starting resistances, the subject is somewhat complex and the present article is the first accurate mathematical solution that we remember to have seen. Generally speaking, in designing rheostats for new types of machines, the values for the resistance steps have been arrived at by trial by comparison with other cases that have been found sufficiently accurate with other motors. Graphical methods may be employed for the purpose, but these also involve trial and error. The present accurate analytical method should therefore prove of much value.

NOTES ON THE MAGNITUDE OF THE LOSSES INCIDENTAL TO THE TRANSFORMATION OF THE ENERGY IN COAL INTO ELECTRICAL ENERGY*

PART I

By Dr. Ernst J. Berg

The specific case of a 1000 kw. steam turbine station has been chosen to illustrate the heat balance in the conversion into electrical energy of the energy in coal.

It will be assumed that the combined efficiency of the turbine and generator is 65 per cent. and that the turbine is supplied with steam at 200 lbs. absolute pressure and 150° F. superheat; and, further, that the condenser pressure is 0.75 lb. absolute, or that corresponding to a 28.1 in. vacuum with a barometer pressure of 30 in.

The available energy in foot-pounds in each pound of superheated steam, when expanded adiabatically from a given pressure and superheat to the pressure of the vacuum, is the difference between the total heat input and that which is left as liquid heat and latent heat in the mixture at the lower pressure.

Thus

$$E = 778\,[H_1 + C_p t_1 - (q_2 + x_2 r_2)] \qquad (1)$$

where H_1 = total heat of sat. steam at initial press p_1

C_p = spec. heat of superheated steam

t_1 = superheat in ° F. at pressure p_1

q_2 = heat of liquid at lower pressure p_2

x_2 = quality of the steam at the pressure p_2

r_2 = latent heat at the pressure p_2

The steam tables enable us to insert all values in the above equation except the value of x_2. This quantity is known from the fact that the entropy is constant before and after the expansion; that is, the mathematical expression entropy, which is the ratio of the heat received to the absolute temperature of reception, is constant. The entropy of superheated steam

$$= C_p \log_e \frac{T_1 - t_1}{T_1} + \frac{r_1}{T_1} + \phi_1. \qquad (2)$$

The entropy of moist steam

$$= \frac{x_2 r_2}{T_2} + \phi_2; \qquad (3)$$

thus

$$x_2 = \frac{T_2}{r_2}\left(C_p \log_e \frac{T_1 + t_1}{T_1} + \frac{r_1}{T_1} + \phi_1 - \phi_2\right) \qquad (4)$$

In the particular instance referred to above we have—

p_1 = 200 lbs. abs.

p_2 = 0.75 lbs. abs.

H_1 = 1198.3 (from steam tables)

C_p assumed to be = 0.5

T_2 = 92.1° F. = 552.1° abs.

T_1 = 381.6° F. = 841.6° abs.

t_1 = 150° F. Superheat at p_1

r_1 = 813.4 latent heat at p_1

r_2 = 1049.8 latent heat at p_2

ϕ_1 = 0.5129 entropy of the liquid

ϕ_2 = 0.1152 entropy of the liquid

Thus

$$x_2 = \frac{552.1}{1049.8}\left[0.5\left(2.3 \log_{10} \frac{841.6+150}{841}\right) + \frac{813.4}{841.6} + 0.5129 - 0.1152\right] = 0.8 \qquad (5)$$

Substituting this value in the energy equation above we get—

$$E = 778\left[\left(1198 + (0.5 \times 150)\right) - \left(60.2 + (0.8 \times 1049.8)\right)\right] = 290{,}000 \text{ ft. lbs.} \qquad (6)$$

Since 1 kw. hr. is equivalent to

$\left(\frac{1000}{746} \times 33{,}000 \times 60\right) = 2{,}651{,}000$ ft. lbs., the amount of steam consumed per kilowatt hour under these conditions will be—

$\frac{2{,}651{,}000}{290{,}000} = 9.15$ lb., which is the theoretical water rate; but since the efficiency of the turbine is only 65 per cent., the real water rate will be—

$$\frac{9.15}{0.65} = 14.1 \text{ lb. per kw. hr.} \qquad (8)$$

Therefore the total flow for 1000 kw. hr. is 14,100 lbs. per hour. The total heat in each pound of superheated steam, assuming C_p = 0.5, is 1198.3 + .5 × 150 = 1273.3 B.t.u. (9) Thus the total heat of 14,100 lbs. is 14,100 × 1,273.3 = 17,960,000 B.t.u. (Since one kw. hr. corresponds to 3,410 B.t.u., the energy converted to electricity.) Therefore the energy not converted is 14,550,000, or 81 per cent. (10)

Some of these losses are caused by the generator windage, copper and iron losses,

* The first of a series of three papers read before employees of the Commonwealth Edison Company. The second and third papers will be published later.

THEORETICAL WATER RATE

for Various Values of Pressure, Vacuum and Superheat

SUPERHEAT F		200°	150°	100°	50°	0°
Lbs. Abs. Pres.	In. Vac.			Theoretical W.R.		
215	29	8.45	8.7	8.95	7.2	9.45
215	28	9.	9.25	9.5	9.75	10.
215	27	9.5	9.75	10.05	10.3	10.55
215	26	9.9	10.2	10.50	10.8	11.11
215	20	11.65	12.07	12.50	12.87	13.25
215	10	13.65	14.15	14.65	15.15	15.65
215	0	15.25	15.8	16.4	16.9	17.4
215	2 lb. bk. pres.	15.05	16.07	17.1	17.6	18.2
200	29	8.55	8.8	9.05	9.32	9.6
200	28	9.1	9.4	9.7	9.95	10.2
200	27	9.6	9.9	10.2	10.45	10.75
200	26	10.	10.32	10.65	10.97	11.3
200	20	11.75	12.4	12.8	13.2	13.6
200	10	14.	14.5	15.05	15.57	16.
200	0	15.6	16.2	16.9	17.4	17.9
200	2 lb. bk. pres.	16.3	16.9	17.5	18.	18.7
175	29	8.75	9.02	9.3	9.55	9.8
175	28	9.35	9.62	9.9	10.18	10.45
175	27	9.85	10.15	10.45	10.75	11.05
175	26	10.3	10.65	11.	11.3	11.6
175	20	12.4	12.82	13.25	13.65	14.05
175	10	14.65	15.77	15.70	16.25	16.8
175	0	16.4	17.35	18.3	18.6	18.9
175	2 lb. bk. pres.	17.1	17.75	18.4	19.1	12.8
165	29	8.85	9.12	9.4	9.63	9.86
165	28	9.45	9.72	10.	10.3	10.6
165	27	10.	10.32	10.65	11.	11.3
165	26	10.5	10.85	11.2	11.55	11.9
165	20	12.6	13.05	13.5	13.9	14.3
165	10	14.9	15.05	16.1	16.57	17.05
165	0	16.85	17.52	18.2	18.75	19.3
165	2 lb. bk. pres.	17.6	17.3	19.	...	20.3
140	29	9.12	9.37	9.65	9.9	10.2
140	28	9.75	10.05	10.35	10.65	10.95
140	27	10.3	10.62	10.95	11.28	11.62
140	26	10.85	11.20	11.55	11.95	12.3
140	20	13.1	13.6	14.1	14.6	15.1
140	10	15.8	16.4	17.	17.6	18.2
140	0	17.9	18.6	19.3	20.	20.65
140	2 lb. bk. pres.	18.6	18.95	20.3	21.	21.8
125	29	9.35	...	9.88	...	10.4
125	28	10.03		10.6	...	11.2
125	27	10.70		11.3	11.6	11.9
125	26	11.23		11.9	...	12.55
125	20	13.65		14.6	.	15.50
125	10	16.50		17.7		18.98
125	0	18.90		20.4		21.80
125	2 lb. bk. pres.	19.85		21.6		23.1
100	29	9.77		10.25		10.89
100	28	10.50		11.16		11.72
100	27	11.2		11.9		12.50
100	26	11.83		12.65		13.23
100	20	14.70		15.80		16.65
100	10	18.		19.45		20.7
100	0	20.9		22.28		24.25
100	2 lb. bk. pres.	22.15		24.25		25.82
Atmos. (14.7 lb.)	29	15.4		16.65		17.7
Atmos. (14.7 lb.)	28	17.65		19.1		20.4
Atmos. (14.7 lb.)	27	20.		21.8		23.3
Atmos. (14.7 lb.)	26	22.40		24.5		25.4
10 in. Vac. (10 lb.)	29	17.25		18.8		20.2
	28	20.20		22.1		24.2
	27	23.50		25.8		28.6
	26	26.95		30.		33.

and some by the bearings. These losses, which have nothing directly to do with the steam, amount to about 6 per cent. of the electrical output, or $0.06 \times 3,410,000 = 204,600$ B.t.u. (11)

The rest of the losses are found in the energy of the condensed steam, in the cooling water, in the friction loss in the turbine, in the heat convection and radiation from the turbine case, and in the condenser, piping, etc.

These losses thus amount to $14,550,000 - 204,600 = 14,345,400$ B.t.u. (12)

The temperature of the condensed steam at 28.4 in. vacuum, or 0.75 pounds abs. pressure, is, as seen from steam tables, 92.5° F. It is evident from our previous calculations that the exhaust is not superheated, i.e., contains in reality about 8.6 per cent. moisture, the actual moisture being less than that corresponding to adiabatic expansion on account of the re-evaporation of a part of the moisture by the heat caused by the rotation loss of the turbine wheels.

Since the combined efficiency of the turbine unit including the generator is assumed as 65 per cent. and as in all probability the generator has an efficiency of about 96 per cent., it is evident that the turbine efficiency is 67.8 per cent. The loss is largely all converted into heat and thus while the available energy is 290,000 ft. lbs. per lb. of steam, 32.2 per cent. is partially wasted as heat; that is, $.322 \times 290,000 = 93,500$ ft. lbs., or 120 B.t.u. Considering, for simplicity's sake, that all work was done in one single pressure stage or turbine, then the pressure in the stage would be 0.75 lbs. The latent heat at that pressure is 1050 B.t.u.; thus 120 B.t.u. evaporate 11.4 per cent. of the moisture and we obtain the value, 20 per cent – 11.4 per cent., or 8.6 per cent. as given above.

In returning the condensed steam to the boiler its temperature will drop slightly, due to conduction and radiation. This drop may be 7.5° F. The returned liquid heat of the water corresponds therefore to a temperature of 85° F. and is 53.06 B.t.u. Thus the total heat returned in the feed water is $53.06 \times 14,100 = 750,000$ B.t.u. (14)

The heat lost in the feed water is obviously

$7.5 \times 14,100 = 105,800$ B.t.u. (15)

Since the condensed steam at 92.5° F contains as liquid heat $60.7 \times 14,100 = 855,800$ B.t.u., it is evident that the cooling water contains $14,345,400 - 855,800 = 13,489,600$ B.t.u.

As the steam goes from the boiler to the turbine there is a loss of heat which will be found as a drop in superheat. This might be 50° F. so that the steam as it leaves the boiler has a superheat of 200° F. This loss in heat then represents

$50 \times 0.5 \times 14,100 = 352,500$ B.t.u. (17)

The boiler must therefore supply

$17,960,000 + 352,500 = 18,312,500$ B.t.u. (18)

Through the return of the feed water, however, we get 750,000 B.t.u.; thus the necessary coal corresponds to 17,562,500 B.t.u.

At a boiler efficiency of 80 per cent. this means that $\frac{17,562,500}{.80} = 21,953,000$ B.t.u. (20)

of coal must be supplied corresponding to an amount of 1690 lbs. per hr., or $\frac{21,953,000}{1,000 \times 13,000}$ $= 1.69$ lbs. of coal per kw. hr. with coal containing 13,000 B.t.u. per lb. (21)

Heat Balance	B. T. U.	Per Cent.
Boiler plant loss	4,390,500	20.0
High press. steam pipe loss	352,500	1.6
Rotation losses, gen.	204,600	.9
Electrical output, gen.	3,410,000	15.6
Cooling water loss	13,489,600	61.4
Heat lost in feed water	105,800	.5
Total	21,953,000	100.0

NOTES ON THE RELATIVE ECONOMY OF STEAM HEATING FROM AN INDEPENDENT LOW PRESSURE STEAM BOILER AND FROM THE EXHAUST OF THE STEAM TURBINE

Part II

To get some practical basis for comparison, it will be assumed that 1,000 kw. in electric power is wanted and that this power can be obtained from the turbine, even if it is operating non-condensing with a back pressure of 10 lbs.; that is, at an absolute pressure of 24.7 lbs. It will be assumed, as in the preceding case, that the initial pressure is 200 lbs. absolute and the superheat at the turbine, 150° F.; the combined efficiency of the turbine and generator being taken as 61 per cent. This efficiency is lower than that assumed in the first case, since the turbine losses due to rotation are greater. From equations (1) and (4) the following values are obtained:

$p_1 = 200$
$p_2 = 24.7$
$H_1 = 1198.3$
$C_p = .5.$
$T_2 = 239.5 + 460 = 699.5$
$T_1 = 381.6 + 460 = 841.6$
$t_1 = 150.$
$r_1 = 843.4$
$r_2 = 946.5$
$\phi_1 = .5429$
$\phi_2 = .353$

Substituting these values in (4) and (1) we get $x_2 = 0.94$ and $E = 137,600$ ft. lbs. per lb. of steam.

Thus the theoretical water rate is $\frac{2,654,000}{137,600} = 19.3$ and the actual water rate is $\frac{19.3}{.64} = 30.2$ lb. per hour.

With 1,000 kw. output, the flow is thus 30,200 lb. per hour. The total heat input is $1273.3 \times 30,200 = 38,454,000$ B.t.u. and the electrical output is 3,410,000 B.t.u. Thus the energy not converted into electrical energy is 35,044,000 B.t.u., or 91.2 per cent.

In carrying the investigation farther we will assume that the same percentage loss by various inefficiencies not connected with the steam part is 6 per cent = 204,600 B.t.u., and the remaining losses are therefore 34,839,400 B.t.u. This energy is available for steam heating and for heating the feed water. It may be assumed that the condensed steam returns from the radiators at a temperature of 85° F. and that this water is fed to the boilers. The liquid heat at this temperature is 53.06; thus the heat returned is $53.06 \times 30,200 = 1,602,400$ B.t.u., and the heat used for heating is:

$$34,839,400 - 1,602,400 = 33,237,000 \text{ B.t.u.}$$

To complete the heat balance, we may assume as before a drop in temperature of the superheated steam of 50° F., corresponding to 755,000 B.t.u. The boiler must thus produce 38,454,000 + 755,000 (the returned heat), or 37,606,600 B.t.u. With the boiler efficiency of 80 per cent., this corresponds to 47,008,200 B.t.u. from the coal, or with coal at 13,000 B.t.u. per pound, 3,616 lbs. of coal per hour for 1,000 kw. electrical output and 33,237,000 B.t.u. for steam heating.

If, instead of using exhaust steam, the turbine was run condensing and a special low pressure boiler of 24.7 lbs. abs. pressure supplied the steam required for heating, we would get the heat balance shown in second table following; assuming, as in the previous case, that 33,237,000 B.t.u. is needed for steam heating and 1,000 kw. electric power is obtained from a turbine operating with an initial pressure of 200 lbs. abs., 28.4 in. vacuum, and 150° F. superheat. It will also be assumed that the condensed steam from the heating

Heat Balance	B. T. U.	Per Cent.
Loss in boiler	9,401,600	20.0
Loss in steam pipes	755,000	1.6
Loss in radiation, etc.	204,600	.4
Electric energy	3,410,000	7.2
Heating purposes	33,327,000	70.8
Total	47,008,200	100.0

system is returned to the low pressure boiler at 85° F. We then have: B.t.u. required for heating = 33,237,000; B.t.u. required from coal at 80 per cent. boiler efficiency = 41,546,200. In other words, with coal of 13,000 B.t.u. per lb., 3.196 lbs. per hour is required for heating purposes.

Heat Balance for Low Pressure Boiler	B. T. U.	Per Cent.
Heating	33,237,000	80
Loss in boiler	8,309,200	20
Total	41,546,200	100

The coal required for one hour for heating by independent boiler and for furnishing 1,000 kw. from condensing turbine is, therefore, 3,196 + 1,690 = 4,886 lbs. per hour.

In comparing the two systems we have: For steam heating from turbine exhaust and 1,000 kw. electrical energy, 3,616 lbs. of coal per hour; and for steam heating from independent boiler and 1,000 kw. supplied by separate condensing turbine, 4,886 lbs. of coal per hour. In other words there is a saving by the first method of 1,270 lbs. of coal per hour, or 26 per cent. Incidentally, it is necessary to note that if all the coal required for steam heating in the second case is charged up to heating in the first case, we find that the coal required for electric power is only 3,616 − 3,196 = 420 lbs., or 0.42 lb. per kw. hr. This is but 24.8 per cent. of the coal required for the generation of electric power, even under the most favorable conditions of superheat and vacuum.

The calculations emphasize the desirability of steam heating from the exhaust steam and show numerically the magnitude of the gain.

GENERAL ELECTRIC REPAIR SHOP AND WAREHOUSE CHICAGO, ILL.

By John Liston

As a rule, modern electrical machinery and auxiliary apparatus are properly designed, are constructed of good materials, and embody a high standard of mechanical and electrical efficiency. Under normal conditions, uninterrupted service may be depended on, and protective devices insure immunity from injury due to overloads or temporary strains on the distribution system. Those parts subject to excessive wear can generally be easily replaced, and the average electrical installation is usually provided with a certain amount of reserve machinery which can be set up promptly if the regular equipment is injured.

Due to long continued service, excessive overloading or accidents, persons in charge of installations of any size are sooner or later confronted with the necessity of repairing portions of the equipment which are of vital importance and on which the necessary repair and replacement work cannot be properly done without experienced workmen and a suitable mechanical equipment.

Transformer and Regulator Repairing and Testing. South Bay

The construction of electrical machinery involves the use of special tools and must be supplemented by thorough testing. When repairs have to be made, the necessary operation can be most efficiently performed in a shop equipped solely for that class of work; having available, in addition, the services of men who are specialists in repair work and who have the necessary facilities and experience for making those mechanical and electrical tests which are essential in obtaining reliability in the future operation of repaired apparatus.

Receiving and Storage of Parts

It is evident that a plant so equipped, and with a record of many years of successful work in the repair of all classes of apparatus, can effect repairs more promptly and economically than the average shop, where

Winding a Field Coil in Repair Shop

the repair department is considered merely as an auxiliary and in which the cost of the special machinery required would not be justified by the value of the limited service ordinarily performed in repair work. It will therefore be of interest to all users of electrical apparatus in or near the city of Chicago to note the thoroughness with which the General Electric repair shop has been equipped, in order to handle promptly all classes of electrical repair work.

The repair shop is located in the Pugh terminal warehouse, which is the largest building of its kind in the world, being six stories in height, 1800 feet long, and of heavy mill construction throughout. It is located on the north pier facing the slip, and therefore has ready access to the lighterage facilities of the Chicago river. Three tracks of the Chicago & Northwestern Railroad run parallel to the building on one side for its entire length, while the basement contains a terminal of the Illinois Underground Railroad; thus ample facilities are available for receiving and shipping apparatus.

Two sections of this building having a total floor space of 155,000 square feet are occupied by the General Electric repair shop warehouse. The repair shop occupies the top floor and has a saw-tooth roof, which insures excellent lighting conditions by day, while numerous arc and incandescent lamps are provided to give ample illumination for night work.

The repair work handled in this shop covers all forms of electrical apparatus which have been built during the last twenty years, the larger part of which consists of generators, turbines, motors, motor-generator sets, rotary converters, railway apparatus, rheostats, controllers, compensators, current and potential transformers, regulators, meters and instruments, arc lamps, heating and cooking devices, mercury arc rectifiers, switch and panel boards and electrical supplies.

About sixty men are constantly employed and approximately twenty of these devote a large part of their time to outside repair, testing and construction work. Many of these men have given their time exclusively to repair work for a number of years, having had a variety of experience that renders them qualified experts in this line. Their knowledge of apparatus is not confined to that manufactured by the General Electric Company, but extends to types of

General View of Repair Shop

electrical machinery as built by practically all makers of electrical apparatus whose products have been on the market for the past twenty years. This fact is made evident by an inspection of the armature winding section of the shop, in which may be seen a variety of armatures of different types and date of manufacture from that of the old bi-polar Edison machines to the latest form of polyphase induction motors and generators. The advantage of having this class of labor to draw upon for the repair of machinery which is too bulky to be readily shipped to the repair shop, or for installation and repair work which can be easily done on the premises, is obvious, and as the men are divided into groups, each group confining its efforts to one particular line of work, an expert best suited for any given condition can usually be sent at once upon receipt of a customer's request.

It frequently happens that before deciding on the type of apparatus for a particular installation, a customer considers it advisable to observe the operation of different makes or types of machine in actual service. These can be temporarily installed in the testing section of the repair shop and their performance noted and compared.

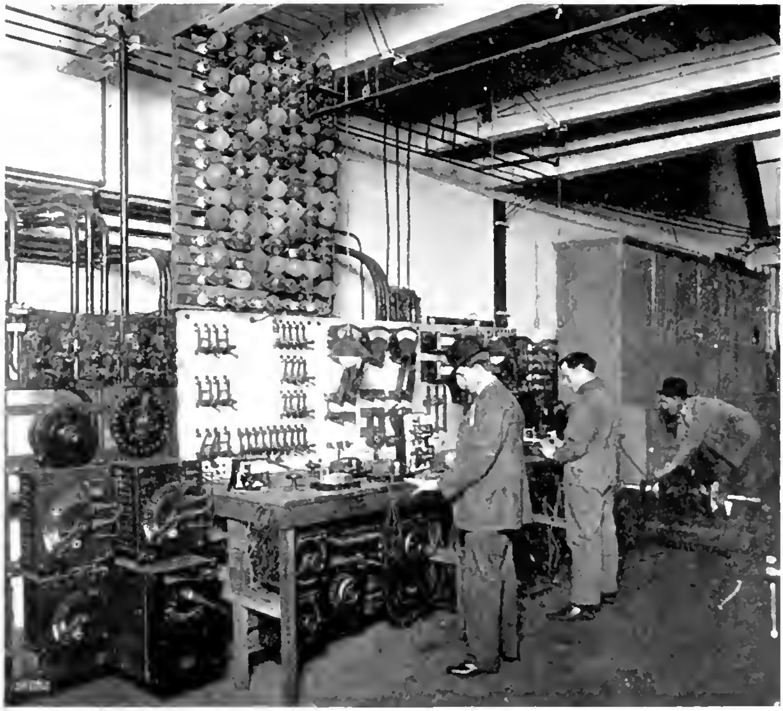
In order to provide current for testing different classes of apparatus, this section of the repair shop is provided with a very complete machine equipment. Direct current is received from the Commonwealth Edison Company's lines at 220 volts, and by means of motor generator sets direct current at 125, 250 and 500 volts is obtained. Alternating current at frequencies of 25, 60

Arc Lamp and Fan Motor Repairing and Testing

Multiple and Series Rectifier Tempering Furnaces and 125 cycles, and 110, 220, 440 and 2200 volts is also available.

For high potential tests, transformers are provided which step up to 50,000 volts and

The winding benches are served by monorail cranes, and the two main bays of the repair shop are provided with 5-ton motor driven cranes.



Meter and Instrument Testing Board

constant current transformers and regulators are also installed for arc lamp and regulator testing. The testing equipment includes a main switchboard and a switchboard for instruments and meter testing, suitable for instruments up to 3000 amperes capacity direct current and all frequencies and capacities alternating current. Special switchboards are used for arc lamp testing and for cooking and heating apparatus.

The re-winding of armatures constitutes a large proportion of the work done, and an expert crew of armature winders is always retained exclusively for getting out work of this kind on short notice. Form wound coils for standard machines are held in stock, and forms suitable for winding every variety of field coils are kept on hand. The machines for field winding and for banding armatures are motor driven and capable of handling work for any size armature up to six feet in diameter.

Steam Turbine Section

In the arc lamp section, rectifier sets, charging outfits, headlights and searchlight projectors of any size are repaired and refinished. The equipment includes an electric oil tempering furnace, and compressed air for brazing and cleaning is supplied by a standard General Electric motor-driven air compressor set.

A separate section of the repair shop is devoted to the testing of steam turbine generator sets and ample boiler capacity is available for sizes up to 100 kw.

Warehouse

In order to facilitate the prompt shipment of all standard apparatus, the General Electric Company has established in this building a completely stocked warehouse, from which shipments varying from 25 to 30 car loads per day are sent. The extent of the available stock is indicated by the following statements:

Incandescent Lamps in Warehouse

Steel Bins for Loose Stock

Under normal conditions there are on hand never less than 1500 power motors of all capacities up to 150 h.p., and about 10,000 fan motors. There is a very complete stock of wiring material, including sockets, receptacles, cleats, etc., together with rubber covered and weatherproof wire and overhead railway line material. There are approximately two million incandescent lamps boxed for immediate shipment, and various types of arc lamps for all commercial circuits. Current and potential lighting and power transformers are kept in sizes up to 50 kw., and a reserve supply of 5000 gallons of transformer oil is also maintained. The stock includes rectifier outfits for both lighting and battery charging and a complete line of heating and cooking devices.

For the storage of broken stock, such as instruments, heating and cooking apparatus, supply parts, etc., 4700 bins are used; nearly all of these are made of steel.

The heavy construction of the building makes it entirely safe to store the great quantity of relatively heavy apparatus, and an overhead motor driven monorail crane facilitates the storing of material and handling it for shipment.

The tunnel of the Illinois underground railroad runs the entire length of the building, and the railroad tracks of the Chicago & Northwestern railroad, located along the side of the building, provide rail space for 21 cars. About 50 men are employed in the warehouse, from which a large percentage of the less than-carload shipments of General Electric apparatus in the Chicago territory are made.

ELECTRICALLY DRIVEN PORTABLE ELEVATORS AND CONVEYANCES

Wherever it is necessary to handle large quantities of those commodities which are ordinarily transported in bales, sacks, boxes, barrels, etc., it is of prime importance that the work be done quickly and cheaply, especially in localities where labor is scarce or expensive.

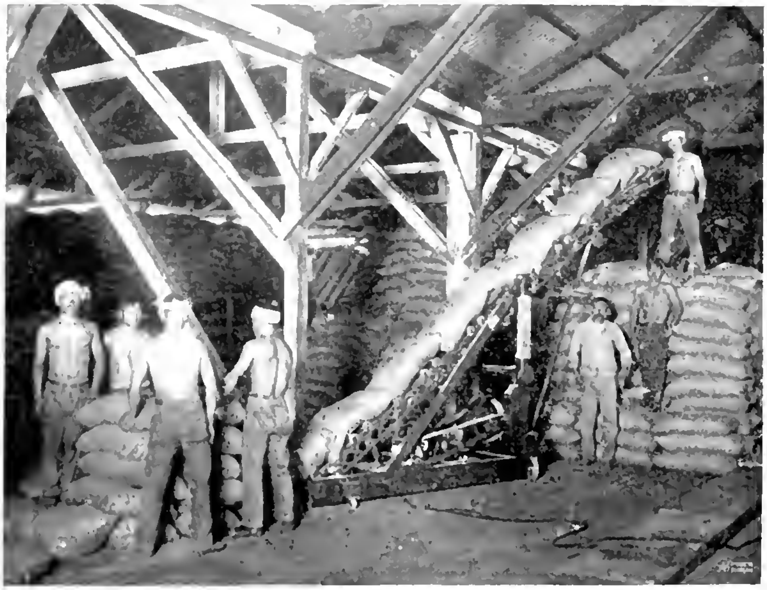


Fig. 1 Brown Portable Sack Elevator, Driven by 2 H.P. General Electric Motor Capacity, Twelve to Fourteen 150 lb. Sacks per Minute

Even in those localities where the cost of labor is a minimum, the accomplishment of this work by means of a motor driven portable elevator will still effect a large saving, although the cost of electric power be unusually high. The conditions which exist in the larger agricultural areas and storage centers of the country impose the necessity for very efficient transportation and handling facilities and have resulted in the invention and manufacture of some exceedingly valuable motor driven machinery for replacing the comparatively slow, unreliable and expensive handling by manual labor.

In the GENERAL ELECTRIC REVIEW for May, 1908, an article was published descriptive of two electrically driven portable elevators manufactured by the Brown Portable Elevator Co., Portland, Oregon. Additions have recently been made to this Company's line of elevators and conveying machines, which include a number of refinements in the matter of design, operation, etc., that will warrant an additional description in these pages.

Fig. 1 shows a Brown portable sack elevator having a capacity for piling from 12 to 14 150 lb. sacks per minute. This machine is driven by a General Electric 2 h.p. direct current motor, through a jack shaft and double belt. This motor is shown mounted on a movable base frame, which also carries

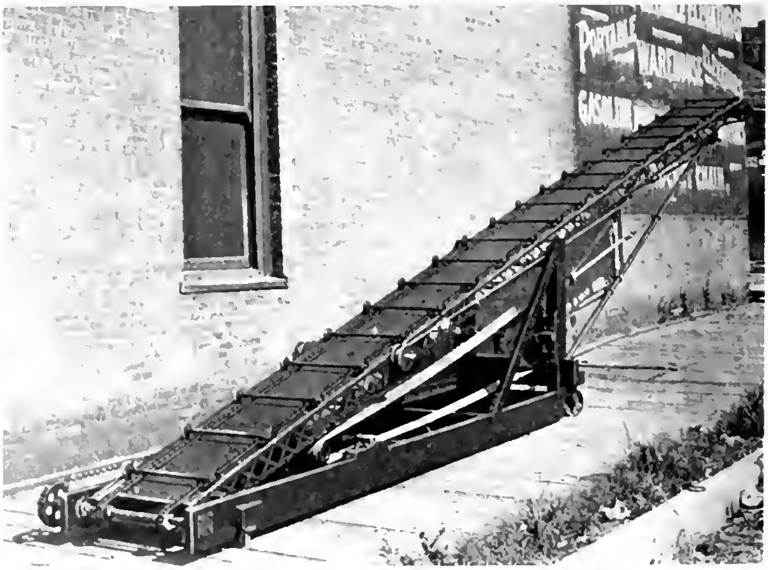


Fig. 2. Brown 5 Ton Standard Conveyor, Driven by General Electric Motor

Fig. 4. Brown Portable Elevator for Unloading Gondola Cars

the runway or conveyor platform and the necessary steel cables and winch head by means of which the height of the delivery platform may be varied.

Fig. 2 shows very clearly the general design of the Brown standard 5 ton conveyor. As will be seen, the main driving sprocket is keyed to a shaft upon which are mounted 2 small sprockets engaging two parallel chains, these chains supporting at intervals axles carrying small wheels which run on rails fastened to the steel lattice work forming the sides of the runway.

All these elevators are fitted with ball bearing castors which permit of ready transportation of the apparatus from place to place. Since the winch permits the carrier to be easily raised, the material which is being elevated may be delivered at any desired height.

The success which has attended the use of the sack elevator encouraged the manufacturers to develop a similar machine for elevating baled hay, straw, fodder, etc. This machine is shown in Fig. 3 and differs from its prototype (Fig. 1) only in that the conveyor platform is longer, this being necessary since bales are often piled to a height of from 30 to 35 ft. This elevator will raise from one to three tons of baled material per minute, and will serve equally well for the handling of produce in sacks.

In the agricultural districts of the country, grain is shipped largely in open gondola cars. For loading or unloading such cars, the portable conveyor shown in Fig. 4 is used, the runway of which may be operated in either direction by simply reversing the direction of rotation of the driving motor.

Brown portable elevators of the latest models are now made in a variety of sizes and types, the smallest of which weighs 900 lbs. and is driven by a 2 h.p. motor. This machine has a maximum rise of runway of 14 ft. and a capacity of one ton per minute. The largest standard size (Fig. 2) is equipped with a 5 h.p. motor and will lift 5 tons per minute to a height of 25 ft. Special machines are built to order.

Fig. 3. Brown Portable Elevator with Extra Long Conveyor Platform

The profit to be derived from the use of the Brown portable elevators is shown by the following example:

To pile 300 tons of sacked grain in one day requires the services of 15 men, assuming that each man can handle 20 tons per day. At a wage rate of $2.00 per man per day, the labor cost is therefore 10 cents per ton, or $30.00 per day. The same work when performed by a Brown portable elevator will cost, with current at 5 cents per kw. hour, approximately as follows:

Electric energy for 3 h.p. motor operating at 50 per cent. load factor 10 hours per day	$1.35
Three men at $2.00 per day	6.00
Total	$7.35
Net saving per day	$22.65

This saving might be materially increased if the elevator were operated at its maximum capacity of 7,000 sacks per day, or approximately 525 tons.

Brown portable elevators were originally designed to be driven by internal combustion engines, and in certain sections of the country where electric power is still unavailable, these engines are used. However, where electric power can be had, the electric motor is naturally the preferable form of drive, owing to its greater reliability, simplicity and facility of control, and to the reduced fire risk resulting from its use.

SOME CONSIDERATIONS AS TO THE NATURE OF COMETS AND THEIR PROBABLE RELATION TO THE SUN*

By Prof. Elihu Thomson

The ideas herein put forward are not all original with the author, though it is believed some of them may be. It is hoped that the considerations may, however, help to a simple rational understanding of the major facts regarding the behavior of comets.

The exceedingly high temperature of the sun causes it to be surrounded by an atmosphere of vapors. Some of the vaporized matter condenses in the outermost layers and eruptions are constantly occurring which partly fill the space around it with very fine particles, the smaller of which are repelled by the pressure of the sun's radiation, which pressure even overcomes the gravitative force of the sun itself. These ejected particles probably constitute the streamers which are visible during total eclipses as extending outwardly from the sun to immense distances. What we see is the effect of innumerable overlapping streams. Their extreme tenuity is evidenced by the comparatively feeble luminosity, in spite of the great depth of the flux which we are at any time observing. This depth is, of course, greater than the diameter of the sun. Such corona streamers are by no means uniformly distributed about the sun, but in certain directions varying continually may be more dense than in others, coinciding perhaps with great eruptive areas of the sun's surface. It probably happens that when the outbreak is unusually violent, and when the earth happens to be passing through that part of space occupied by an abnormally extended streamer, an aurora of greater or lesser intensity or duration may attend the sweeping of the earth by such a streamer. The particles are probably ions, or carry electric charges, and induced auroral streamers in the earth's atmosphere are for the time being visible on its dark side away from the sun.

It has been thought that comets may act in a somewhat similar way to disclose the condition of the ejected material of the sun, or, as may be conceived, to disclose a stratification or unevenness of distribution of the ejected matter from the sun. Since there is reason to believe that much of this matter is in a highly electrified state, it is not to be doubted that electrical phenomena are at the same time produced, with accompanying evolution of light. Indeed, in the free space around the sun, there must be a great intensity of ultra violet radiation, which of itself would cause emission of negative ions from matter in its path and produce electrical disturbances. But, aside from this possibility, the comet is recognized as an assemblage of particles, larger or smaller, moving in an orbit which involves great variations of its distance from the

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sun. In passing through the depths of space far away from the sun, these parts or particles may tend, by their feeble gravitative effect, to gather up any finer particles which, on account of the intense cold of space, are substantially solid, even though at ordinary temperatures they would be gaseous. The parts of the comet's nucleus more or less porous would, in this way, accumulate upon their surfaces and in their pores occluded gases, condensed material and fine dust; and there would be a period of many years in which this gathering up process, as in the case of Donati's and other long period comets, would occur.

Let a comet, as an assemblage of such small masses, after its long course through remote space, during which it has gathered fine particles ejected from the sun or from other bodies, reach, in approaching the sun, a part of its orbit where the temperature, given by the solar radiation to the surfaces of the masses, is sufficient to boil off or regasify the condensed material; then not only is the gas blown off into vacuous space around the nucleus of the comet, but it is naturally blown off in the direction towards the sun, from the heated side of each mass, and at the same time that the gas leaves the mass, other fine particles are lifted by the force of the escaping gas. This is due to the fact that these fine or dust-like particles are not held with any strong gravitative tendency. Ultra violet radiation may also add its effect in causing discharge of negative ions. The result of this is that jets or flows of materials from the nucleus tend into the vacuum towards the sun from the warmed or radiation absorbing surfaces of the comet's nuclear masses. As soon as they leave the nucleus or the warmed surfaces, they are again cold and mainly condensed. But though exceedingly fine they are now absorbers, more or less solid, of the sun's radiation, and are gradually thrust backward by the pressure of the light and radiation, and are blown off in the opposite direction by this pressure, so forming a tail in the contrary direction from the sun, or in a direction opposite to that in which they were first ejected.

There being in matter all grades of volatility, as the cometary body approaches the sun, material more and more refractory, so-to-speak, is evolved, until finally, if the approach is near enough to the sun, even ordinarily solid substances will be vaporized from the nuclear masses and projected to form a tail, as has just been described. Some of this vaporized matter will immediately condense on getting a little farther away and form solid particles in the tail. The comet of January, 1910, showed sodium lines, showing that the temperature of the nuclear masses had probably reached the vaporization point of sodium. The greatest extension of a comet's tail usually comes just after the comet passes perihelion, because the heating process keeps on, as it were, a little past perihelion; just as the hottest parts of our summer days are two or three o'clock in the afternoon.

Now, if the comet stays in proximity to the sun long enough, it will have discharged nearly all of its volatile material for a particular temperature reached. But on leaving the sun after the tail has shrunk, (which is a very natural thing for it to do when the body passes through regions less heated by solar rays), it may again be in the condition to gather up the condensed and practically solid gases and vapors in the space around it. And if its period is a long one, such as 2000 years, as in the case of Donati's comet, it should not surprise us if there is sufficient material to form a fair tail, which only lasts a few weeks at the most.

Then it must be borne in mind, too, that an extremely small amount of material diffused in space under solar radiation will suffice to form a very large tail, as every particle, even of extremely small mass, becomes substantially a light source. Take for instance the amount of tobacco smoke that can cloud up a room when the sun is shining in it, and it will be found to be a very small quantity; but, if the room be black as night, and a hole be made in a shutter through which a small beam of sunlight enters, and the minutest body of smoke be diffused in the room, there will be a "comet's tail" extending from the opening across the room where the sunbeam passes, because it will be seen in the blackness, and that is the condition of our seeing comets' tails in the darkness of night. Then we must remember how deep the space is which is occupied as a visible thickness in a comet's tail, say 150,000 miles. We thus get an idea of how *free* of particles space must be ***not*** to shine with a luminosity equal to that of a comet's tail when we look off into the dark night irradiated by the intense solar beams.

Doubtless the simple view here given is complicated by many other actions, electric, etc. Comets' tails sometimes vary greatly and rapidly. We need not be surprised at this when boiling points are known to be critical: when, in other words, a few degrees increase in temperature may vaporize a substance which would not otherwise have been vaporized. Furthermore, it is quite possible that the comet in moving around the sun, entangles itself in the stream of material driven from the sun, and varies in its effect in accordance with its being or not being in a solar streamer more or less dense for the time being, speaking relatively. It is easily conceivable that an assumed stratification of space may be a cause of variations of comets' tail brightness. Putting it properly, it is conceivable that a comet may act as an indicator of the condition of space around the sun, the space in which the comet, for the time being, is moving. Even under the idea that there is volatile matter emitted from the sun which ordinarily would not be visible, let such matter strike into the nucleus of a comet and meet matter from the comet itself, it is easily seen that interactions, electrical or otherwise, or even physical collisions, may add to the light of a comet's tail.

The chief point, however, which I have endeavored to emphasize by the comparisons above made, is the excessive tenuity of the matter which would be sufficient to give rise to a brilliant appendage to a comet, and the exceedingly small amount of volatile matter needed. This fact renders it possible that the comet may, in the lapse of many years, replenish itself in the depths of space and may account for the fact that at each return to close proximity to the sun, a tail is developed. Otherwise, since the matter of the tail certainly does not return to the comet, it would seem that the volatile matter would be distilled off and lost in very few perihelion passages.

In regard to the predicted sweep of the earth by the tail of Halley's Comet on May 18th, it is evident from the accounts that have been received that such passage of the earth through the comet's tail did not occur on time. It was evidently more gradual than was anticipated and was delayed for two or three days. This is not to be wondered at, for the reason that in viewing a comet like Halley's, the orbit lies in the general plane of the earth's orbit, or not many degrees inclined thereto. We see the tail straight, although if we could see it from a position at right angles it might be heavily curved. Theoretically, the material which forms the tail, having been expelled from the nucleus and driven backward, the portions of the tail farthest from the comet would naturally correspond to positions of the comet farther back in its orbit; hence the stream of material would have a bend backward as the comet advances. Not only is this the case, but from the fact that without doubt the material of the tail consists of particles of varying size and density which would be repelled backward at different velocities, the curvature would vary with the size and velocity of the particles expelled, which would have the effect of broadening out or fanning out the tail into a sort of curved fan-like appendage in the plane of its orbit, or making multiple tails. From our position this would be impossible to observe, but it would account for the apparent fact that the earth took a considerable time to traverse this broadened out tail bent strongly backward. This would also account for the fact that parts of the tail might be seen in the east even after the nucleus had passed the sun, and would also explain why parts of the tail were seen in the west while there was an appearance of some of the remaining material of the tail in the east. In such case, the earth would really be in the position of passing through the spread out curved tail and the passage might take two or three days.

At the present writing, May 26th, the tail of Halley's Comet is completely seen in the west after sunset, and is apparently straight, which, of course, is due to a line of vision coinciding nearly with its direction of recession. The telescope shows the nucleus to be of only moderate size, a few hundred miles in diameter at the most, and that in the direction towards the sun there is a great emanation of matter which is luminous and which forms a bright cloud for a considerable distance around the nucleus on the side towards the sun. This is, however, seen to bend backward and apparently form the elongated tail which expands for many degrees away from the sun and has a very considerable breadth.

DISTRIBUTION OF ELECTRIC ENERGY TO INTERURBAN POINTS FROM A SMALL CENTRAL STATION

AS EXEMPLIFIED BY THE HILLSBORO ELECTRIC LIGHT AND POWER COMPANY

By C. R. Croninger

The Hillsboro Electric Light and Power Company, of Hillsboro, Ill., capitalized at $63,000 and bonded for $12,000, furnishes electric current to the towns of Hillsboro, Coffeen, Irving, Witt, Raymond and Harvel, all situated within a radius of 20 miles from the power house at Hillsboro and possessing a total population of 8700 inhabitants. The property held by the Company represents a total investment of about $92,400, and the gross receipts for the year 1909 were $42,707.19.

The transmission lines supplying these towns have an aggregate length of about 40 miles and some 160 kw. in stepdown transformers is connected thereto. The diagram and accompanying data on the following page have been prepared to show the arrangement of the lines and to give concise information relating to the several installations: length and cost of lines, cost of substations and apparatus, number of customers (lighting or power specified), number and sizes of motors, etc., etc., are given.

The lines are fed from a 90 kw. engine-driven single-phase alternator, through two 75 kw. transformers; this apparatus, together with a spare alternator of 200 kw. capacity and a 35 kw. constant current transformer, being located in the power house at Hillsboro. This constant current transformer supplies current to 38 arc and 33 75-watt series incandescent lamps for lighting the streets of Hillsboro; the multiple incandescent lighting system of this town receiving its current direct from the alternator bus bars at 1100 volts. Thus it is seen that apparatus with a total rated capacity of more than 185 kw. is directly supplied with current from the one 90 kw. generator—a fact that is interesting and perhaps somewhat surprising.

Current is generated at a potential of 1100 volts and is delivered to the transmission lines at 16,500 volts. At the receiving ends of the lines, the voltage is stepped down to 2300, at which potential the local distribution systems are supplied. Current for Harvel is obtained at a potential of 2300 volts from the secondary windings of the transformers at Raymond, distant four miles.

The transmission lines, with the exception of the one from Hillsboro to Coffeen, are all of No. 8 B.&S. hard drawn copper wire strung on wooden poles; the line to Coffeen being of No. 6 copper wire strung on 30 ft. white cedar poles with 6 in. tops. In future the Company will construct all new lines of No. 6 B.&S. wire or larger; in fact, it has seriously considered the adoption of No. 4 B.&S. as standard.

The average cost per mile for all lines was $353.22. The total cost of the Coffeen line was $5,145.00, made up as follows:

1½ miles 40 ft. pole line in town	$690.00	
Labor on same	204.00	
6½ miles 30 ft. pole in country	1826.00	
Labor on same	468.00	
		$3188.00
Substation at Coffeen	$400.00	
2—50 kw. transformers	900.00	
1—Lightning arrester	180.00	
1—Wooley arrester	107.00	
1—Switchboard	140.00	
1—Time switch	45.00	
		1872.00
Trees bought	$52.00	
Private right of way	33.00	
		85.00
Total cost of line		$5145.00

The Coffeen line is the most modern of all the lines, and although the others were constructed along public highways under permit of the County Board, the Company believed that it would be to its advantage to construct this line over a private right of way. Upon investigation, it was found that this privilege could be secured at a cost of 35 cents per pole, and the necessary steps were taken to acquire the right of way.

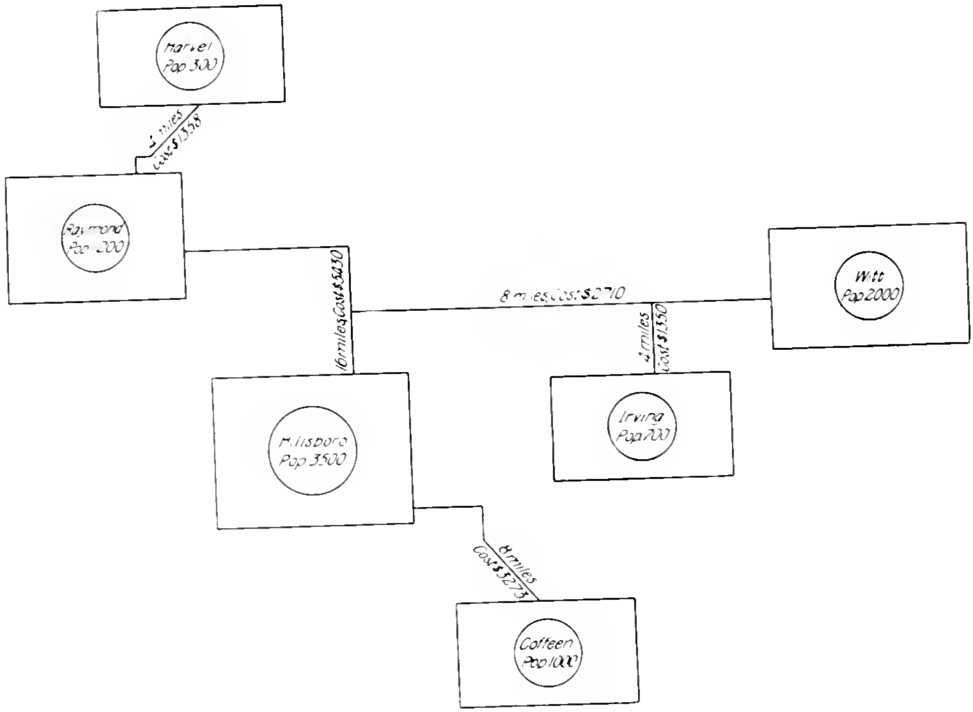
The Company has adopted a uniform system of rates, as follows:

Series arc lamps, 6.6 amps., all night moonlight schedule	$72.00 per yr.
Series Mazda lamps, 75 watt, 6.6 amps., all night moonlight schedule	24.00 per yr.

(Towns to renew lamps at own expense.)

Lighting, 15 cts. per kw-hr. for first 15 hours and 10 cts. per kw-hr. for all quantities in excess of this amount; minimum charge per meter per month, 50 cts.

Power, 6 cts. per kw-hr. maximum, and 3 cts. per kw-hr. minimum.



HILLSBORO

Capital stock, $63,000.
Bonds, $12,000.00. Distribution, $15,300.
Cost power plant, $27,120
Coal, slack, $1.00 per ton delivered in bin.
Water, $0.03 M gallons
1– 90 kw., 60 cycle, 1100 volt single-phase generator.
1–200 kw., 60 cycle, 1100 volt single-phase generator.
2–75 kw., 1100/2200/16,500 volt stepup transformers.
1–35 kw., 6.6 amp. constant current transformer.
City contract. Schedule moonlt. all night.
38–6.6 arc lamps, $32 per year.
33–75 watt series inc. lamps, $24 per year.

Commercial customers	123
Residence customers	340
Power customers	12
Total customers	475

Motors connected 58½ h.p.

HARVEL

Cost of substation and distribution, $1976.
Receives 2300 volt current from Raymond.
City contract. Schedule, moonlt. all night.
27–75 watt series inc. lamps, $24 per year.

Commercial customers	12
Residence customers	33
Power customers	3
Total customers	48

1–35 h.p. motor. Brick and tile works.
1– 5 h.p. motor for blacksmith shop.
1– 5 h.p. motor for blacksmith shop.

RAYMOND

Cost substation and distribution, $6795.
1–40 kw., 1100/2200/16,500 volt stepdown [illegible]
1–12 kw., 6.6 amp. constant current transformer.
City contract. Schedule moonlt. all night.
17–6.6 amp. arc lamps, $75 per year.
12–75 watt series inc. lamps, $24 per year.

Commercial customers	36
Residence customers	65
Power	2
Total customers	103

1–30 h.p. motor. Elevator.
1–10 h.p. motor. Tile and cement plant.
Labor one man, $50 per month.

IRVING

Cost of substation and distribution, $1229.
1–20 kw., 1100/2200–16,500 volt transformer.
1– 4 kw., 4 amp. constant current transformer.
City contract. Schedule moonlt. all night.
29–75 watt series inc. lamps, $24 per year.

Commercial customers	14
Residence customers	46
Power customers	1
Total customers	61

1–10 h.p. motor. Feed store.

WITT

Cost of substation and distribution, $4,554.
1– 4 kw., 4 amp. constant current transformer.
1–50 kw., 1100/2200/16,500 volt stepdown transformer.
City contract. Schedule moonlt. all night.
25 watt series inc. lamps, $24 per year.

Commercial customers	35
Residence customers	73
Power customers	3
Total customers	111

1–30 h.p. motor. Elevator.
1– 3 h.p. motor. Blacksmith shop.
1– 3 h.p. motor. Baker.
Labor one man, $60 per month.

COFFEEN

Cost of substation and distribution, $7391.
1–50 kw., 1100/2200/16,500 volt stepdown transformer
City contract. Schedule moonlt. all night.
18 multiple 5 amp. arc lamps, $72 per year.

Commercial customers	25
Residence customers	80
Power customers	2
Total customers	107

1–15 h.p. motor. Elevator.
1– 1 h.p. motor. Livery stable.
Labor one man, $15 per month.

Motors aggregating 150 h.p. are connected to the Company's lines in the various towns, and 50 per cent. of these by rating are employed for operating grain elevators that were formerly equipped with steam plants. This industry offers the most extensive and profitable field for the sale of power in small towns situated in this section of the country.

In connection with the electric power plant at Hillsboro, the Company has installed a 20 ton ice making machine and a system for steam heating. These three enterprises are carried on in one building, and the Company is therefore able to generate electric current at a very low cost per kw-hr.

At one time this Company sold current to the system at Witt, which was then operated by an independent concern, at the rate of 5 cents per kw-hr. for the first 2000 kw-hrs. per month, 4 cents for the next 2500 kw-hrs., and 3 cents for the balance. The Witt Company did not find this profitable business and therefore sold out to the Hillsboro Electric Light and Power Company, after which current was billed through the home office, as in the case of the other towns.

Time switches have been installed on the incandescent and series arc circuits in all the towns but Hillsboro, and ordinarily the attendant has no duties to perform for the Company other than to keep the switch wound. The total cost of inspecting the transmission lines and supervising the distribution in the five outlying towns is only $125.00 per month, or an average of $25.00 per town.

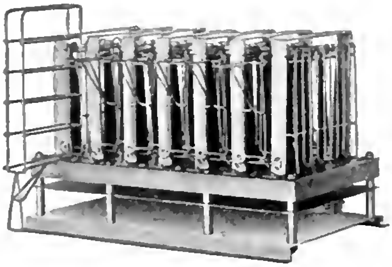
The total output, as recorded by meters on the switchboard at Hillsboro, when checked against the total current sold and accounted for, shows 28 per cent. loss in lines, transformers and meters.

When considering a plant of rather limited equipment, the question of reliability of service naturally arises. By a careful system of line inspection, the Hillsboro Company has been able to keep the interruption of service down to a minimum, and from the time when the transmission line was first put in operation (1905) to the present, there has been but one night when the towns were without current. The trouble on this occasion was caused by a defective insulator, but since that time double petticoat insulators designed to withstand 40,000 volts have been substituted for the old style ones and no further trouble of this kind has been experienced.

At present, three other neighboring towns, with a total population of 5000 people, are negotiating with the Hillsboro Electric Light and Power Company for service. One of these towns, the population of which is perhaps 2500, has a plant already installed, and at the rates quoted by the Hillsboro Company, the management believes that it will be more profitable to purchase current from the above concern than to generate it themselves, since their customers demand a 24 hour service. In this case, the Hillsboro Company will erect a transmission line at its own expense and will install a primary wattmeter in the customer's station, thereby assuming all line and transformer losses.

ELECTRIC TOASTER FOR HOTELS AND RESTAURANTS

The ordinary method of making toast by a coal or charcoal fire does not always produce satisfactory results, for when this work is to be done, it is often found that the live coals have been covered with a fresh supply of fuel, or else that the fire has burned out and is more or less covered with ashes.



Hotels and restaurants are daily required to furnish large quantities of toast which must be prepared on short notice, and it is to the interest of all establishments of this nature to avoid conditions in its cuisine, such as the above, which are prone to result in dissatisfaction.

A six-slice toaster designed specially for hotels and restaurants has just been placed on the market by the General Electric Company. The use of this device insures warm, crisp toast, and the freedom from all soot, ashes, and delay in waiting for the fire to come up.

The operating units consist of vertical coils such as are used in the two-slice toaster, and the toasting is accomplished by means of radiant heat, the maximum temperature being almost instantly available when the current is turned on. It is not necessary to turn the slices of bread, as the heat acts upon both sides of each slice at the same time.

This larger toaster has a maximum capacity of six slices, each slice being placed in a hinged wire rack located between two rows of heating units. Each rack is provided with a wire handle projecting from the top edge, which, when depressed, swings the rack upward and out from between the units. There are thus seven rows of heating units, each row consuming 500 watts and consisting of four vertical heating elements. These rows are arranged in two sections, one of three rows and the other of four rows, it being possible to operate either section alone or in conjunction with the other. Thus two, three, or six slices of toast may be made at one time. The device will produce six slices of toast per minute.

SMALL VENTILATING OUTFITS

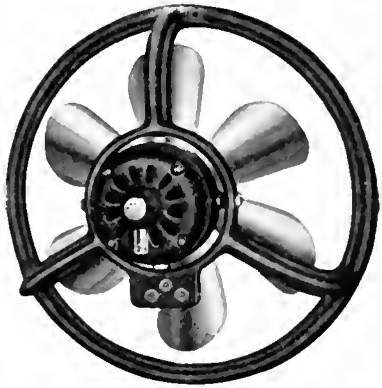
By R. E. Barker

To procure fresh air and to keep it in circulation is a problem of particular interest to those who are compelled to be either temporarily or permanently indoors. In summer especially, and in low and inland

12-Inch Direct Current Ventilating Outfit

sections of the country, arrangements for good ventilating become a matter of business necessity in order to render a store, shop, or factory habitable during the hot months. Good ventilation is equally important where large numbers of people congregate, as in audience rooms, banquet halls, clubs, etc.

Where it is desirable to remove small quantities of air, the General Electric Company is prepared to furnish ventilating fan



12-Inch Alternating Current Ventilating Outfit

outfits, with either 12 or 16 inch fans, for alternating or direct current circuits of standard voltages and frequencies. These outfits are useful in offices, kitchens, dormitories, shops and stores, and are shipped complete ready for operation, with motor, fan, and tripod. Speed controllers are included with the alternating current outfits and may be furnished as extras with the direct current outfits.

The sets are self contained, quiet in operation and comparatively small. Consisting, as they do, of a fan mounted on the same shaft with the motor armature, no power is lost as with a belt or other form of transmission. One of these outfits may be installed in a transom or window, and its operation controlled from any convenient point by means of the controller.

Fig. 1 illustrates a typical example of an up-to-date installation of a twelve inch alternating current outfit with combined starting and speed controlling device giving three speeds

All of our larger cities afford a ready field for the use of the sets described, for ventilating hotel dining rooms, restaurants, cafes, kitchens, saloons, billiard parlors, business

Installation of 12-Inch Alternating Current Ventilating Outfit

offices and accounting rooms, garment manufacturing and tailoring establishments, newspaper offices, job and book printers, binderies, laundries, dyeing houses, and paper, box and tobacco factories.

The alternating current motors are of the induction type, while the direct current motors are series wound. All these motors are fitted with six blade fans properly shaped to provide a good displacement of air.

Alternating current motors are offered for the usual commercial voltages, for 60, 40 and

Combined Starting and Speed Controlling Box

25 cycle circuits, while the direct current motors are supplied for 110 and 220 volt circuits.

The combined starting and speed controlling device, which forms a necessary part of the alternating current outfit, is built in a cast iron box similar to that used for the direct current controller. A substantial and attractive case contains the regulating reactance and indicating lever switch. This switch has four points and provides for three running speeds and an "off" position. The direct current controller contains a resistance made of a material which has unity temperature coefficient and which is permanent in character. Connections between the two devices are simple: one line wire runs to the motor and the other to the controller, the remaining connections being made between motor and controller—two leads for the alternating current and one lead for the direct current outfit. This arrangement permits the installation of the controller at any convenient place independent of the location of the motor.

By means of the controller the speed of the fans can be regulated to suit the conditions of the individual installations, such as quiet running, reduced air delivery, etc. A noteworthy feature of these motors is the reduction in the energy consumption with a reduction in speed, the energy required being approximately proportional to the speed.

These sets are carefully made and well finished. The best testimonial for these devices is the growing demand made for them by the public.

PRODUCER GAS POWER*

By C. L. Straub

The trend of feeling by the engineering fraternity toward gas power has undergone a marked change during as recent a period of time as the last five years. Five years ago gas power plants were installed by men who were classed among the profession as pioneers and visionaries; to-day it is only the uninformed engineer or promoter who contemplates the installation of a power plant without investigating the merits of gas power before making his decision, and rare indeed are the recent installations of power apparatus where the internal combustion engine has not had the weighty and careful consideration it merits.

Only six years ago I had an experience which illustrates the fact stated in my opening remark. I was a party to the sale of a 1400 h.p. gas engine that was to be used for the generation of street railway current. I enthusiastically wrote a literary friend, Mr. Henry Wallace Phillips, who spent his summers fighting with a small gasoline engine launch, advising him of the sale. He answered as follows: "When I learned that a man had bought a 1400 h.p. gas engine, I felt so bad I could have wept. I thought language ran out at about 10 h.p.; personally I find myself at a loss for words with 1½ h.p. on warm days."

It is an indisputable fact that through the persistent and tireless efforts of many capable men the internal combustion engine and its attendant gas producer have been brought to such a remarkable state of perfection that for economy and reliability of operation it has no superior. I know of a number of plants fitted with gas engines and producers where the operation is habitually on the basis of from 60 to 90 twenty-four-hour days per run, each engine carrying from 50 to 100 per cent. of its rated load and sometimes an overload; the units being shut down at regular intervals for inspection and minor adjustments, and again immediately cut into service on the weary grind. Among such plants may be mentioned the following:

American Smelting and Refining Co., Santa Barbara, Chi. Mex., where seven 300 h.p. American Crossley engines and down draft producers are installed.

Milwaukee Northern Railway, Port Washington, Wis., equipped with two 2000 h.p. Allis-Chalmers engines and down-draft producers.

Swift & Co., Bartow, Florida, equipped with three 250 h.p. Rathbun engines and down-draft producers.

Iola Portland Cement Co., Dallas, Texas, equipped with four 1100 h.p. Snow engines and down-draft producers.

American Bridge Co., Pencoyd, Pa., equipped with one 400 h.p. Snow engine and up-draft producer.

Messrs. Crossley Brothers, Manchester, England, point with well deserved pride to one of their 300 h.p. engines which operated on producer gas carrying from 20 to 100 per cent. of rated load for a solid year of 365 twenty-four-hour days, without a single shut-down in that time. I have never heard of any other form of prime mover but a water wheel, if that may be considered as a prime mover, that came anywhere near this record.

The question of fuel consumption in producer gas power plants is a much mooted one. I beg to submit a few authentic records.

Boston Elevated Railway Co., Sommerville, Mass., equipped with:

Two single acting double cylinder horizontal American Crossley engines, 750 h.p. each. Engines direct connected to 550 volt direct current generators.

One 1500 h.p. down-draft bituminous gas generating plant operating on West Virginia coal. The service is 20 hours run daily with one engine in service all day, the other engine in service during the morning and evening peak loads.

One 30 day commercial test showed 1.31 lbs. of fuel per kilowatt hour on the switchboard; one 60 day commercial test showed 1.34 lbs. per kilowatt hour on the switchboard; one 90 day commercial test showed 1.42 lbs. of fuel per kilowatt hour on the switchboard; and one year's record, on the basis of less than 20 per cent. station load factor, showed 1.66 lbs. of fuel per kilowatt hour.

Milwaukee Northern Railway, equipped with:

Two 2000 h.p. twin tandem double acting Allis-Chalmers engines, direct connected to two 1300 kw., 3-phase, 60 cycle alternating current generators.

Two 2000 h.p. down-draft bituminous gas generating plants. Service, 24 hours daily for one engine; the other engine in service during the peak loads, averaging 8 hours per day.

Record of fuel charged to the plant and kilowatt output at the switchboard for the year on a 12 per cent. station load factor shows 1.97 lbs. per kilowatt hour.

Swift & Company, Bartow, Florida, equipped with:

* From a paper read before Schenectady Section A.I.E.E.

Three 250 h.p., 3 cylinder vertical single acting Rathbun engines direct connected to 60 cycle alternators.

One 750 h.p. bituminous gas generating plant.

Two 30 day commercial tests on West Virginia coal showed an average of 1.26 lbs. of fuel per kilowatt hour on the switchboard at an 80 per cent. load factor.

A full year's run on 40 per cent. load factor showed 1.56 lbs. per kilowatt hour.

If time permitted it would be possible to quote many other plants of various sizes with equally good records, and it is not amiss to emphasize here that, contrary to steam plant practice, the economy of a gas producer engine varies but little with the size. To my knowledge, engines as small as 80 h.p. are habitually producing a brake horsepower-hour on less than 10,000 B.t.u. in gas consumed.

The large gas engine is indebted to the gas producer, more than to any other element, for its economy, wonderful development and rapid adoption.

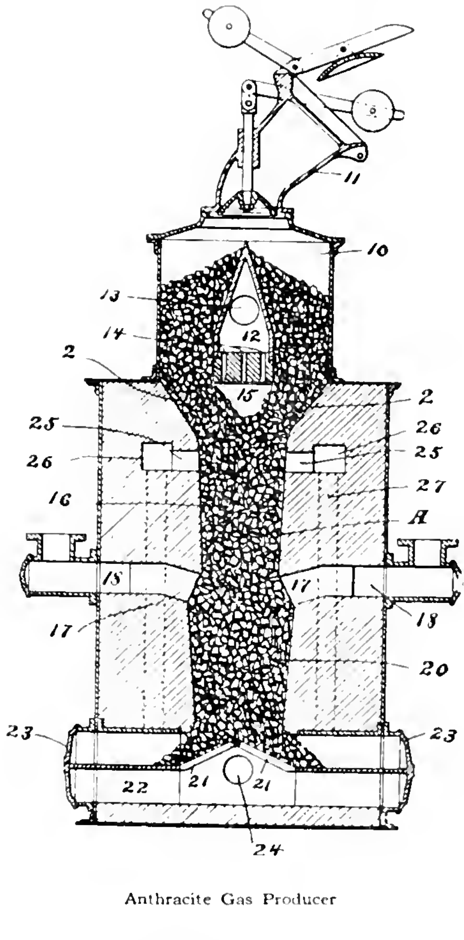
A brief analysis of the several methods of power gas production from solid fuels will, I hope, be interesting.

There are in use to-day two distinct types of gas producers which, by reason of their construction, are adaptable for use with various fuels. The simpler of these is the up-draft anthracite producer. Both types of producers are susceptible to two distinct methods of operation, suction and pressure.

The suction producer, as it is commonly called, is one which, through its scrubber, piping and fittings, is connected directly to the engine inlet pipe. The production of gas is thus automatic and varies with the load on the engine. A brief analysis of the suction producer brings within this catagory any producer which is operated under a vacuum, the gas being drawn from the producer through pipes, scrubber and fittings, and delivered from the exhauster mechanism either through a gas holder or directly to the engine. Such a plant is sometimes erroneously called a pressure producer. The pressure producer proper is one in which the gas is produced by forcing air, steam, or products of combustion through the fuel bed of the producer by pressure. This pressure is sometimes supplied from a fan or blower, but more often from a steam jet blower. Gas made by any of the methods mentioned is not a definite compound, but a mixture of several gases in widely varying proportions. The earliest form of power gas producer was the Dowson producer of 1878.

Dowson Producer

This producer has a cylindrical casing lined with fire brick and fitted at the bottom with fire bars located over a closed ash pit. A fuel hopper, with an internal bell valve, is mounted on the upper part of the producer. Air is forced through the fire by means of a steam jet, the fuel being slowly added from



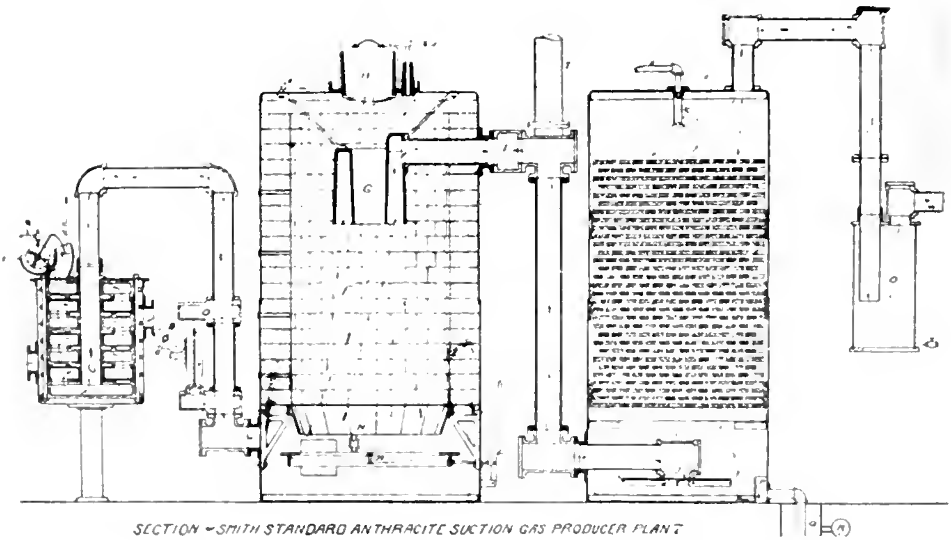
Anthracite Gas Producer

the top until the whole mass is incandescent. The valves of the hopper are then closed and the gas escapes through cooling and scrubbing devices to the gas holder; thence to another scrubber and to the engine.

Bernier Producer

The earliest known form of the common suction producer, where the engine suction stroke is communicated directly to the producer, is the Bernier, which was brought out in 1894 by a Frenchman of that name.

This producer is also of cylindrical design lined with fire brick and with the grate at the bottom. Air and steam come from a receptacle at the top of the fuel bed and pass down underneath the fire, through a space between the cylinder carrying the fuels and the outside cylinder. Since the wall of this chamber is hot, the temperature of the air and steam is raised. Entering the grate at the bottom, the steam passes up through the fuel and the gas generated flows out and over into the scrubber, which is of the water sealed type; thence to the engine. Due to its peculiar design, this producer did not prove very satisfactory.



Section of Smith Standard Anthracite Suction Gas Producer Plant

Smith Suction Producer

This producer is built by the Smith Gas Power Co., Lexington, O., and is probably the best known producer on the American market. It differs from the others described in that the steam for the enrichment of the gas is not generated by the heat of the gas producer but by the heat from the exhaust steam of the engine, the air and water passing through pipes which are heated by this steam. The producer also has a water-sealed charging hopper and a swinging grate. The air in entering the producer draws down a movable vane in the superheating chamber, which acts to open a water carrying device so that a flow of water is had proportional to the amount of this movement. As the suction stroke of the engine is finished, this water carrying device resumes its normal position. The water is converted into superheated steam and the air is pre-heated, the water vapor and air being then carried through into the producer and out as before. This system has another good feature: the gas is taken from the center of the fire instead of from around the sides, thus drawing the air and products of combustion of the fire from the side walls and creating a higher temperature in the center, where it should prevail.

All of the above plants are restricted by their construction to the use of anthracite coal, charcoal or coke.

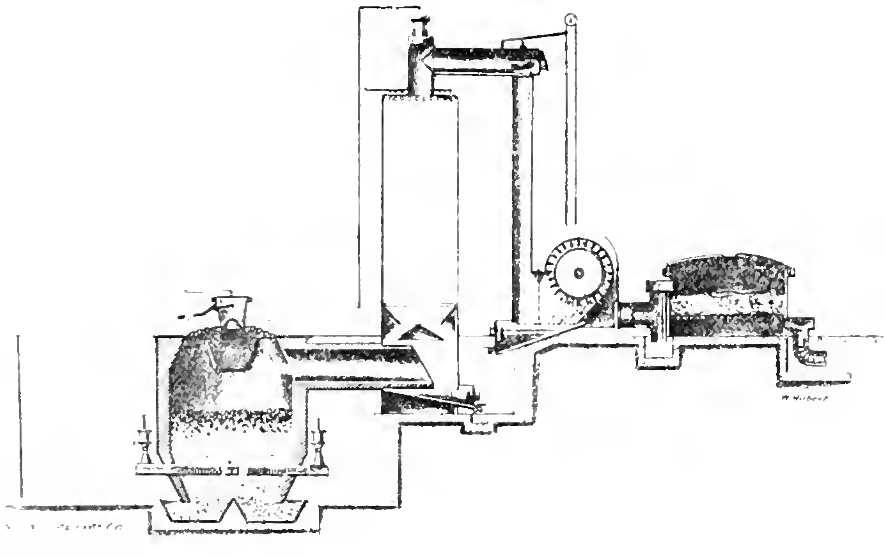
The use of high volatile fuel would result in the formation of tar which, if not removed by means not regularly supplied with these suction producers, would, after formating, almost instantly cause a stoppage of the plant. Tar forming on the inlet valve, stems, igniters and other parts of the engine will cause a stoppage in a very few minutes.

In order to operate on bituminous coal with an up-draft producer, it is absolutely necessary to provide means for the removal of the tar which condenses when the gases are cooled. This is done in a producer built by the R. D. Wood Company by first cooling and washing the gases in a vertical scrubber fitted with coke through which water trickles downward, the gases percolating upward through the interstices of the coke. The cold gas, with part of the tar and dirt removed, is thence taken to a centrifugal extractor which consists of two fans joined together in such a manner that the gases entering the center of the fan are thrown to the periphery by centrifugal force and return against the centrigufal action of an opposed fan, leaving the extractor at the center of the apparatus. The centrifugal force of the two fans is sufficient to keep the tar and other dirts out in a casing beyond the periphery of the fans, whence it is drained and removed. Sometimes even this is not sufficient for a proper cleansing, when sawdust or dry scrubbers are interposed between the extractor and the engine. Tar drip pots are also frequently found in installations of this character, indicating that all of the tar is not removed in at least a single stage centrifugal device.

Other apparatus for the removal of tar consists of relatively wide drums or cylinders fitted with blades arranged to propel the gas in one direction and the water for cleansing in another. The speed of the rotor or drum is sufficient to keep the water and tar against the inner circumference of the surrounding casing. Such apparatus is built by Thieson, Assler and others.

Industrial Producer Plant

Steam and air enter at the bottom under pressure and gas leaves at the top, passing through the scrubber or cooler, where the majority of the tar and dirt is drawn out. Water enters at the top. There is no filling of any kind in the scrubber, dependence being placed entirely upon contact with water for the precipitation of the solids. The gas leaves at the top in a cool condition and enters a centrifugal separator, where the rest of the tar is removed. It then passes to a sawdust scrubber and from there to the engine, the whole system being under pressure.

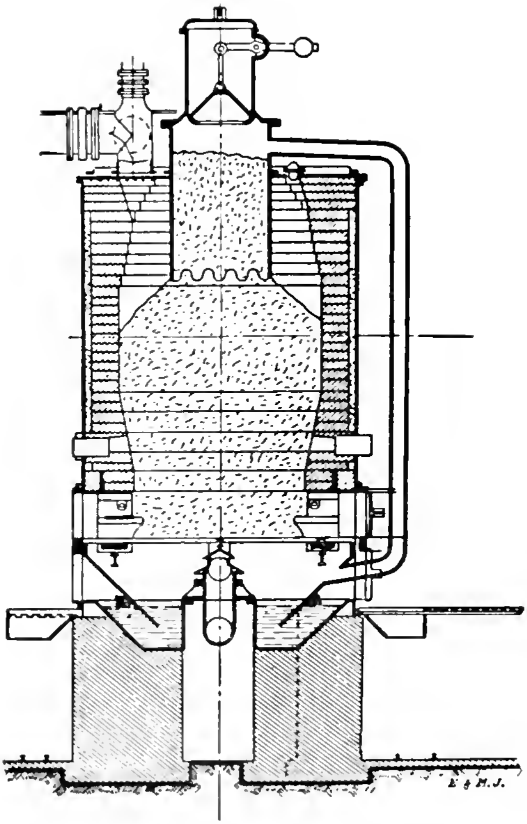


Section of Gas Producer Manufactured by the Industrial Gas Company

Many gas engineers, recognizing the latent danger from tar in the up-draft apparatus, should any of the tar extracting apparatus fail, have devoted themselves to the development of gas-producing apparatus which will eliminate the tar. Descriptions of this class of tar destroying producers follow:

Poetter Gas Producer

The coal is charged from the top as before and is fed down to a lower magazine in the top of the producer. Steam and air are supplied as before and the gas passes upward and out at the top. The hot gases surrounding this fuel reservoir were supposed to serve to drive off the volatile matter, which would then be carried around to the bottom of the producer and burned. Unfortunately this did not work and big engines were crippled on this account.



Section of Poetter Gas Producer

Probably the most successful of the tar destroying producers, and at the same time the most simple, is the down-draft apparatus, where the fuel is charged through an open door at the top and the gas drawn off at the bottom.

Loomis-Pettibone Producer

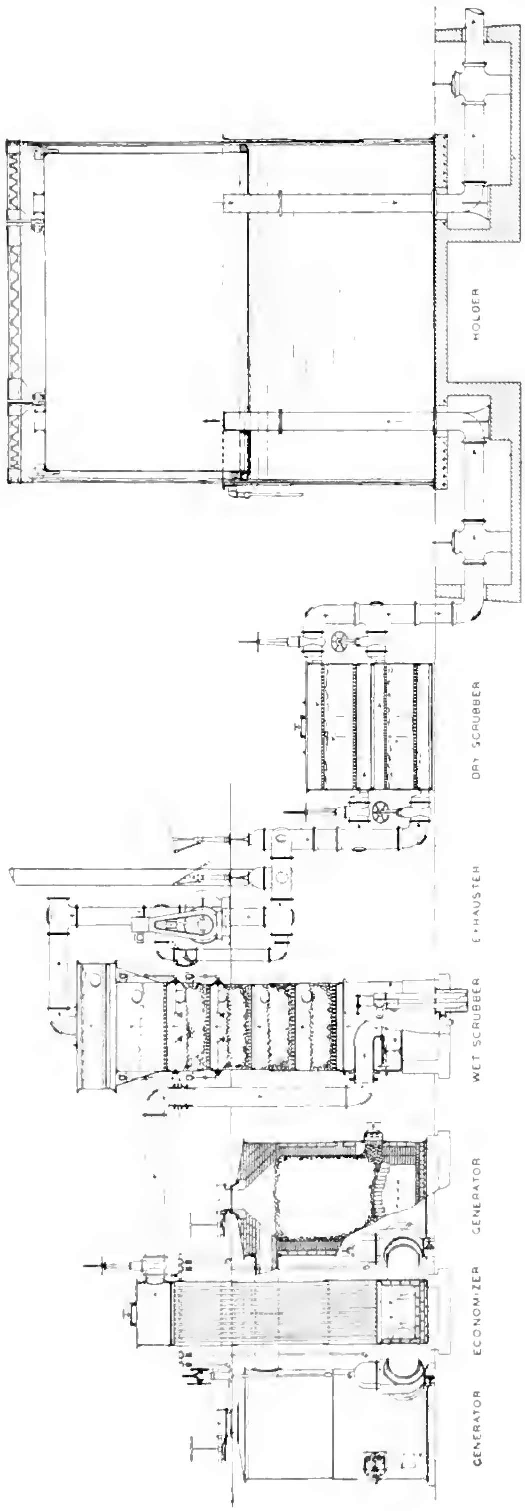
The cut on opposite page shows a section of the Type A Loomis Pettibone gas producer, which is quite extensively used for power generation in this country. Units usually consist of two generators connected together and to an economizer or boiler, where steam is generated. The coal is charged at the top and the gas leaves at the bottom. The grate is of arched fire brick construction. The steam enters the producer through a pipe and is mixed with air and passes down through the fire, completely decomposing the volatiles. The gases, which are heated to about 1200 to 1300° F., leave through fire brick connections at the bottom, thence through the scrubber and gas holder to the engine.

In operating down-draft producers, the smaller portions of the fuel are completely consumed at the top of the fire and, working down by force of gravity and the action of the draft through the fire, serve to plug up the fire, as it were. This congested condition has to be relieved by short reverse runs of compressed air.

These down-draft producers burn anthracite or bituminous coal, wood or charcoal, without producing any tar. It will be observed, however, that partial combustion takes place throughout the whole zone of this producer fire and, contrary to practice in the up-draft type, the greater portion of ash forms at the top and by force of gravity the flow of gas works down through the fire. As a result the fire becomes impregnated with a mass of partially burned coal or coke, ash, clinker and lampblack. If the fire is subjected to a heavy loading, or operated at a high rate of fuel consumption per square foot of grate, the temperatures which ensue will weld this mass of coke, ash and clinker into a very serious conglomeration of hard clinker.

Two methods of cleaning these producers are in vogue, as follows: One partial cleaning, whereby a portion of the fuel bed is withdrawn from the bottom cleaning doors once in every 16 to 24 hours. The remainder of the bed, which by reason of its clinker formation, coke, etc., will bridge across the producer, is then barred down from above and serves as a fixing bed or zone for the next day's run. The laborers sort the larger pieces of coke from the mass of material withdrawn and return it to the producer. A great deal of small or fine coke is lost.

The other method of operating this producer is to run the producer continuously or intermittently until the fuel bed becomes so choked with lampblack, dust, ash and clinker, as to make it impossible to further carry its rated load, when the unit is shut down and the complete mass of material withdrawn from the producer. That this is a trying and difficult occupation cannot be denied. I have in mind a description of the cleaning of such a producer, written by Mr. T. F. Christopher, and I take the liberty of offering several extracts from his description.



Section of Type A Loomis Pettibone Gas Producer

"There is a type of gas producer in use which is so troublesome to clean out that the job is dreaded by every person who is in any way connected with the operation. The ashes and clinkers to be removed are hot, and as the loose ones are raked out they must be quenched by using a hose. The water thrown on them generates clouds of steam that carry the ashes into the eyes and nose and penetrate every opening in the clothing, at the same time matting the hair and forming crusts around the lips and mouth. No amount of clothing will prevent the limbs and body becoming covered with lampblack, soot and ashes; even the shoes do not protect the feet from being also coated in the same manner. Numerous applications of soap and hot water are necessary to remove this greasy smudge. Every part of the producer room is covered, each projection of stone, brick or wood is a resting place for a pyramid of dust, ready to topple over and again fill the air at the slightest jar or puff of wind. After the loose ashes and small clinkers are removed, there still remains a quantity of larger clinker to be barred loose from the side walls, and still larger and harder ones in the center of the generator which have to be broken up in order to remove them through the doorway. This process of breaking requires long cold chisels and sledge hammers; the clinkers are still hot, and the holding of the chisel must be directed by looking through the doorway, requiring a crouching position, which man cannot maintain long at a time. Consequently, the process is slow as well as laborious and requires a number of men who work in shifts of a few minutes at a time. When this producer is finally emptied and ready to refire, a second one must receive the same attention.

"This type of producer is built with a pair of generators to one boiler and scrubber. After the generators are cleaned, the boiler must have its top removed and flue scrapers run through each flue; then openings near the bottom must be removed and all the soot and ashes, which have been loosened or have accumulated during the week's run, cleaned out. Following this is the meanest job of all the cleaning of the traps on the gas line between the scrubbers and the gas holder. A new man must be provided at each cleaning to perform this operation. No man will do it a second time; he will quit the job first. It consists in getting down into a pit almost entirely filled with soot or lampblack and shoveling out this material, which is part dry and part wet. The dry portion is very light and floats around, filling the air. It is carried to the lungs with every breath, and it sticks like glue when moistened. The man who performs this job is a walking paint factory for the next week.

"Cleaning out is a regular necessary weekly performance, usually done on Sunday, as it takes all day with eight men and a superintendent. Any good fuel drawn out with the ashes is saved and used in starting new fires. This is a down-draft type of producer using bituminous coal, and when making producer gas it is worked with the top open. Since little steam is admitted with the air, the inclination to clinker is intensified, especially when no attempt is made by the operator to keep the top of the fire bed leveled off, or to stop the draft holes through it. When asked why, one of these operators replied: 'The top is all caked, and if I stop the hole I will have to make another to let the air pass through.'

"I visited a plant of this kind two days in succession, and was then invited to come on Sunday and see a clean-out. Securing some old clothing proper for the occasion, I arrived at the works on time. They started cleaning at 8:30 in the morning, with a half hour rest at noon. The work was completed and new fires started at 5:30 in the afternoon. The best possible wash-up at the plant after the work was finished was made, and this left me about as presentable as a coal passer just out of the stoke hole. The chief operator, who had superintended the work and handled his men well, making every move count, said each weekly operation varied little, if any, from the one witnessed."

Many engineers, for various reasons, are prone to doubt the reliability of gas power. At a recent meeting of the American Society of Mechanical Engineers, this feeling was expressed by several well known engineers.

In the discussion of several papers, a well known engineer severely criticised the many published reports of the economic performances of gas engine power plants, and claimed that the gas power advocates were comparing the best gas power stations with the poorest steam power stations, and cited an instance of a large pumping plant delivering an indicated horse-power on 1.06 pounds of coal. It will be remembered in this connection that the steam pumping station was of large capacity and operating at its most economic load factor. Unfortunately, the gas power advocates had no installation at that time where continuous high load factors obtained, such as was to be expected in the pumping station of the kind mentioned.

With reference to efficiency in gas producer work, I desire to call your attention to the tests recently made by one of our well known engineers on a very economical type of water tube boiler, known as the Rust boiler. In his report the engineer stated that the test results, high as they were, could undoubtedly be duplicated at any time, when the boilers were operated under the same conditions as those existing when the tests were made; that is:

1st: Uniform rate of driving, without the necessity of having to increase or lower the steam pressure or force the fires.

2nd: Boiler absolutely clean inside and out.

3rd. The fire brick furnace free from air leaks.

4th: Automatic stoker.

5th: The draft and the rate of feeding the coal adjusted to each other so as to burn the coal without smoke and without any greater amount of air than is necessary for complete combustion of the fuel.

Can any of us refer to a boiler installation in commercial operation for any length of time under these ideal conditions? I doubt it.

In the gas producer, however, we have a fire brick lined shell with the practical impossibility of any opportunity for leaks of any kind. All the fuel charged into the producer must be delivered in the form of gas to the engines, faulty firing by the operator notwithstanding.

Uneconomical operation is practically impossible but faulty operation or incompetent handling of the apparatus is always attended with a poor grade of gas, which at times causes interruptions of service at the engine. This result, however, is not obtained excepting from criminal negligence on the part of the operator. The labor, therefore, required to operate a modern gas producer is no more intelligent then that required for the stoking of our ordinary steam boilers.

The only element necessary for the emphatic demonstration of the economical claims of gas power advocates is time. It took time, and a great deal of it, to bring our steam equipments to their present state of perfection, and within a very short while, even now, we see large gas power stations operating in service, to which our steam advocates point with pride.

COMMERCIAL ELECTRICAL TESTING

Part IX

By E. F. Collins

INDUCTION MOTORS (Continued)

Torque

Two methods are used for measuring torque on induction motors, one employing a spring balance and the other a special torque indicator.

In the first method a wooden brake lever is clamped around the pulley as shown in Fig. 41. The size and length of lever depends on the size of the motor, the length being chosen to give a maximum reading at one-half or two-thirds the capacity of the spring balance used. Let the point of attachment to the lever be at X; then the length of the lever arm $= XY$. On the frame of the motor a mark should be made at M, and a pointer, P, attached to the lever as shown. The lever arm is then raised until the distance $XT = YS$, and the pointer set so that it is on mark M. If the weight of the lever alone is not sufficient to overcome the friction

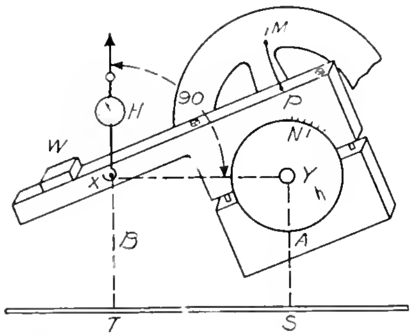


Fig. 41. Measurement of Torque by Means of Spring Balance

of the bearings and turn the rotor round till the end of the lever touches the floor, attach a weight at W. Now if the spring balance H is pulled upwards until the pointer P is on mark M, XY will be parallel to TS, and the pull X will make an angle of 90° with the center of the shaft—the position in which all readings must be taken. Open all switches on the dynamometer board to eliminate the residual magnetism of the alternator, raise the lever arm by pulling vertically on the spring balance till the pointer passes the mark M, and at the instant of passing take a reading of the spring balance. Call this reading $W+F$. Let the lever be raised until the pointer is some distance beyond M; then lower the spring balance and let gravity pull the lever toward the floor, reading the balance when the pointer passes the mark. Call this reading $W-F$. To get good readings, the lever arm should be moved rather slowly, but steadily, and with as nearly constant speed as possible, a reading of the balance being taken every time the pointer passes the mark. As a check, three or four readings should be taken as described above.

Close the line switches and increase the amperes to twice normal and take readings as before; also read volts and amperes. Call the reading obtained as the pointer passes the mark as the lever goes up, $W+F+T$, and that obtained as the lever comes down, $W-F+T$, T representing torque.

Readings should be recorded as below, assuming that they were taken on a 440 volt motor:

Volts, 450; Amps., 40; $W+F$, 9 lbs.; $W-F$, 5 lbs.; $W+F+T$, 19 lbs.; $W-F+T$, 15 lbs.; T, 10 lbs.

To find the torque:

$2W = 14 \ldots w = 7$ lbs.

$2(W+T) = 34$ lbs.

$T = 10$ lbs.

Torque at 1 ft. radius $T \times L$

Where L = length of lever arm

Torque at 1 ft. radius at normal volts

$$= \frac{(\text{normal volts})^2}{(\text{volts read})} \times T \times L$$

On squirrel cage or wound rotors a value of current should be used which will make $W+F+T$ at least twice $W+F$. The maximum and minimum values of $W+F+T$ and of $W-F+T$ should also be taken.

All wound rotors and most squirrel cage rotors will show a torque variation depending on the rotor position.

As a check on the torque readings, the lever should be loosened on the pulley and the pulley rolled forward until the mark on its rim at X is in line with a second mark on the lever arm, thus changing the relative positions of the rotor and stator. Further readings should be taken and this procedure repeated for four or five different points. The torque should be the same for all points on Form K motors.

A special consideration to be observed in making a test for torque is the maintaining of a constant and correct generator speed. The volts read, when amperes are 200 per cent. normal on the first point, should be held constant on all other points, since the torque varies as the square of the volts. The torque also increases as the resistance of the rotor winding increases owing to heating. On large machines the rotor winding sometimes becomes quite hot, so that the temperature of the end rings and bars of the winding should be taken and recorded.

Starting Resistance

The Form L motor has a starting resistance in the rotor which in the smaller sizes is controlled by means of a rod sliding within the shaft and in the larger machines by a lever and ratchet combination. The resistance of the different starting steps must be measured.

The rod should be pulled out to the full extent by means of the knob handle, thus putting all the resistance in circuit. The rod is then divided into five equal parts and from the impedance test the voltage that will give about 125 per cent. normal amperes when the rod is in the running position (resistance all cut out) is found. Apply this voltage, and with the rod in the first position read volts and amperes stator. Similar readings should be taken on each of five different steps marked on the rod. The same procedure holds good for the larger machines, where the resistance is cut out step by step. These readings, with the resistance in circuit, must be taken as quickly as possible, otherwise the resistance becomes unduly heated and may be injured.

Table XVIII shows the form used in calculating stationary torque on induction motors.

Efficiency

Input-output efficiency and power factor tests can be made by either the "string brake" or "pumping back" methods. Neither of these methods are particularly accurate nor are they recommended. In certain cases, however, these tests are made on induction motors, though not on any other type of alternating or direct current motor.

In the "brake method" the size of the brake limits the size of the motor tested. In Fig. 42, *L* is a lever or scale beam suspended at the point *X*. From *T* the small platform *A* is suspended, on which calibrated weights are placed. *P* is a *flat* faced pulley on the shaft of the motor, running in the direction shown by the arrow: *i.e.*, toward the lever *L*. One end of a small rope is attached at *B*, which is wound one or more times around the pulley. The other end is made fast to a spring balance *G*. A strip bearing a mark is located at *K* so that when the point of the lever *L* comes opposite to the mark, the lever is in a horizontal position at an angle of 90 degrees to the force exerted by the pulley.

Since the stress along a rope is transmitted through its center, adjust the brake until the points *M* and *N* are a distance apart equal to the diameter of the pulley plus the diameter of the rope, one-half the diameter of the rope being added to each side of the pulley. This adjustment must be accurately made and care taken to see that nothing moves to throw the brake out of line or proper adjustment. When ready, slip the rope off the pulley but leave it attached at *B* and *G*, then balance the lever until the pointer on the end comes to rest at the mark *K*. This balancing of *L* must be repeated each time the rope is changed.

The motor should be run light for at least one hour before the test proper is commenced, so that friction may become constant. Since speed is one of the important factors

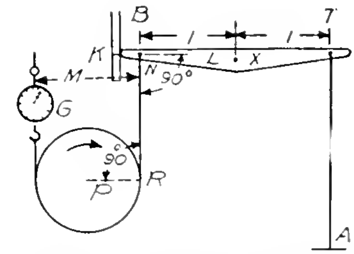


Fig. 42. Diagram of Apparatus Used in Taking Input Output by the String Brake Method

in the output of the motor, it should be taken very carefully. The slip should be taken with the slip machine.

Running light readings should now be taken on the motor, the impressed voltage, as well as the frequency, being held constant. A small weight is next attached to the spring balance to give enough tension on the spring for a reading on the balance of a quarter or half a pound. This "no load" scale reading must be recorded and subtracted from all subsequent readings taken.

A small weight is now placed on A and the spring balance G pulled up until the pointer on lever L reaches K; when the motor volts and speed of the generator are normal and all meters are steady, the volts, amperes, watts, weights on A, spring balance deflection, and speed given by the tachometer should be read. A reading should also be taken with the slip machine. Continue to add weight to A and take readings until the breakdown load of the motor is reached. The readings should be recorded in the following manner:

Volts Amps	+ Watts	− Watts	Weight On A	Tension On Balance	Speed of Slip Motor

A rope of small diameter gives better results than one of larger diameter, even though it may require more time to make the tests on account of having to renew the rope more frequently. For motors up to 20 h.p., a 1/4 in. oiled hemp rope is best, and for motors from 20 h.p. to 50 h.p., a 1/2 in. rope can be used. The rope will usually last longer if doubled and two strands used in parallel. The rope should be wrapped around the pulley one and a half times, care being taken to have no strands twisted or crossing each other; all strands should lie closely and evenly together on the face of the pulley. The tension read on the balance G will vary with the temperature of the rope and may differ widely with different loads.

The additional weight added to A each time should be such as to allow of from fifteen to twenty readings between no-load and breakdown.

When the breakdown point has been reached and complete readings taken and recorded, the diameter of the pulley should be carefully measured.

Weight on A − (tension on balance) − ("no load" reading on balance) = actual load in pounds = P.

Normal speed − slip = actual speed of motor.

R = radius of pulley in inches + 1/2 diameter of rope.

S = speed in revolutions per minute.

$$\text{Power factor} = \frac{\text{watts}}{\text{volts and amps.}}$$

$$\text{Then horse-power} = \frac{2\pi R}{P \times 12 \times S \times 33{,}000}$$

$$\text{Efficiency} = \frac{\text{horse-power output} \times 746}{\text{watts input}}$$

Considering Fig. 43, let M be the motor and L the load machine, the latter being a direct current machine of about the same capacity as the motor, belted to the motor and separately excited from a suitable source.

To make the efficiency test, connect M so that the total input can be obtained. The necessary connections are not given, as they vary widely, depending on whether M is a one, two or three-phase machine. Separately excite the field of L and connect an ammeter and a variable resistance in circuit. Connect the armature of L to a

TABLE XVIII

STATIONARY TORQUE ON A 15 H.P., 220 V., 6-POLE, 60 CYCLE, 2-PHASE INDUCTION MOTOR

Lever Arm.	Controller Pos.	Volts	Amp.	W + F	W − F	W + F + T	W − F + T	W	W + T	T	Norm. T 1 Ft.
2 ft.	1	220	21–41	16.25	14.25	33	33	15.25	33	17.75	35.5
	2	220	36–39	17.25	14.25	50.75	48.75	15.75	49.75	34	68
2.292 ft.	2	220	38–37	17.25	16.25	47.75	47.75	16.75	47.75	31	71
	3	220	57–34	17.25	16.25	54.75	53.75	16.75	51.25	37.5	86
	4	220	96–44	17.25	17.25	67	66	17.25	66.5	49.25	113
	4	220	98–45	17.25	17.25	68	66	17.25	67	49.75	114
	6	209	121–92	16.25	16.25	78	78	16.25	78	61.75	156
	7	187	195–97	17.25	16.25	61.75	59.75	16.75	60.75	44	139
	8	175	173–162	16.25	15.25	51.75	50.75	15.75	51.25	35.5	128.7

Lever Arm. = 2 ft. and 2.292 ft.
Normal running torque at 1 ft. radius = 65.6 lbs.

water-box or to a motor, the load of which can be varied. An ammeter should be placed in the circuit and a voltmeter across the brush terminals. If the test involves a considerable range of speeds, run *M* over that range and hold the field current of *L* constant, its value being such that the speeds or loads required for *M* can be obtained.

Having made the necessary connections, etc., keep the field current of *L* constant at its predetermined value. Vary the load on *L* by changing the water resistance or the load on the motor to which it is connected to suit the testing conditions required on *M*. The efficiency of *M* may be required for a series of speeds or of loads. Read the input and speed of *M* and the volts and amperes of *L*. Vary its speed from slightly below to slightly above the speeds used before when running as a motor and take a number of readings at different speeds, reading volts and amperes input and speed; *L* being separately excited with the same value of current that was used in the two previous cases. The necessary readings are now complete for calculating the efficiency.

Case A

Let *Wm* be the total input of *M*.

Let *Wl* be the product of volts and amperes read for *L*.

Let *Fm* be *M's* friction, windage, etc.

Let *Fl* be *L's* friction, windage, etc.

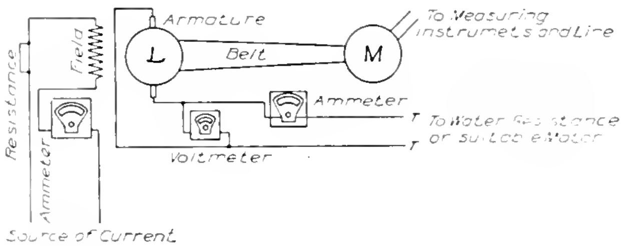


Fig. 43. Connections for Measuring Input Output by Pumping Back

The "counter torque" must now be obtained to complete the calculations. To obtain this, disconnect *M*, connect *L* to a source of current which can be varied so as to give *L* different speeds, keeping *L* separately excited. If the "pumping back" method for loading *L* has been used, the connection will probably not require any change. Run *L* as a motor driving *M*, keeping the field current of *L* constant at the same value that it had when *L* was used as a generator.

Vary the speed of *L* so that the speed of *M* can be varied slightly from below its previous minimum speed to slightly above its maximum speed. Take a number of readings at varying speeds, reading volts and amperes input of *L* and speeds of *L* and *M*. If the electrical efficiency alone is desired (Case A), sufficient readings have been taken. If the commercial efficiency is desired (Case B), take off the belt from *L* and run it light as a motor.

Divide the belt friction equally between *L* and *M*, including this in *Fm* and *Fl*.

Let *R* be the hot resistance of *L's* armature, which must be measured.

Let *C* be the current in *L's* armature.

$$\text{Then electrical efficiency} = \frac{Wl + C^2R + CT}{Wm}$$

where *CT* is the mechanical losses in *L* and *M* and the belt loss.

For Case B

$$\text{Efficiency} = \frac{Wl + C^2R + CT}{Wm}$$ where *CT* is the mechanical losses of *L*, including belt loss.

In running the counter torque curves, the field of *L* must be held constant throughout and readings must not be taken when accelerating.

(To be continued)

DUCTILE TUNGSTEN AND MOLYBDENUM*

By Colin G. Fink, Ph.D.

Tungsten has heretofore been known chiefly as a steel-hardening metal. In recent years, however, it has become an important material for filaments of incandescent lamps, and is today the most efficient metal for this purpose, owing to its high melting point (3000° C.), which is higher than that of any other metal, and its low vapor tension.

It is well known that tungsten is described in all of the textbooks as a brittle gray metal, and that numerous attempts have been made to reduce it to ductile form, as is evidenced by publications emanating from various research laboratories. Roscoe and Schorlemmer, in the latest edition of their "Treatise on Chemistry" state that "the purest forms of tungsten at present obtainable are hard and brittle and are not ductile, either at ordinary temperatures or when heated."

The metal has ordinarily been obtainable in commerce in the form of a dark gray powder, usually made by the reduction of the yellow oxide by hydrogen or by carbon. This powder, when bought on the open market, is generally impure, and is purified by various well known methods, particularly if the metal is to be used for filaments of incandescent lamps. These filaments have been made on a large scale and are in common use in this country and abroad. Even in ordinary commercial lamps, the filaments are of a degree of purity so high that no impurities can be discovered by the most searching methods of chemical analysis known. Not only is this true, but these filaments, during the course of commercial production, are exposed to temperatures high enough to drive out by mere vaporization almost any impurity.

Nevertheless, these filaments show no traces whatever of ductility, or even pliability, but on the contrary, though strong enough for mounting in commercial lamps, they are exceedingly brittle and incapable of taking a permanent set. Attempts have hitherto been made—but always without success—to produce ductile tungsten by various purification processes, varying the ore from which the tungsten is obtained by trying first wolframite (an iron-manganese tungstate) and then scheelite (the calcium tungstate). Whichever ore is used, it is customary to produce from it the yellow oxide, and a high degree of purity has been sought by repeated precipitations. Various methods of reduction have been tried; among other reducing agents, hydrogen, carbon, aluminum, zinc and magnesium have been used. Reduction has also been effected by electrolytic methods. Since tungsten metal produced in this way has been so pure that no impurities could be detected by ordinary chemical or physical means, and has yet retained its characteristic hardness and brittleness, it has generally been concluded that the metal is entirely lacking in that physical property which is ordinarily termed ductility.

Announcement has recently been made, however, of the production of tungsten in a form in which it is ductile. This ductile tungsten would seem to be a new substance, from the point of view of the physical chemist,

TABLE I—TENSILE STRENGTH

Tungsten Wire

Diam. in mm.	5.0 0.125	2.8 0.070	1.5 0.038	1.2 0.030
Lbs. per sq. in.	460,000 to 490,000	480,000 to 530,000	550,000 to 600,000	580,000 to 610,000
Kg. per sq. mm.	322 to 343	336 to 371	385 to 420	406 to 427

Molybdenum Wire

Lbs. per sq. in.	200,000 to 260,000	230,000 to 270,000	270,000 to 310,000
Kg. per sq. mm.	140 to 182	161 to 189	189 to 217

* Paper presented before American Electro Chemical Society, May 5, 1910.

and it has seemed to me that this society would be interested in learning something of the properties of this product, since only those of us who have been connected with the Research Laboratory of the General Electric Company have as yet had an opportunity to study it.

Ductile tungsten is a bright, tough, steel-colored metal, which can be drawn into the finest wire, much below one thousandth of an inch. The tensile strength of the wire increases as the drawing proceeds; or, in other words, the more the metal is mechanically worked, the tougher and stronger it gets. In the following table a few figures on the strength of tungsten wires are given. They are the average obtained from a large number of measurements.

A piece of hard drawn piano wire, tested with the same apparatus, registered, on the average, 507,000 lbs. (35 kg. per sq. mm.), the diameter of the wire being 3 thousandths of an inch (0.075 mm.). According to Schnabel, aluminum shows a similar behavior as regards the effect of drawing: Cast aluminum gives but 17,000 lbs. per square inch (11.9 kg. per sq. mm.), whereas the drawn metal has a tensile strength of 36,000 to 39,000 lbs. (25.2 to 27.3 kg. per sq. mm.)

The density or specific gravity values of ductile tungsten likewise increase with the amount of working. The values for ductile molybdenum were also determined at our laboratory.

TABLE II SPECIFIC GRAVITY

Diameter, Inches	Diameter, mm.	Tungsten	Molybdenum
Before Drawing			
		18.81	10.02
After Drawing			
0.150	3.75,	19.30 to 19.30	10.04
0.010	0.25,	19.58 to 19.64	10.29
0.0015	0.038,	19.86 to 20.19	10.32

Martin (1907) found the density of melted tungsten, analyzing 98.96 per cent. pure, to be 16.28; Moissan (1896) and Weiss (1910) give the values of 18.70 and 18.72 for the brittle metal. As is seen from the table, the density increases very appreciably with the amount of mechanical working applied. This same phenomenon is well known in the case of copper, zinc and other metals. The density of cast copper according to Marchand and Scheerer is 8.92, and that of rolled and hammered copper 9.95. Distilled zinc gives 6.92 and wrought zinc 7.25.

The electrical resistance and the temperature coefficient of the two metals are given in Table 3. We used the Wheatstone bridge method. The resistance was measured at room temperature and at 170°, employing two oil thermostats.

TABLE III

		Resistivity (25°) in microhms per cu. cm.	Temp. Coeff. per degree between 0° and 170° C.
Tungsten	*d.*	6.2	0.0051
	a.	5.0	
Molybdenum	*d.*	5.6	0.0050
	a.	4.8	

The values marked *d* are for hard drawn wire; those marked *a* were obtained after annealing. This resistivity value for tungsten is a good deal lower than that given by Gin (Trans. Am. Electrochem. Soc. XIII, 483). The coefficient for copper (0° to 160°) is 0.00445 (Reichardt); the registry values for copper are 1.62 for the hard drawn and 1.58 for the annealed wire.

The hardness of both tungsten and molybdenum depends very much upon the amount of mechanical working to which the metals have been subjected, and also upon the presence of impurities. Whereas the hard varieties scratch glass, the soft varieties are easily cut with a file.

The thermal coefficients of the two metals were determined on wire 5 thousandths of an inch in diameter. A reading of one degree on the scale was equivalent to an elongation of the wire of 0.000545 inches. The values obtained are $336 \times 10_{\pi}^{-8}$ for tungsten and $360 \times 10_{\pi}^{-8}$ for molybdenum, the temperature range being 20°–100°. The platinum value for the same range is $884 \times 10_{\pi}^{-8}$ (Dulong and Pitit).

Chemically, the two ductile metals behave similarly in many respects. The drawn wire retains its lustre almost indefinitely. Both metals are readily attacked by fused oxidizing salts, such as $NaNO_3$, $KHSO_4$ and Na_2O_2. Acids (HCl, HNO_3, H_2SO_4) attack tungsten very slowly, but molybdenum rather readily. I have heated fine drawn tungsten wire in a mixture of chromic and sulphuric acids for sixteen hours but could detect only a very small loss in weight.

Original weight: 16.7330 grams; after 16 hrs., 16.7329 grams.

Original weight: 1.3638 grams; after 14 hrs., 1.3635 grams.

Apparently the metal becomes passive just like iron.

ELECTRIC CURRENT IN RAIN AND SNOW STORMS

By J. B. Taylor

The Meteorological Office of the government of India has recently been making a systematic record of the amount of electricity brought down by rain. These records show that for 70 per cent. of the rain storms, the particles of water are charged positively, and during some exceptional storms, measurements of the charge brought along with each cubic centimeter of rain water, in connection with the rate of rainfall, gives a current of about 300×10^{-15} amperes per square centimeter of the earth's surface.

Expressed in these units, we do not have any tangible idea of the current strength in the rain, but by changing the unit of area from the square centimeter to the square mile, the current in the latter area is found to be approximately 10 amperes.

For those who wish more data on these Indian records, reference may be made to a paper by G. C. Simpson, in the Royal Society Proceedings, May 6, 1909.

An abstract of this paper recalled to the writer some tests and measurements made ten or eleven years ago on telephone lines during snow storms. These tests have already been referred to in the discussion of an A.I.E.E. paper *, the point of the discussion being to show that, under some conditions, each individual snow flake carries a charge and that a telephone line some miles in length will be struck by a sufficient number of these flakes to give, if the line be connected to earth, a practically steady current of such magnitude as to be easily read on commercial measuring instruments.

A recollection of this test in connection with the figures on rain drop charges in India, has led to some additional calculation, based on the data of the snow storm test.

On one occasion, with a metallic circuit telephone line approximately 60 miles long, a Weston voltmeter between telephone wires and ground indicated a steady current of approximately 0.003 of an ampere. If we take the diameter of each wire as $\frac{1}{10}$ of an inch, the 60 miles of line (2 wires) will have a total projected area of $2 \times 60 \times \frac{1}{10} \times \frac{1}{5280} \times \frac{1}{12}$ square miles, which equals approximately $\frac{1}{5280}$ of a square mile. Since 0.003 of an ampere is carried by snow flakes striking this area, we may say, roughly, that under the average conditions at time of test, a current of $\frac{3}{1000} \div \frac{1}{5280}$, or 16 amperes was flowing from clouds to each square mile of earth, through the medium of the snow flakes. It is interesting to note that this figure is very nearly the same as that deduced from the electrostatic measurement of charge from the rain test in India.

The Royal Society paper referred to gives further interesting data on the electrification of water particles in a stream of air, and outlines a theory for the formation of thunder clouds.

Since positive charges sufficient to represent a current of 10 or 15 amperes per square mile can not come to earth without leaving an equivalent negative charge in the clouds, it should be apparent that from these figures we have some basis for estimating the quantity of electricity involved in a lightning flash, provided we have data on the number of flashes in a given area in a given time, as well as data on the amount of charge brought to earth by the rain.

While lightning discharges and thunder are not entirely unknown during snow storms, they are unusual; and it is interesting to speculate as to what becomes of the negative charge during a snow storm which is bringing sufficient charge to earth to represent a current of 15 amperes per square mile.

It does not appear that we have yet sufficient data to elaborate any theory, and before such information can be of much value in analyzing thunder storm conditions, it would seem necessary to have simultaneous measurements made at many points over an extensive area, of the polarity and the amount of charge in rain drops or snow flakes.

*Transactions of the A.I.E.E. Vol. XXIV, Page 906.

HYPERBOLIC FUNCTIONS AND THEIR APPLICATION TO TRANSMISSION LINE PROBLEMS

PART IV

By W. E. Miller

Telephone Lines

As already mentioned, the hyperbolic equations can be applied to accurately determine the variation of volts, amperes and power factor along telephone lines. If the length of the line is considerable, the hyperbolic functions must be separately determined for each point, the functions given in the REVIEW Supplement not covering the range required. The reduction formulæ (see page 221, May REVIEW) can be used to advantage in such cases. In these problems, it is usual to consider that the very complex speech wave can be approximately represented by a wave having the average frequency, this being about 800 cycles per second. Where, however, an accurate representation of the phase and amplitude changes of the wave are required at each point of the line, the method outlined in the editorial of the May REVIEW must be followed; that is, the equations must be applied to each harmonic separately.

In telephone lines, the electrical conditions at the sending or receiving end are only those that generally require determining, and the conditions along the line are not of great importance from a practical point of view. For air lines longer than 700 miles, the hyperbolic equations can then be considerably simplified, since in such lines the wave reflected at the receiving end is negligible at the sending end. Equations (23) and (24), page 222, May REVIEW, can then be reduced as follows, by substituting the exponential values of the hyperbolic functions.

Thus

$$e = E_r \cosh mx + I_r m_1 \sinh mx = \frac{E_r}{2}\left(\epsilon^{mx} + \epsilon^{-mx}\right) + \frac{I_r}{2} m_1 \left(\epsilon^{mx} - \epsilon^{-mx}\right)$$

Now x, the line length in miles, is measured from the receiving end; hence ϵ^{mx} increases from the receiving to the sending end, whereas, ϵ^{-mx} decreases between the same points; that is to say, ϵ^{mx} can be regarded as measuring the decrease of amplitude, and the phase change of the wave transmitted from the sending end and ϵ^{-mx} the decrease of the amplitude, and the phase change of the wave reflected from the receiving end, the latter becoming vanishingly small at the sending end in long lines and, therefore, negligible. Thus, the volts at the sending end equal $\frac{\epsilon^{mx}}{2}\left(E_r + I_r m_1\right)$. Similarly, the current at the sending end $= \frac{\epsilon^{mx}}{2}\left(I_r + \frac{E_r}{m_1}\right)$

If $m = a + jb$ then $\epsilon^{mx} = \epsilon^{x(a+jb)} = \epsilon^{ax} \times \epsilon^{jbx}$

Since $\epsilon^{jbx} = \cos bx + j \sin bx$ (see formulæ (10) and (11), page 179, April REVIEW), the equations can be written

$$e_s = \frac{\epsilon^{ax}}{2}\left(E_r + I_r m_1\right)\left(\cos bx + j \sin bx\right) \qquad (35)$$

and

$$i_s = \frac{\epsilon^{ax}}{2}\left(I_r + \frac{E_r}{m_1}\right)\left(\cos bx + j \sin bx\right) \qquad (36)$$

when x = length of the line in miles. These equations are accurate only at or near the transmitting end.

Thus ϵ^{ax} measures the rate of decay of the volts or current from the sending end along the line, a being called the attenuation constant per mile for the line at the given frequency.

The trigonometrical function terms measure the rate of phase twist; that is, b is inversely proportional to the wave length, or $\frac{2\pi}{b}$ = wave length where

$$b = \sqrt{\frac{pC}{2}\left(pL + \sqrt{r^2 + p^2L^2}\right)} \qquad (37)$$

The value of the attenuation constant a is

$$a = \frac{r\sqrt{pC}}{\sqrt{2\left(pL + \sqrt{r^2 + p^2L^2}\right)}} = \frac{\sqrt{pC\left(\sqrt{r^2 + p^2L^2} - pL\right)}}{\sqrt{2}} \qquad (38)$$

These values follow immediately from the value of m given in formula 27, page 222, May REVIEW; a being the real part of m and b the j term. They can, however, be more readily calculated by equating the real terms of the value of the expression m^2 to the real terms of the value of the expression $(a + jb)^2$, and by equating the lengths of these vectors together. If this is done, b^2 or a^2 can be at once eliminated and the values of a or b found.

From calculations from equations (23) and (24), page 222, May REVIEW, Figs. 16 and 17 have been drawn to show how the volts and current vary along a telephone line consisting of two No. 6 B.&S. copper wires twelve inches apart, the length of line being 1000 miles and the frequency 1000 cycles per second. The instantaneous, as well as the maximum, values of the current and voltage are plotted to show the shift of phase along the line at the epoch chosen at the receiving end. The telephone receiving apparatus is assumed to require .2 volts and ½ milliampere at a power factor .50 lagging. The epoch chosen at the receiving end is that at which the volts are maximum, the current being, at this power factor, half its maximum value at that moment. The attenuation constant of this line for 1000 cycles per second is .0035 per mile and the wave length 183 miles. Harmonics of lower frequency will have smaller attenuation constants and those of higher frequency than 1000 greater attenuation constants, as will be seen from equation (38). The number of complete phase reversals along this line is $\frac{1000}{183}$; that is, over five complete reversals. As the power factor along the line is approximately unity (see Fig. 18), the velocity of the propagation of power along the line can be taken as $183 \times 1000 = 183{,}000$ miles per second without great error, and there fore the time required for transmission is about $\frac{1}{200}$th of a second.

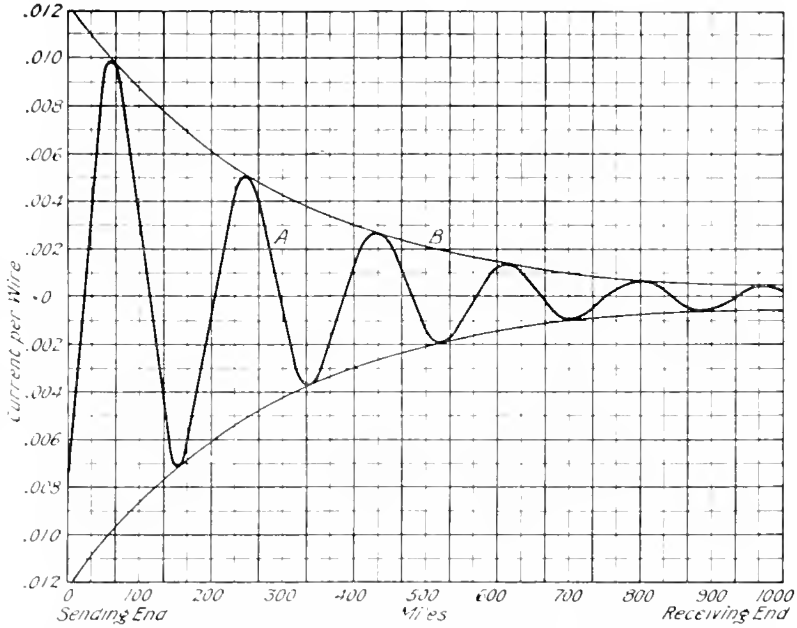


Fig. 17. Curve B Gives Maximum Values of Amperes Along a 1000 Mile Telephone Line Using Two No. 6 B.& S. Copper Wires 12 Inches Apart. Frequency 1000 Cycles. Curve A Gives Instantaneous Values. Receiving End, .20 Volts Between Wires, .50 Milli-Amperes at .50 Power Factor Lagging

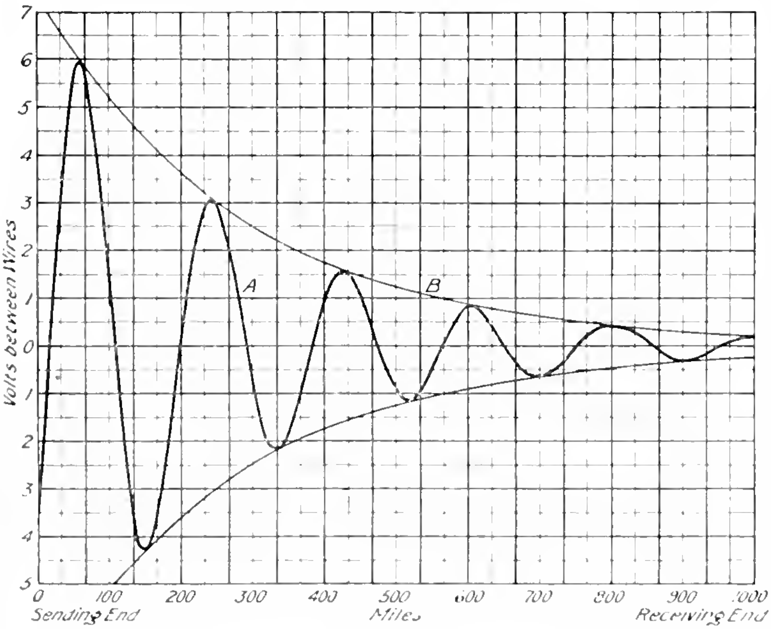


Fig. 16. Curve B Gives Maximum Values of Volts Along a 1000 Mile Telephone Line Using Two No. 6 B.& S. Copper Wires 12 Inches Apart. Frequency 1000 Cycles. Curve A Gives Instantaneous Values. Receiving End, .20 Volts Between Wires, .50 Milli-Amperes at .50 Power Factor Lagging

Loaded Telephone Lines

As already mentioned, the electric wave transmitted along telephone lines is extremely complex, containing both even and odd harmonics, which are usually considered to range from about 200 up to 2400 cycles per second or more. Under ordinary conditions, the higher the frequency of the harmonic, the more is its amplitude attenuated; thus the quality of the sound received may be entirely different to that transmitted and, in long aerial lines or through shorter submarine cables which necessarily possess high inductive capacity, the received wave may be so

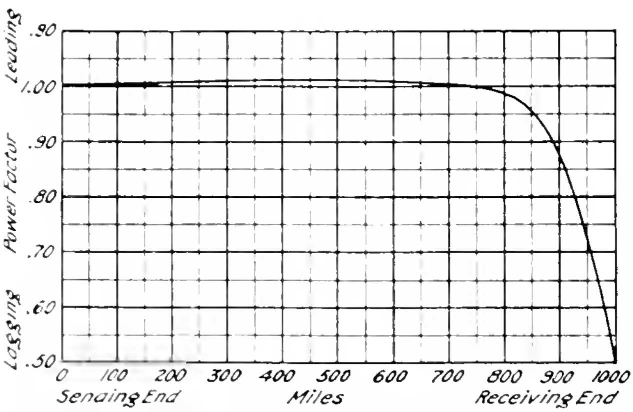


Fig. 18 Variation of Power Factor Along 1000 Mile Telephone Line, Using Two No. 6 B.& S. Copper Wires 12 Inches Apart. Frequency 1000 Cycles. Receiving End. 20 Volts Between Wires, .50 Milli-Amperes at .50 Power Factor Lagging

different from that transmitted as to prevent clear conversation between the points. Some of the higher harmonics may be entirely wiped out in their passage along the line. This is usually called wave distortion. Besides the unequal decrease of each harmonic's amplitude along the line, the speed at which each harmonic is transmitted is different, so that the received wave is built up of harmonics with entirely different phase relations from those that obtain in the transmitted wave.

Phase relations alone, however, do not affect hearing, since the ear can pick out and respond to each harmonic separately, the brain synthesizing the harmonics into the same sound, no matter what the phase relations of the harmonics, provided the harmonics retain the same relative amplitudes. If this were not the case, the positions of the various instruments in an orchestra, relative to the audience, would determine the sound produced at different points. In fact, music in its present form would be impossible.

To overcome the difficulty of the unequal attenuation of each harmonic, various schemes have been proposed. To reduce the attenuation constant, a common practice is to load telephone cables by inserting induction coils spaced at equal distances along the line. This method was introduced by Pupin and gives good results in practice. The coils should not be placed at greater intervals than 1/8 of the wave length of the normal frequency harmonic, otherwise reflection will occur at each coil, and calculations from equations formed on the assumption of uniformly distributed inductance will be vitiated.

An interesting example of this method of loading is found in the recently completed submarine cable which will be laid under the English Channel between Abbott's Cliff and Cape Gris Nez, a distance of about 24 miles. Iron cored induction coils are inserted in the cable every nautical mile. By their means, the attenuation constant at 750 cycles per second has been reduced from .045 to .014 per mile. This cable will be connected by means of an air line to Paris from the French side and to London from the English. It is contemplated extending the line to Scotland.

The cable was made by Siemens Brothers and contains duplicate telephone lines, having a resistance of 12½ ohms per loop mile and a capacity of .12 microfarads between wires. Thus the capacity is about 12 times the usual capacity of air lines. The induction coils each have a resistance of 6 ohms, with a self induction of .1 henry; *viz.*, about 30 times the self induction between wires per mile of air telephone lines. The diameter of the cable over the induction coils is 1½ inches, and this increased diameter extends for about 3½ ft.

The comparison of the attenuation constants and wave propagation velocities in this loaded cable, with those that would occur in a similar but unloaded cable, for two different frequencies, clearly brings out the advantage of loading. The following calculations were made on the assumption that the self induction due to the induction coils is distributed uniformly along the cable, and that therefore formulæ (37) and (38) apply.

If the cable is loaded and has the circuit constants already given, the attenuation constant per mile at 750 cycles per second equals .01, nearly, which is somewhat lower than the value .014 experimentally determined, as would be expected. The wave length is 12 miles, which gives a wave propagation velocity of 9000 miles per second, or only 1/20 that of light. If the frequency is doubled; that is, if a harmonic with a frequency of 1500 cycles per second is taken, the attenuation constant per mile and velocity of propagation are practically the same as in the previous case. Thus the loading has about the correct value to obtain equal attenuations and velocities over a wide range of harmonics and the quality of the sound at the end of the cable will be practically the same as at the sending end.

Assuming that two No. 10 B.&S. copper wires are used somewhat less than 1/2 inch apart, which would make the cable capacity and resistance approximately correspond with the values given for these constants, the self induction of the unloaded cable will be about .30 *milli*henrys per mile between wires, as against .10 henrys when the induction coils are included. On this basis, the unloaded cable has an attenuation constant of .056 per mile at 750 cycles and .075 per mile at 1500 cycles; that is, the higher harmonic is damped out more quickly than that of lower frequency. These values are more than five and seven times the corresponding values calculated for the loaded cable. At 750 cycles, the velocity of the wave is 74,000 miles per second, and 100,000 miles per second at 1500 cycles, the latter velocity being 35 per cent. greater than the former.

Thus not only will the various harmonics be unequally attenuated in the unloaded cable, but also the phase relations will appreciably differ at the receiving end from those at the transmitting end, even in the case of a 24 mile cable.

Telephone Lines with Distributed Leakage

If distributed leakage is artificially allowed along the line, it can be shown theoretically that the same attenuation constant can be obtained for all harmonics and that, therefore, the quality of the transmitted wave is unchanged at the receiving end, though its amplitude has been diminished. If the dielectric leakage current per mile is proportional to the voltage at any point, the following proof is applicable to the problem.

$m^2 = (g + jpC)(r + jpL)$, (see page 222, May REVIEW).

If $m = a + jb$, then $a^2 + b^2 = \sqrt{(r^2 + p^2L^2)(g^2 + p^2C^2)}$

and $a^2 - b^2 + 2\,jab = rg - p^2LC + j(pLg + pCr)$

Then, by equating the real parts of the second equation together and adding it to the first, the values of a^2 and b^2 are immediately obtained, which can be written as follows:

$$2\,a^2 = \sqrt{(rg + p^2LC)^2 + (rpC - pLg)^2} + rg - p^2LC \quad (39)$$

and

$$2\,b^2 = \sqrt{(rg + p^2LC)^2 + (rpC - pLg)^2} - rg + p^2LC \quad (40)$$

If, therefore, $rC = Lg$ then $a^2 = rg$ and $b^2 = p^2LC$.

That is to say, if the product of resistance and capacity is equal to the product of the self induction and dielectric conductance per mile, then the attenuation constant a per mile is equal to the square root of the product of the resistance r and the dielectric conductance g per mile, and is independent of the frequency and, therefore, will be the same for every harmonic. The wave length $\frac{2\pi}{b}$ will also vary inversely as the frequency. Hence, the velocity of propagation of each harmonic will be the same, and all harmonics will arrive at the receiving end in the same phase relations as at the transmitting end. In order to obtain this result, the self induction per mile must be artificially increased and the insulation resistance of the cable must also be decreased per mile considerably below normal. Hence, the leakage current per mile must be high, though it must not be increased too much, otherwise the attenuation constant will be too great. This method has theoretical interest, but as it is extremely difficult of application, it has not been used in commercial work so far as the author is aware.

Exponential Values of Accurate Transmission and Telephone Line Equations

Equations 23, 24, 25, 26, page 222, May REVIEW, can be written as follows by substituting the exponential and trigonometrical values of the hyperbolics. In this form, the direct and reflected waves are separated and the physical meaning of the equations is clearer than when written in the hyperbolic form, although the equations are not so well adapted for calculations. Steinmetz uses the exponential form in his "Transient Electric Phenomena."

If $m = a + jb$; that is, a is the real term of the constant m given in the REVIEW supplement and b is the j term. As already stated, a is called the attenuation constant per mile and b is the inverse of the wave length; that is, wave length $= \frac{2\pi}{b}$. The constants m_1 and $\frac{1}{m_1}$ per mile have the same values as given in the

REVIEW Supplement for the frequencies 25 and 60 cycles, and given circuit constants.

When the conditions are determined at the receiving end and x is the distance in miles measured from this end, then

$$e = \frac{\epsilon^{ax}}{2}\left(E_r + I_r m_1\right)\left(\cos bx + j \sin bx\right) + \frac{\epsilon^{-ax}}{2}\left(E_r - I_r m_1\right)\left(\cos bx - j \sin bx\right) \quad (41)$$

$$i = \frac{\epsilon^{ax}}{2}\left(I_r + \frac{E_r}{m_1}\right)\left(\cos bx + j \sin bx\right) + \frac{\epsilon^{-ax}}{2}\left(I_r - \frac{E_r}{m_1}\right)\left(\cos bx - j \sin bx\right) \quad (42)$$

When the conditions are determined at the generator or sending end, and the distance x in miles is measured from this end, then

$$e = \frac{\epsilon^{ax}}{2}\left(E_s - I_s m_1\right)\left(\cos bx + j \sin bx\right) + \frac{\epsilon^{-ax}}{2}\left(E_s + I_s m_1\right)\left(\cos bx - j \sin bx\right) \quad (43)$$

$$i = \frac{\epsilon^{ax}}{2}\left(I_s - \frac{E_s}{m_1}\right)\left(\cos bx + j \sin bx\right) + \frac{\epsilon^{-ax}}{2}\left(I_s + \frac{E_s}{m_1}\right)\left(\cos bx - j \sin bx\right) \quad (44)$$

In the case of telephone lines or cables, the constants a and b can be calculated for any frequency or line constants from equations (37) and (38) respectively. The constants m_1 and $\frac{1}{m_1}$ can then be calculated from formulæ (28) and (29), page 222, May REVIEW. The values so obtained must be substituted in the equations for each harmonic and the variation of that harmonic along the line can then be calculated. The sum of the instantaneous values of all harmonics at any point of the line gives the instantaneous value of the complex wave at that point.

It must be remembered in the case of telephone lines that if the volts between wires are substituted in the equations, L and C must be given in henrys and farads per mile between wires, and r in ohms per loop mile. The value of p is $2\pi f$ where f is the frequency.

Sign Conventions As Affecting Equations, Constants and Hyperbolic Functions

In all that precedes, a contraclockwise rotation of the current or voltage vector represents a current or voltage leading the standard phase; a clockwise rotation represents a lagging current or voltage. That is to say, a leading current is written $i = i_1 + ji_2$, and a lagging current $i = i_1 - ji_2$, voltages being written in a similar manner. With this notation impedance is written $r + jpL$ and admittance $g + jpC$. This notation has been used in the Supplement as well as in these articles.

If the opposite notation is used; that is to say, if a minus sign is placed in front of the j term for a leading voltage or current, and a positive sign for a lagging voltage or current, then impedance is written $r - jpL$, and admittance $g - jpC$, and the following changes must be made. The constant m must be written $a - jb$ instead of $a + jb$, and, therefore, the values of $\cosh mx$ and $\sinh mx$ must have the negative sign prefixed before the j term instead of the positive sign. The constant m_1 must be written with the positive sign before its j term, and the constant $\frac{1}{m_1}$ with the negative sign before its j term. In fact, the signs in front of the j terms for currents, voltages, constants or values of the hyperbolic functions must be changed from plus to minus or vice versa in order to make them correspond to the change of notation. The numerical values are, of course, unaltered, and no changes must be made in the signs prefixed before the real terms of any quantity.

In the case of the exponential forms of the hyperbolic equations, Nos. 41, 42, 43 and 44, the complex trigonometrical expressions must be interchanged in each equation; that is to say, the trigonometrical complex multiplier of ϵ^{ax} must have a negative sign placed before its j term and the multiplier of ϵ^{-ax} must have a plus sign placed before its j term. The constants m_1 and $\frac{1}{m_1}$ must also be changed as noted above.

Also, in the approximate equations for short lines, Nos. 5, 6, 7 and 8, REVIEW Supplement (Nos. 30, 31, 32 and 33, May REVIEW, page 223), the negative sign must be written before the j terms in each equation instead of the positive sign. The constants m_1 and $\frac{1}{m_1}$ must also be changed as noted above.

DETERMINATION OF RESISTANCE STEPS FOR THE ACCELERATION OF SERIES MOTORS

By E. R. Carichoff, M.A., and Harold Pender, Ph.D.

SUMMARY

The problem to be solved is the following: Given

Speed-current curve of motor corresponding to line voltage V.

The current I_1 at which the controller is to be advanced.

The number of steps (n) in the starting resistance.

To find the proper values of the resistances R_n, R_{n-1} ----- R_3, R_2, R_1, such that the current I_2 taken by the motor at the instant of advance of controller from one step to the next shall be the same for each point of the controller.

In addition to the above symbols let

S_1 = speed from speed current curve corresponding to I_1.

S = speed from speed current curve corresponding to a greater current I.

$$A_1 = \frac{V - I_1 r}{S_1 I_1}$$

$$A = \frac{V - I r}{S I}$$

$$D = \frac{A_1}{A}$$

Then plot the curve

$$Y = A_1(S_1 - S)(1 + D + D^2 + \text{-----} D^n)$$

against the current I as abscissa.

Case I. A single motor connected through the controller to the line.

Let I_2 be the value of I on the y curve which corresponds to $y = \frac{V - I_1 r}{I_1}$, and S_2 the speed from the speed current curve corresponding to $I = I_2$, and A_2 the corresponding value of A. Put $D_2 = \frac{A_1}{A_2}$; then the proper values for the resistance steps are:

$$R_1 = A_1(S_1 - S_2)$$
$$R_2 = R_1(1 + D_2)$$
$$R_3 = R_1(1 + D_2 + D_2^2)$$
$$\cdot \qquad (a)$$
$$\cdot$$
$$\cdot$$
$$\cdot$$
$$R_n = R_1(1 + D_2 + D_2^2 + \text{-- -- --} D_2^{n-1})$$

Case II. To find the proper values of the resistance steps for each of two motors in parallel which are changed over from full series at the instant when the current drops to the given value I_1.

Use the same y curve as in Case I, but find the current I_2 corresponding to $\frac{V}{2I_1}$, and let S_2 be the speed from the speed current curve corresponding to this value of I_2, and A_2 the corresponding value of A; putting $D_2 = \frac{A_1}{A_2}$. The proper values for the resistance steps are then given by the equations (a) as before.

Case III. To find the proper values of the resistance steps for two motors in series started from rest.

Using the same symbols as above, plot the curve

$$y = \left[r\left(\frac{A_1}{A} - 1\right) + A_1\left(S_1 - S\right)\right] \times \left[1 + D + D^2 + \text{----} D^n\right]$$

Let I_2 be the value of I corresponding to $y = \frac{V - 2I_1 r}{I_1}$; S_2 the speed from the speed current curve corresponding to $I = I_2$; and A_2 the corresponding value of A; putting $D_2 = \frac{A_1}{A_2}$. The proper values for the resistance steps are then given by equations (a) except that $R_1 = r\left(\frac{A_1}{A_2} - 1\right) + A_1\left(S_1 - S_2\right)$

EXAMPLE

From a given motor speed curve the following values were taken:

$I_1 = 200$

$V = 600$

$r = .134$

$S_1 = 17.57$

Then the values of S corresponding to different values of I were read and the curve, $S_1 - S$, was plotted with I as abscissæ.

The values of D were computed and plotted on the same sheet, Fig. 1.

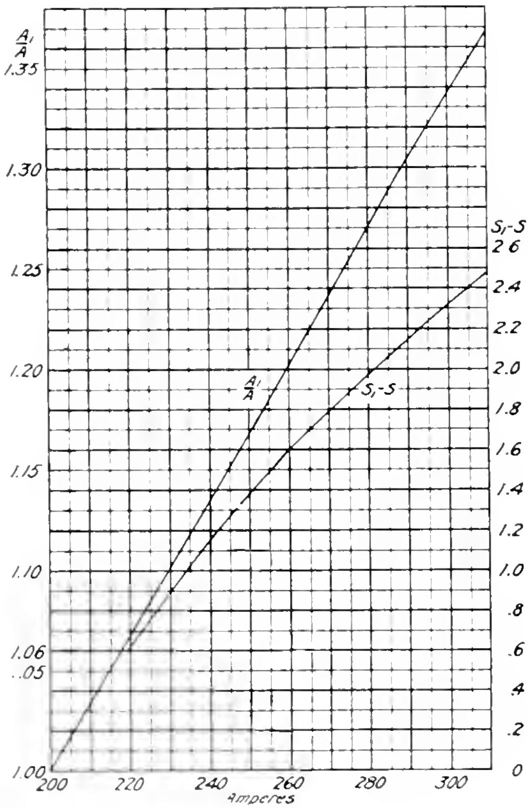


Fig. 1

In Fig. 2 were plotted the following curves for corresponding values of I and S.

$A_1(S_1-S)$	Curve (1)
$A_1(S_1-S)[1+D]$	Curve (2)
$A_1(S_1-S)[1+D+D^2]$	Curve (3)
$A_1(S_1-S)[1+D+D^2+D^3]$	Curve (4)
$A_1(S_1-S)[1+D+D^2+D^3+D^4]$	Curve (5)
$A_1(S_1-S)[1+D+D^2+D^3+D^4+D^5]$	Curve (6)

The computed values

$$\frac{V-I_1r}{I_1}=2.866 \qquad \text{Case I}$$

$$\frac{V}{2I_1}=1.5 \qquad \text{Case II}$$

were indicated at the margin.

Case I

For a six point controller the ordinate 2.866 corresponds to a current $I_2=266$ on curve (6).

The ordinates for $I_2=266$ on curves (1), (2), (3), (4) and (5) are the values of the resistance steps.

$R_1=.28$

$R_2=.62$

$R_3=1.03$

$R_4=1.53$

$R_5=2.13$

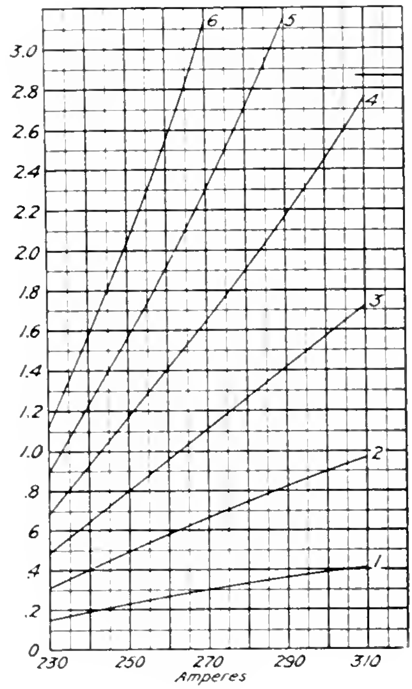


Fig. 2

Similarly for a five point controller the values are as follows:

$I_2=284$

$R_1=.33$

$R_2=.76$

$R_3=1.3$

$R_4=1.99$

Case II

The ordinate 1.5 corresponds to $I_2=239$ on curve (6). Therefore, for a six point controller, the values are

$R_1=.18$

$R_2=.39$

$R_3=.61$

$R_4=.88$

$R_5=1.17$

Similarly for a five point controller

$I_2=249$

$R_1=.22$

$R_2=.47$

$R_3=.77$

$R_4=1.12$

And for a four point controller

$I_2=265$

$R_1=.27$

$R_2=.61$

$R_3=1.01$

Also for a three point controller

$I_2=297$

$R_1=.37$

$R_2=.85$

Case III

For this case it is necessary to plot another set of curves corresponding to curves (1), (2), (3), (4), (5) and (6), which may be obtained by increasing the ordinates of curve (1) by $r(D-1)$ for each value of C, and of curve (2) by $r(D^2-1)$, of curve (3) by $r(D^3-1)$.... and finally of curve (6) by $r(D^6-1)$.

The intersection of the computed value

$$\frac{V-2I_1r}{I_1}=2.73$$

with the new curve (6) gives a value I_2 the ordinates of which on the other curves are the values of the resistance steps for a six point controller.

Similarly the values of the resistance steps for five or four point controllers may be read at a glance.

THEORY

The counter e.m.f. of a motor is proportional to the product of the flux per pole and the speed. In a series motor the flux is a function of the line current, being approximately proportional to the current. Hence we may write the counter e.m.f.

$$E=ASI$$

where in general A is a factor depending on the value of the current. (If the reluctance of the magnetic circuit were constant, A would likewise be constant.)

Let r = resistance of motor.

V = voltage at which speed current curve is determined.

I_1 = any chosen value of the current.

S_1 = corresponding speed from speed-current curves.

A_1 = corresponding value of the factor A.

Then $E=V-I_1r=A_1S_1I_1$

$$\text{Whence } A_1=\frac{V-I_1r}{S_1I_1} \qquad (1)$$

Similarly, for any other value of the current

$$A_2=\frac{V-I_2r}{S_2I_2} \qquad (2)$$

Now let

s = speed of motor with any given external resistance in series, at the instant the controller is advanced from one notch to the next.

I_1 = the current immediately before the advance.

I_2 the current immediately after the advance.

R = the external resistance before the advance.

R' = the external resistance after the advance.

Then

$$V=I_1(R+r)+A_1sI_1 \qquad (3)$$

$$V=I_2(R'+r)+A_2sI_2 \qquad (4)$$

But $V-I_1r=A_1I_1S_1$ and $V-I_2r=A_2I_2S_2$

Hence, substituting these values in (3) and (4) respectively, we get

$$A_1I_1S_1=I_1R+A_1sI_1$$

$$A_2I_2S_2=I_2R'+A_2sI_2$$

Dividing by A_1I_1 and A_2I_2 respectively

$$S_1 = \frac{R}{A_1} + s$$

$$S_2 = \frac{R'}{A_2} + s$$

Subtracting

$$S_1 - S_2 = \frac{R}{A_1} - \frac{R'}{A_2}$$

Whence

$$R = \frac{A_1}{A_2}R' + A_1(S_1 - S_2) \qquad (5)$$

Now let

$n+1$ = Number of steps on the controller.

n = number of blocks of resistance.

R_n, R_{n+1} - - - - R_3, R_2, R_1 be the external resistances in order, R_n being the largest and corresponding to first point on the controller.

R_{n+1} = total external resistance required to hold the current at I_1 when the armature is blocked.

When the controller is advanced from the next to the last step to the last step, thus cutting out all external resistance, we have in equation (5) that $R = R_1$ and $R' = 0$. Hence

$$R_1 = A_1(S_1 - S_2) \qquad (6)$$

For the next preceding advance of the controller we have in equation (5) that $R = R_2$ and $R' = R_1$. Hence

$$R_2 = \frac{A_1}{A_2}R_1 + A_1(S_1 - S_2)$$

$$= \frac{A_1}{A_2}R_1 + R_1$$

$$= R_1\left[1 + \frac{A_1}{A_2}\right]$$

Similarly

$$R_3 = R_1\left[1 + \frac{A_1}{A_2} + \left(\frac{A_1}{A_2}\right)^2\right]$$

$$R_n = R_1\left[1 + \frac{A_1}{A_2} + \left(\frac{A_1}{A_2}\right)^2 + \text{-------}\left(\frac{A_1}{A_2}\right)^{n-1}\right]$$

$$R_{n+1} = R_1\left[1 + \frac{A_1}{A_2} + \left(\frac{A_1}{A_2}\right)^2 + \text{------}\left(\frac{A_1}{A_2}\right)^n\right]$$

But for a *single* motor connected to the line, $R_{n+1} = \frac{V - I_1r}{I_1}$; hence I_2 must satisfy the condition that

$$\frac{V - I_1r}{I_1} = R_1\left[1 + \frac{A_1}{A_2} + \left(\frac{A_1}{A_2}\right)^2 + \text{------}\left(\frac{A_1}{A_2}\right)^n\right] \qquad (7)$$

where $R_1 = A_1(S_1 - S_2)$

Having *two motors* in full series taking a current I_1 is equivalent to having each motor connected directly to the line in series with an external resistance equal to $\frac{V}{2I_1}$. Hence if R_n is the external resistance for each motor corresponding to the first parallel notch on the controller, the equivalent resistance R_{n+1} corresponding to the next preceding notch is equal to $\frac{V}{2I_1}$. Hence for the parallel part of the controller period I_2 must satisfy the condition.

$$\frac{V}{2I_1} = R_1\left[1 + \frac{A_1}{A_2} + \left(\frac{A_1}{A_2}\right)^2 + \text{------}\left(\frac{A_1}{A_2}\right)^n\right] \qquad (9)$$

Where

$$R_1 = A_1(S_1 - S_2)$$

For *two motors in series*, equations (3) and (4) become

$$V = I_1(R + 2r) + 2A_1sI_1 \qquad (3a)$$

$$V = I_2(R' + 2r) + 2A_2sI_2 \qquad (4a)$$

and from a similar course of reasoning as before, we get, instead of equation (5), the equation

$$R + r = \frac{A_1}{A_2}(R' + r) + A_1(S_1 - S_2) \qquad (5a)$$

The last resistance step is then

$$R_1 = r\left[\frac{A_1}{A_2} - 1\right] + A_1(S_1 - S_2) \qquad (6a)$$

Then as before

$$R_2 = R_1\left[1 + \frac{A_1}{A_2}\right]$$

.
.
.
.
.

$$R_n = R_1\left[1 + \frac{A_1}{A_2} + \left(\frac{A_1}{A_2}\right)^2 + \text{----}\left(\frac{A_1}{A_2}\right)^{n-1}\right]$$

$$R_{n+1} = R_1\left[1 + \frac{A_1}{A_2} + \left(\frac{A_1}{A_2}\right)^2 + \text{----}\left(\frac{A_1}{A_2}\right)^n\right]$$

In this case, $R_{n+1} = \frac{V - 2I_1r}{I_1}$; hence for two motors in series I_2 must satisfy the condition that

$$\frac{V - 2I_1r}{I_1} = R_1\left[1 + \frac{A_1}{A_2} + \left(\frac{A_1}{A_2}\right)^2 + \text{----}\left(\frac{A_1}{A_2}\right)^n\right] \qquad (8)$$

Where

$$R_1 = r\left[\frac{A_1}{A_2} - 1\right] + A_1(S_1 - S_2)$$

400,000 VOLT TESTING TRANSFORMER

By John J. Frank

In the General Electric Review for December, 1904, the writer described two 150 kw., 160,000 volt testing transformers, which were built by the General Electric Company for the Columbia Improvement Company.

These machines were referred to at that time as being of exceptional design because of their high voltage rating. Recently a transformer designed for a much greater voltage has been shipped from the Pittsfield factory of the General Electric Company.

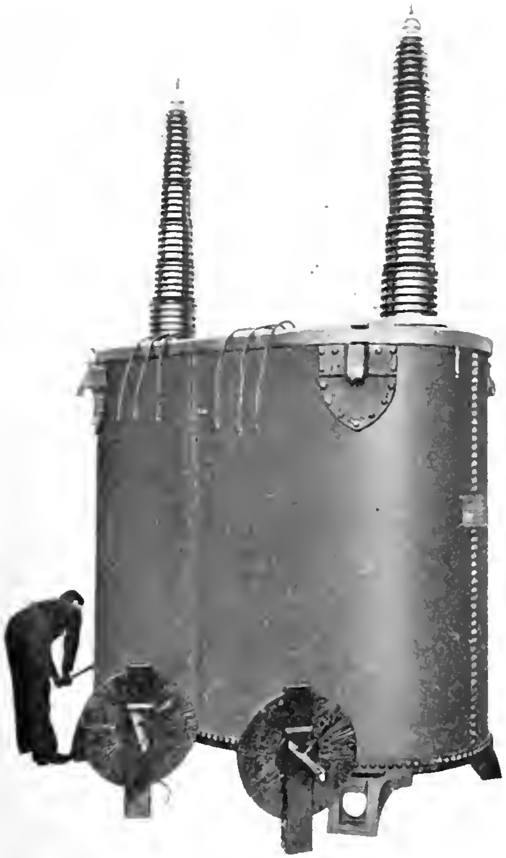


Fig. 1. 150 Kw., 400,000 Volt Testing Transformer

This transformer was built for the R. Thomas & Sons Company, of East Liverpool, Ohio, and is intended for the general testing of transmission line insulators manufactured by that concern.

Some idea of the size and construction of this transformer may be had from an inspec-

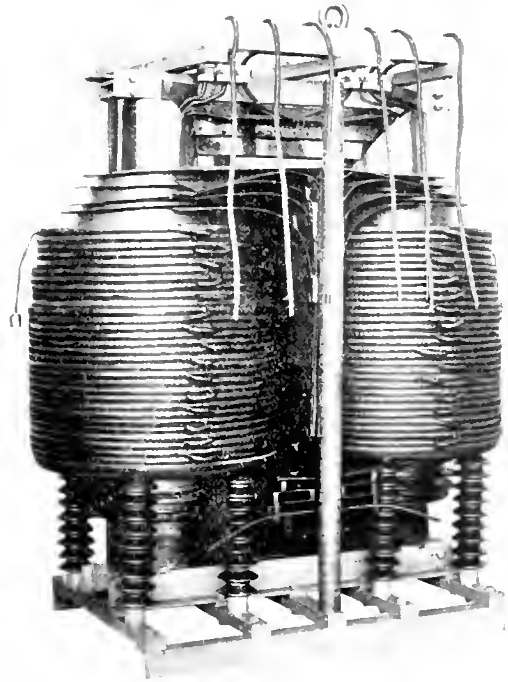


Fig. 2. Transformer Removed from Case

tion of the accompanying illustrations. Fig. 1 shows a view of the assembled transformer with the high tension coils and their supporting insulators on the outside, while Fig. 2 shows the completed transformer. This transformer is of 250 kw. capacity and is intended to operate at 60 cycles, with a primary voltage of 1150 or 2300 and a secondary voltage of 400,000. The low tension winding is wound directly on the core and in construction follows the usual practice for transformers of this description. The winding is provided with taps so that when connected for either 1150 or 2300 volts the center of the winding can be grounded. The high tension winding consists of a large number of circular disc coils, separately wound and insulated. A bare conductor is used and this is wound one turn per layer and placed between the selvaged edge of the intervening insulation, thereby making it practically impossible for any of the turns to become displaced. These coils are then taped and impregnated with insulating compound, with the result that the coil forms a solid mass of insulation and winding. This method of constructing the coils has been generally adopted for transformers of high voltage, since it has given universal satisfaction wherever used and makes possible the designing and building of a transformer that will operate satisfactorily at high voltage, such as that at which the transformer under consideration is intended to work.

As shown by the photograph, the high tension winding is supported by sectional porcelain insulators, and between the primary and secondary windings are placed concentric cylinders with flanged ends. Between these cylinders vertical and horizontal ducts are arranged to allow for the circulation of the oil, thus providing sufficient creepage surface to prevent any appreciable leakage from the high tension winding to ground.

The high tension transformer leads are similar in design to the usual high tension leads; in other words, consist of sectional leads filled with oil.

The cover of the transformer is of cast iron and is provided with a manhole to facilitate examination and inspection of the interior of the transformer. The necessity of disturbing any of the external connections is thus avoided.

One of the tests to which this transformer was subjected before shipment was a one-half hour run at 650,000 volts, with the center of the high tension winding grounded. It has also been tested with first one and then the other of the high tension terminals grounded and the winding excited at 400,000 volts.

Within the last year a considerable number of transformers of similar design, ranging in voltage from 150,000 to 300,000 volts, have been built and tested, but, so far as is known, this transformer operates at a higher voltage than any other which has been built for commercial work.

The general characteristics of the transformer are as follows:

Core loss	8400 watts
Copper loss	1270 watts
Total	9670 watts
Efficiency, full load	96.3 %
Exciting current	7.18%
Impedance	5.4 %
CR drop	0.51%
Reactance	5.4 %
Floor space	5 ft., 7½ ins. by 10 ft.
Height to top of lead	16 ft., 9¼ ins.
No. gallons of oil	2270 gals.
Net weight	20,000 lbs.

BOOKS RECEIVED

The GENERAL ELECTRIC REVIEW has recently received the following books, reviews of which will be published later; these works, together with those previously received, may be examined at the REVIEW office:

Ball, Sources of Power.
Bedell, Direct and Alternating Current Testing.
Blaine, Calculus and Its Applications.
Bottone, Magnetos for Automobilists.
Brewer, The Motor Car.
Bright, Life of Charles Tilson Bright.
Carpenter & Diederichs, Combustion Engines.
Davies, Electric Power and Traction.
Del Mar, Electric Power Conductors.
Fowle, Protection of Railroads from Overhead Transmission Line Crossings.
Groth, Welding and Cutting Metals by Gases or Electricity.
Gueldner, Combustion Engines.
Hobart, Electricity.
Hobart, Heavy Electrical Engineering.
Hogle, International Combustion Engines.
Koester, Hydroelectric Developments & Engineering.
Koester, Steam-Electric Power Plants.
Sloane, Elementary Electrical Calculations.
Solomon, Electric Lamps.
Sothern, The Marine Steam Turbine.
The Copper Handbook, Vol. IX.

PREVIOUSLY RECEIVED

Ashcroft, Study of Electrothermal & Electrolytic Industries.
Auerbacher, Electrical Contracting.
Barrows, Electrical Illuminating Engineering.
Bowker, Dynamo, Motor and Switchboard Circuits.
Franklin & Esty, Elements of Electrical Engineering.
Kershaw, Electro-Metallurgy.
McAllister, Alternating Current Motors.
Monckton, Radio-Telegraphy.
Russell, Electric Cables & Networks.
Taylor, Stationary Transformers.

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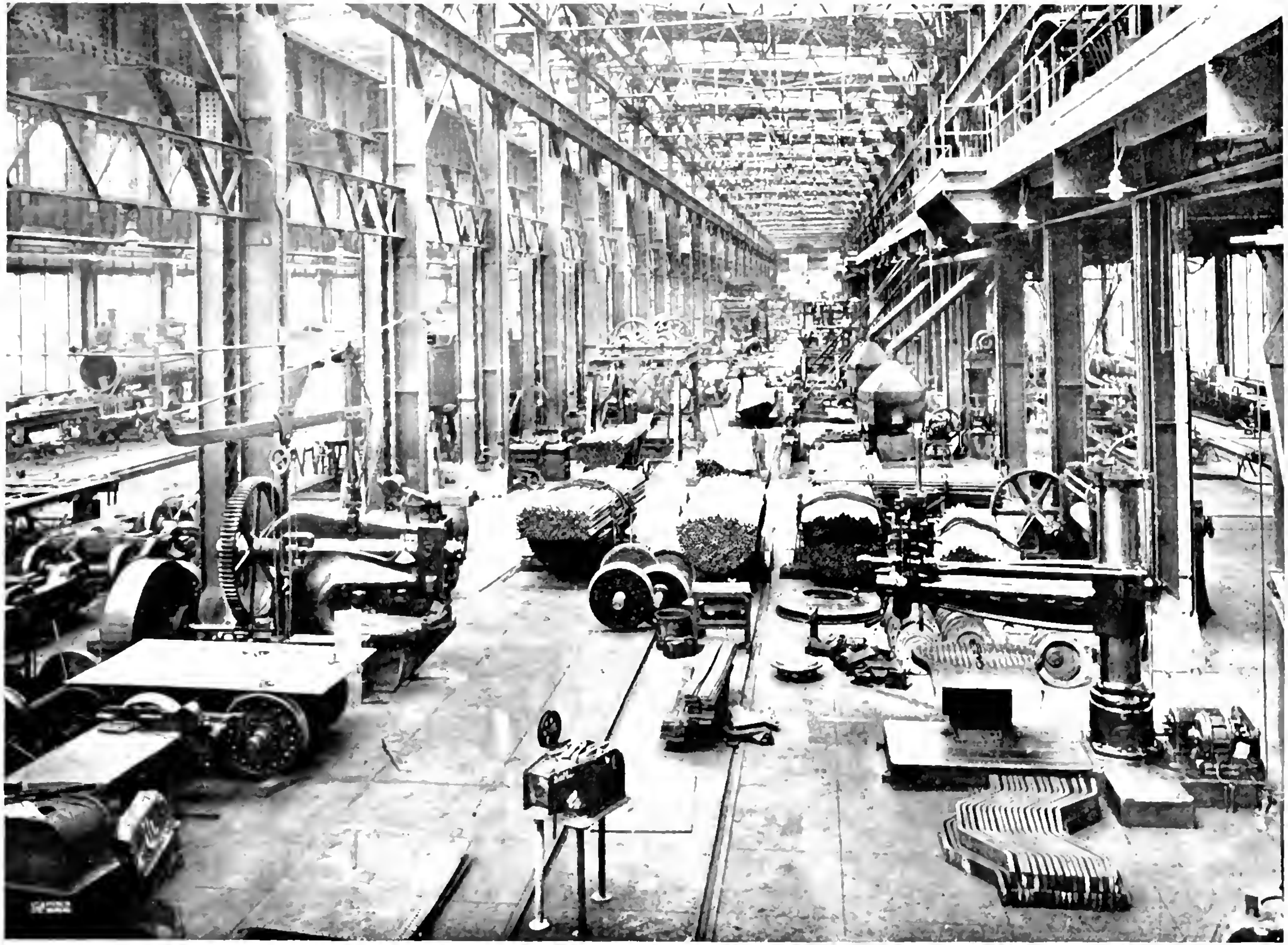


General View of Repair Shop of N. Y., N. H. & H. R. R., Readville, Mass.
(See page 367)

GENERAL ELECTRIC REVIEW

LUMINESCENCE

The problem of artificial lighting has confronted mankind since the dawn of history; but, as in many other fields of endeavor, a greater advance has been made in the past century—and more particularly in the last 30 years—than in all the centuries that went before; the lamps of our forefathers in the 18th century being but little better than those used by the ancients, the main dependence for artificial light being placed upon candles.

The first real advances over the use of the candle were the introduction of illuminating gas, in the early years of the 19th century, and the replacement of sperm oil by kerosene which followed the discovery and development of the oil fields. The next epoch-making advance came with the utilization of electricity in the carbon arc light and the incandescent lamp.

Thus far the phenomenon of luminescence played no part in commercial lighting; the light both from the carbon arc and the incandescent lamp is due to temperature, the temperature of the upper electrode (mainly) and of the filament, respectively. Thus the light obtainable from these sources is limited by the temperatures available: *viz.*, the boiling point of carbon in the case of the arc—3750 deg. cent.; and about 1800 deg. cent. in the case of the carbon incandescent lamp, a higher temperature than this causing an excessive deterioration of the filament by evaporation. Were it possible to operate the filament at higher temperature switchout deterioration, the efficiency would be materially bettered, as that portion of the total radiation which is visible increases with the temperature. Along these lines there has been much research to obtain a material sufficiently refractory, and with a vapor tension low enough to withstand higher temperatures without evaporating. The "metallized" carbon filament, on account of its low vapor tension, was a long step in the right direction and reduced the power consumption to 2.3—2.6 watts per candle-power. Far superior, however, are the metals osmium, tantalum, and tungsten. With these metals, the operating temperature is limited by the melting point—not by evaporation as in the case of carbon. Of the three tungsten is the best, reducing as it does the power consumption to between 1 and 1.25 watts per candle-power. Happily, the available supply is practically unlimited.

While tunsgten is to-day the best material for the purpose, it is curious that Mendelejeff's periodic law indicates the existence of a metal, as yet unknown, of even higher melting point, which should therefore serve still better as a filament.

It has been suggested, however, that we may not have exhausted the possibilities of carbon, and that in some one of its allotropic forms, it may again take the lead as the most efficient filament.

As has been said, both the light from the carbon arc and from the incandescent lamp is due to and depends upon temperature, but the phenomena of luminescence—as explained by Dr. Steinmetz in his article on the subject in the present issue—do not follow the temperature law. Not only does the efficiency of light production fail to increase with the temperature, but sometimes quite the reverse. The author explains that the phenomenon consists essentially in setting the particles of the illuminating material in vibration under such conditions that they can vibrate at their natural frequency, thus producing characteristic radiations. When the selective radiations are within the range of the visible spectrum, a light of characteristic color results. The author shows that there are two convenient ways of obtaining these phenomena, *chemically* and *electrically*. The former method is used commercially in fireworks and signal sights, while the latter—which is by far the more important of the two—is exemplified in the Moore tube, the mercury arc and the flame arc lamps.

Electro-luminescence may be produced

in two ways, *i.e.*, by disruptive conduction and by continuous conduction. Disruptive conduction, of which the Geissler tube is an example, has been employed to very little extent commercially. A relatively high voltage is required at the terminals, and in order to obtain reasonable efficiency, the tube must be very long, so that the useful energy expended in the stream may be much greater than the energy lost at the terminals. For this reason, the tubes are essentially large units.

In the case of continuous conduction, in contradistinction to disruptive conduction, the current generates its own conducting vapor by evaporating the electrode material. Examples of this may be seen in the flame and luminous arc lamps. In the ordinary carbon arc lamp, the arc stream is almost non-luminous, practically all the light coming from the heat of the electrodes. In the flame and luminous arc lamps, on the contrary, it is the arc stream itself that is the source of light; this light being due to luminescence and the color depending upon the material of which the electrodes are composed. The efficiency of the light production therefore depends upon selecting materials for the electrodes such that a large proportion of the radiations will be in the visable spectrum. The best materials for this purpose are mercury, calcium and titanium. The first of these is used in the mercury arc, the last two in the flame and the luminous arc, respectively, *i.e.*, calcium giving a characteristic yellow-orange colored light of high efficiency, and titanium an exceedingly efficient white light.

To introduce the luminescent materials into the arc stream two methods are employed, *electro-conduction* and *heat evaporation*. In the former the luminescent material is placed in the negative electrode and itself forms the vapor that conducts the current. Lamps of this description are called "*luminous arcs*."

The lamps employing the method of heat evaporation are called "*flame arcs*;" in them the luminescent material does not engender the arc stream but is introduced into it by being vaporized by heat from one or both of the electrodes. An intensely hot arc is necessary in this case and the carbon arc is used, the calcium or other material being mixed with the hotter positive electrode, or sometimes with both electrodes.

Each of the above methods has its advantages and its disadvantages. In the case of electro-conduction, higher efficiencies may be obtained and, since the material forms the arc by electro-conduction and not by heat, the electrodes may be of any convenient size. The positive may therefore be permanent and the negative of such a size as to last for 100 or 200 hours.

On the other hand, the substances that can be used for electrodes are limited. Calcium can not be employed as no stable compound of calcium is known that forms a conducting vapor. When operating on the alternating current the choice of electrode material is even more limited, titanium carbide being the one titanium compound that seems to be satisfactory.

With the method of heat evaporation, however, the choice of luminescent materials is wide. The material need not be conducting, the carbon with which it is mixed furnishing the conducting vapor. Calcium compound may thus be used, as may a number of other substances that are not suitable for the luminous arc. The employment of carbon also insures a steady light, and, furthermore, renders the arc easily operative on the alternating current. On account, however, of the high temperature that must be maintained at the end of the electrodes, these must be small, and for this reason their life is short.

To summarize: of the three best materials for electro-luminescence, mercury is used in the mercury arc lamp, and the arc stream is supplied by electro-conduction from the negative; calcium is used in the flame arc and is invariably fed into the arc stream by heat evaporation from the positive electrode, or sometimes from both electrodes; titanium is usually employed in the luminous arc, and itself furnishes the arc stream from the negative electrode. It is also used in the flame arc lamp, when it is fed into the stream by heat evaporation.

By means of these materials efficiencies have been obtained far better than have ever been secured by temperature radiation. A specific consumption of 0.25 watts per candle-power is not uncommon with large flame arcs, and even better efficiencies have been noted. In fact there seems to be no limit to the possible efficiencies that may be reached through research in the field of luminescence.

POWER IN THE SILK MILL*

By Andrew Kidd, Jr.

Consulting Engineer

The object of this article is to endeavor, as far as possible, to point out to silk manufacturers and their operating superintendents the advancement that has been made in recent years in the driving of the different machines used in the silk industry.

It has been the privilege of the writer to follow closely the power requirements of silk mills for several years past, and, consequently, he has been brought in contact with all sorts of conditions.

The larger silk manufacturer is willing to spend judiciously far more money in proportion on his power equipment than the smaller manufacturer, if he estimates that his cost of production per yard will be correspondingly reduced or the quality of his product improved.

The cost of power in the average mill is probably less than 2½ per cent. of the finished product; therefore, a manufacturer can afford to allow an increase in the cost of his power if by so doing he can increase his production with practically the same operating expenses.

Many manufacturers rent their buildings with power. Those who generate their own power should investigate existing conditions from the coal to the finished product. It sometimes appears that a cheaper grade of coal is more advantageous than the higher grades, but this is not true except in very few cases. The cheaper grades of coal do not have the same number of heat units as the better grades, consequently, there is more firing, more ashes, more cleaning of boilers, etc., for the same amount of horse-power delivered.

In the older mills the boilers installed carry from 80 to 90 pounds pressure; in recent years the tendency among all textile manufacturers has been to install boilers for 125 to 150 pounds pressure.

In selecting an engine for motive power, the question is raised as to whether it shall be a Corliss, a high-speed type, or a steam turbine. If the plant is to be mechanically driven, the Corliss or high-speed type is applicable; but should electricity be under consideration as a means of distributing power, the steam turbine can be adapted under certain conditions. The high-speed engine, which is the cheapest in first cost, does not have the life of the Corliss or the steam turbine. The maintenance item on the high-speed engine is, consequently, more than on either of the others.

In many cases all exhaust steam from the engine can be used for process work or for heating the buildings in winter, and on units up to 150 horse-power it is a question whether or not a condenser system in connection with the engines will pay, if the exhaust steam can be used in any way. With an engine probably the condenser will not pay in any event, as the depreciation, interest on investment, and cost of power required to drive the auxiliaries relative to the condenser apparatus, will be a greater item than the amount of coal saved when running the plant non-condensing.

Every engine room should be equipped with a steam engine indicator, and cards taken at least once a week; or, what is much better, if the plant is equipped electrically, a recording wattmeter should be installed and readings taken every half day and averaged every week. The indicator cards will give a general idea as to power conditions in the mill. They will show, assuming that the mill is running under normal conditions when the cards are taken, whether or not the line shafting is still true and whether any abnormal conditions exist in the drive. The wattmeter readings will give the exact amount of power used in the mill, and these readings, together with the number of yards produced, furnish a very accurate record of the power requirements; in fact, in some large installations a wattmeter is placed in each department, so that an exact record may be kept of the power required to run that particular branch.

The mechanical system of driving is efficient if the mill is a one-story building of short length, and the power house placed in the center of the drive; but even in such cases, the many advantages of electric drive often call for its adoption. Where cross-belts, right-angle turns and the transmitting power from floor to floor and from building to building is considered, the efficiency of this plan is not comparable with that of the electric drive.

* Reprinted from Silk

Fig. 1 shows an indicator card taken on an engine driving only the line shafting in a large silk mill, and Fig. 2 the card taken when the mill was in full operation. From these cards it will readily be seen that the amount of

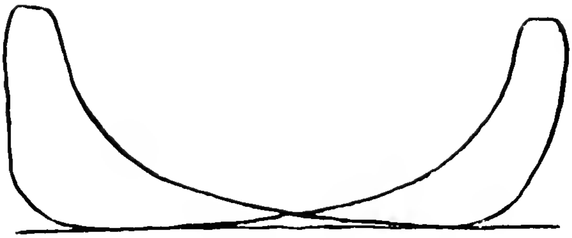


Fig. I.

Showing an Indicator Card Taken on an Engine Driving the Line Shafting Alone in a Large Silk Mill

power necessary to turn all the line shafting, belts and loose pulleys is a large percentage of the total horse-power delivered by the engine when working under full load conditions.

Should the mill be one of fairly good size, the mechanical drive is not so efficient as the electric drive since considerable line shafting and the large, heavy belts used for the main distribution of power are eliminated.

When considering the electric drive for a mill, the first point to be settled is the current to be used. The silk manufacturers and their operating superintendents are not always familiar with electrical subjects and are therefore not in a position to decide whether they should install alternating or direct current machines, and for their benefit I would like to point out the many advantages of the alternating current over the direct current for silk mill work, except silk printing, where the direct current is better suited

Direct current is equal in every respect to alternating current for lighting, but owing to the inherent characteristics of a direct current motor, it is not so suitable as the alternating current (known also as the induction) motor for power in the case of silk mills. The direct current motor, if allowed to run under load, will change its speed from 5 to 10 per cent. from 7:00 a.m. until 10:00 a.m.; that is, at 7:00 a.m the line shafting may be running at, say, 130 r.p.m., and if the speed of the motor is not regulated by the person in charge, at 10:00 a.m. the line shafting will be running at approximately 138 r.p.m.; consequently, the driven machines, whether they be throwing preparatory or looms, will have a corresponding increase in speed. If these machines will run satisfactorily at the higher speed, then while the motor is increasing in speed the manufacturer is losing an amount of production proportional to the difference between the speeds.

In mills having the direct current motor, a field rheostat is usually installed in the circuit, so that the speed of the motor can be regulated, thereby maintaining a constant speed on the line shaft. Regardless of the design or make of the direct current motor, this condition of speed change, due to the heat, is bound to exist, and necessitates manipulating a field rheostat to maintain an approximate constant speed. With the direct current motor the commutator and brushes must be inspected continually. After reasonable length of time, the commutator will necessitate truing up and the brushes are bound to wear out; thus the maintenance item should not be overlooked. Another feature is that the direct current motor should not be run at a load which exceeds its nameplate rating, as it is liable to spark and set fire to the lint and fly common in textile mills.

The alternating current motor does not have any of these features, as it is without commutator and brushes, and, with the exception of a slight variation due to changes

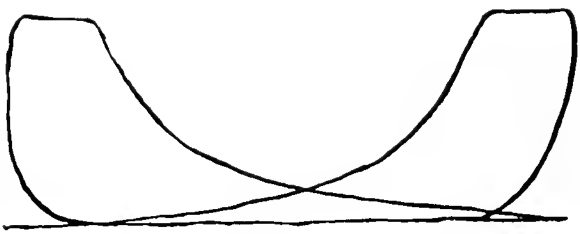


Fig. 2.

Showing an Indicator Card Taken When the Mill was in Full Operation

in load, its speed does not change except with a change in the speed of the generator in the power house.

The remainder of this article will deal principally with the alternating current system, as it is without question the better suited for silk mills.

The switchboard of to-day is somewhat different from that built years ago. In the olden days any board equipped with a voltmeter, ammeter and main line switch was considered sufficient; to-day there is as much attention given to the switchboard as to either generators or motors.

When there is both a motor and a lighting circuit on the generator, there should be installed an ammeter in each phase of a two- or three-phase equipment, so as to be able to determine whether the generator is properly balanced. Any unbalancing is due to an uneven distribution of lamps on the different phases, for when the generator is delivering power for polyphase motors only, the current in each phase is the same.

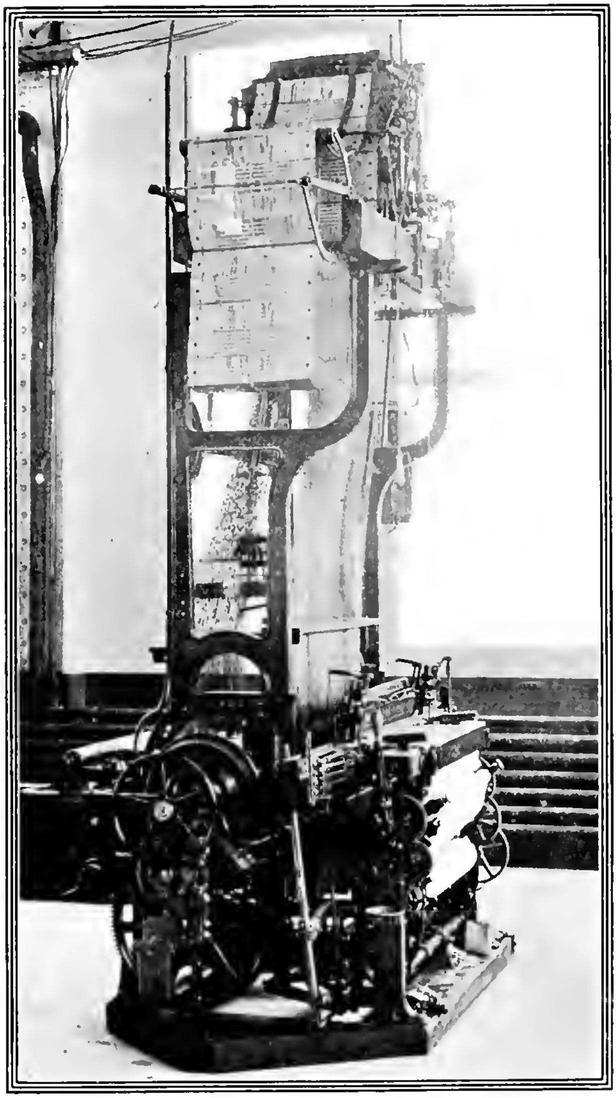
It is advisable to have a recording wattmeter on the board, or, if the plant is of sufficient size, a wattmeter can be placed in each circuit.

Knife switches with enclosed fuses are suitable for 220 volt power feeder circuits, but when 440 or 550 volts are used, these circuits should be controlled by oil switches having overload release. Knife switches on these higher voltages will hold an arc which not only burns the contact parts, but also mars the slate or marble board. This does not occur with oil switches, as the operating mechanism is usually the only part of the switch on the face of the board, while the switch itself is supported back of it. As the contact parts are immersed in oil, there is no injurious arcing, for when the circuit is broken the oil suppresses any arc which may occur; moreover, the oil switch is an important factor of safety to the operator.

The lighting circuit of 110 volts can be obtained by either balancer coils or transformers. Knife switches are suitable for the control of these lighting circuits.

A 220 volt circuit is suitable for most silk mills, but where the buildings are scattered and long circuits required, the voltage should be either 440 or 550. This reduces the size of wire necessary to transmit the same amount of horse-power. In choosing alternating current motors, the phase, frequency, efficiency, power factor and slip should be considered, and the most important of the last three items is the slip.

The grouping of machines under one motor is next to be considered. The motor should be placed as near to the center of the power load as possible; right-angle turns in the drives being avoided, and also belts from one floor to another. Motors from 15 to 25 horse-power in capacity are best suited for either a throwing or weaving mill; for when the motors are larger a large part of the flexibility of electric drive is lost, and with the squirrel cage rotor type of motor which is commonly used the starting current is relatively large. The current when starting under load amounts to between three and four times the normal running current, so that, should a large motor be thrown on a generator of limited capacity at a time when other motors and lights were in operation, this excessive current would mean a sudden overload on the



Individual Motor Drive Applied to Jaquard Loom generator, which would show up principally in a dip or flicker of the lights.

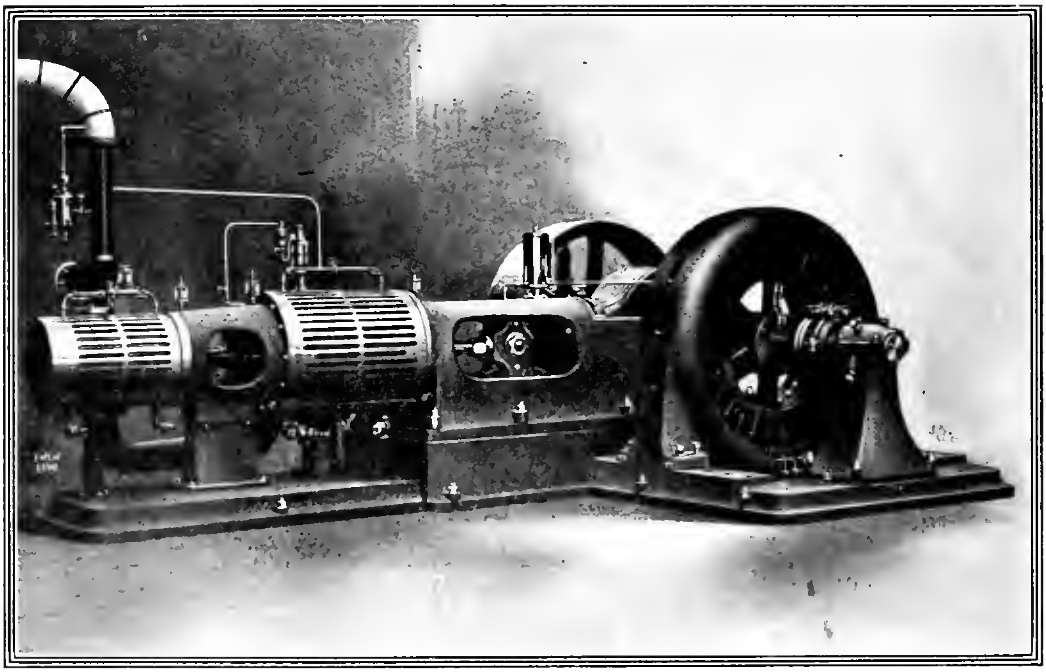
High speed motors should be installed whenever possible, as the power factor and efficiency of these motors is better than that of the slow speed motors.

The slip of an induction motor is the difference in speed caused by a difference in load and, in the writer's opinion, it is far more important than efficiency. A motor with 4 per cent. slip and 87 per cent. efficiency is preferable to a motor with 6 per cent. slip and 89 per cent. efficiency, especially in the weave shed, where the load on the motor may vary from 40 to 100 per cent.

The group system is the most used, but the individual system for looms is coming into popular favor, as some of the largest silk manufacturers have adopted it and have pronounced it a decided success.

This individual system has not the same advantages for throwing machines or preparatory machines, such as warpers, winders, quillers, etc., that it has for looms, as the load factor on the former machines should be about 100 per cent. The preparatory machines take very little power—winders and quillers about 3/4 horse-power each. The driving of these two machines calls for a constant load, but when we take the warping machines, the conditions are entirely different, especially when beaming is in progress.

During the process of warping the power required is approximately 1/4 horse-power. When the operation of beaming starts the power required is approximately 1/2 horse-power, and this increases as the roll becomes larger in diameter and more weights are added, until the warp is about beamed, when the motor is called upon to give about 1 1/4 horse-power. This will cover about all warpers that are beaming less than 20,000 ends, and with a length of warp of approximately 450 yards.



105 K.W., 60-Cycle, 3-Phase Generator Direct Connected to Tandem Compound High Speed Engine

On one occasion the writer installed the individual drive on some warpers and a 3/4 horse-power motor was used, this motor being capable of delivering for very short periods of time, up to $1\frac{1}{2}$ horse-power. It was found later that the operator could not put the required tension on the warp, and that when this was attempted the motor was stalled. The motor was tested out and it was found that the power taken when stalled was between $1\frac{3}{4}$ and $1\frac{7}{8}$ horse-power.

On further investigation, it was found that the warp consisted of 40,000 ends and extra-heavy weights were used. This condition is the exception rather than the rule. A $1\frac{1}{2}$ horse-power motor was then installed and tested under similar conditions as before, when it was found that the maximum power required was $2\frac{3}{4}$ horse-power.

The warping operation lasts from four to six days, which, as explained, requires $\frac{1}{4}$ horse-power, and the beaming lasts from $2\frac{1}{2}$ to 4 hours and requires from $1\frac{1}{4}$ to $2\frac{3}{4}$ horse-power. The load is very intermittent while beaming, as the operator is required to stop very frequently to tie threads, etc. It is evident that the individual system for these machines entails a comparatively greater outlay of money than that required by the group system. It is seldom that out of ten warpers there are more than three beaming at once, and the overload capacity of the large motor in the group system would easily take care of this heavy power condition, giving the group system a far higher efficiency and the circuit a better power factor.

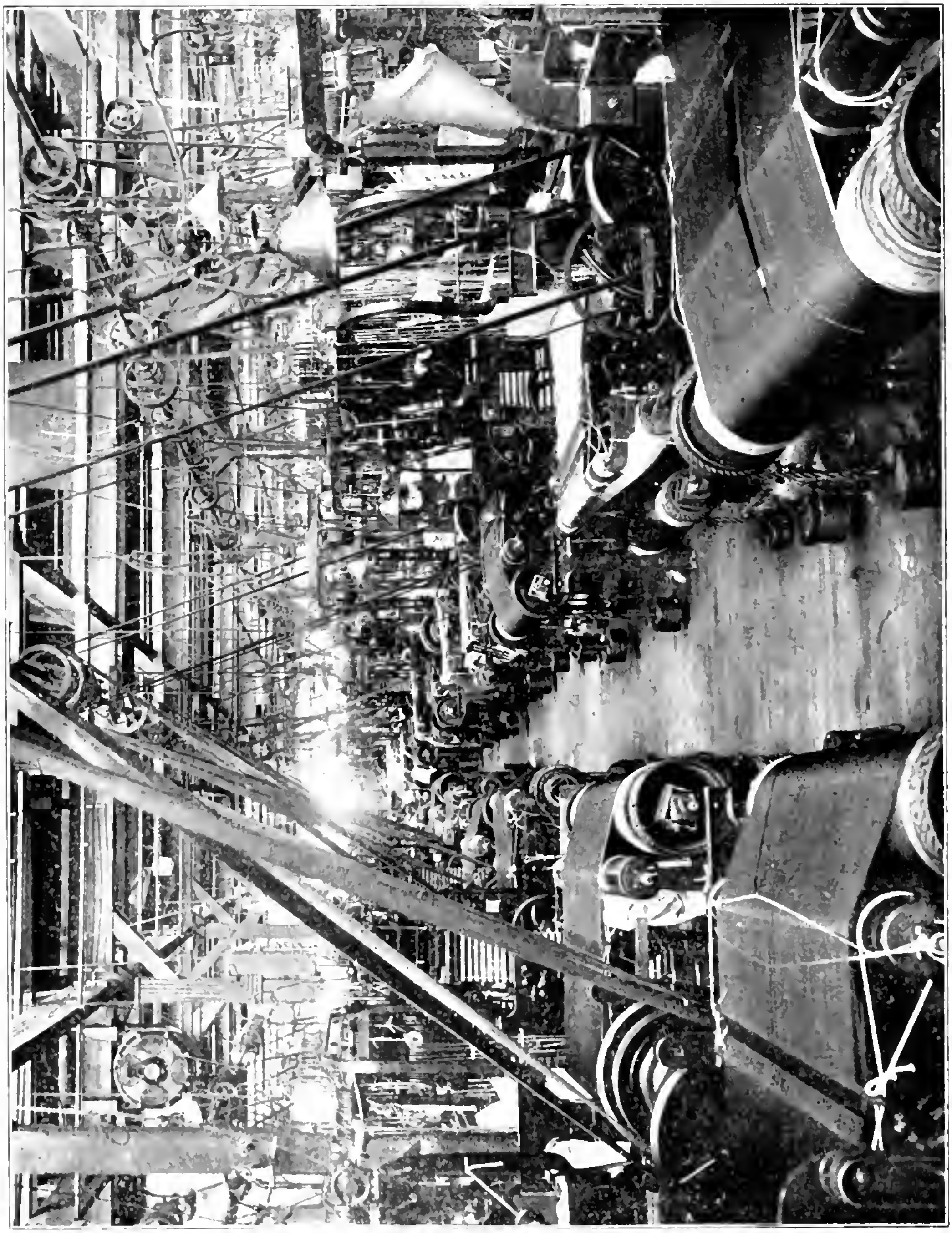
The efficiency of the mill is *no more* with the individual system than with the group system, and, when purchasing motors for the individual drive of looms, one should not be led to believe that it is. The efficiency of a 20 horse-power motor, used in the group system, is approximately 88 per cent., while the efficiency of a $\frac{1}{2}$ horse-power motor, used in the individual system, is approximately 70 per cent. It can readily be understood that this loss is equal to, or greater than, the loss of a belt transmission from the motor to the line shaft and from the line shaft to the loom. However, there are points more vital than efficiency to be considered, first among which is the increased production, then low maintenance cost, absence of oil and dirt overhead, absence of belts, better light (both natural and artificial), and the convenience of placing machines in any position without regard to line shaft.

The individual drive facilitates the easy changing of the speed of looms to suit different classes of silk. These changes are made by using different pinions on the motor, one pinion tooth making a variation of approximately 7 picks on the loom.

The horse-power of the motors used on looms differs materially and depends on the width of the loom, number of picks per minute, class of goods, and whether or not the motor starts and stops with the loom. The practice most commonly followed is to start and stop the motor with the loom. With this method there is an element of flexibility, usually a slip gear, installed in the drive, and the throwing of the shipper handle operates an oil switch which starts and stops the motor; in fact, the operation for the weaver is exactly the same as when the tight and loose pulley or friction pulley is used. There are many equipments installed where the friction pulley is retained and the shipper handle mechanism connected in such a way that the oil switch is thrown just a trifle sooner than the friction clutch, the theory being that the motor has a chance to accelerate at least part way before the load is thrown on. Should the oil switch be thrown in with no element of flexibility in the drive (either a slip gear or a friction pulley), considerable damage would result to the warp, which would show up principally in broken threads, owing to the fact that the motor would start the loom too suddenly.

The motor used on the individual drive must have sufficient capacity to start the loom quickly and make a good, clean pick, throwing the shuttle full across the loom; also to force the filling thread back against the weave, so that there will be no marks in the cloth. If the motor is too small it will pick up too slowly, and the above difficulty will become evident. If the motor is of too large capacity, the starting of the loom can be regulated by the tension on the slip gear or the friction clutch.

On looms from 27 in. to 36 in., a $\frac{3}{8}$ horse-power motor should be used, and from 36 in. to 60 in., a $\frac{1}{2}$ horse-power motor. On box looms a $\frac{3}{4}$ horse-power motor should be used, as the mechanism of this loom is heavy and the loom usually wide, even though the speed rarely exceeds 110 picks per minute. It takes almost as much power to run these looms up to speed without a warp as it does to run them when the weaving is in progress. Velvet and plush looms are heavier, and a one horse-power motor is usually installed.



Weave Shed Under Group Drive. Motor Suspended From Ceiling

Regarding narrow fabric looms, the operation of this loom is somewhat different from that of the broad looms. Under this class of fabrics would be placed silk ribbons, hatbands and elastic goods. The element of flexibility is not provided with these looms, as the mechanism does not require it. The quicker the loom can start and get in full operation the less liability there is of having a mark in the weave.

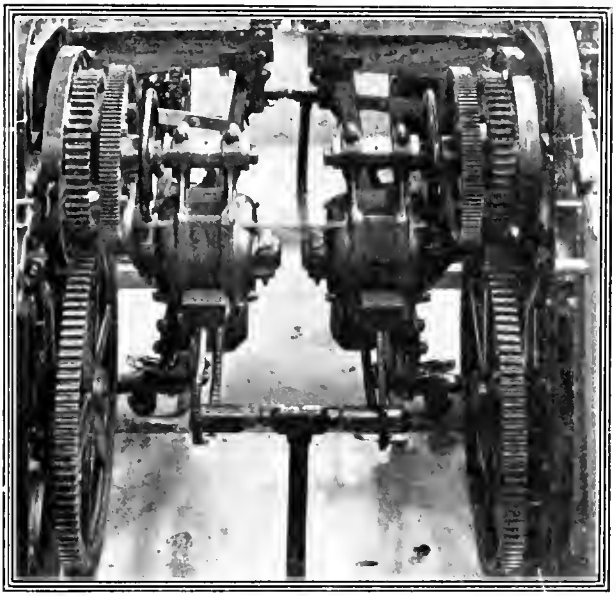
On the silk ribbon and hatband looms the motor is geared direct to the loom, and is started and stopped by means of an oil switch. The size of the motor on ribbon looms varies from 1/4 to 1/2 horse-power, depending on the number of shuttles. Hatband looms run with approximately the same power requirements but the elastic looms take considerably more power and are usually run at a higher speed. The tension of the elastic calls for considerable power, and in some cases the number of picks per minute on these looms is as high as 155. The ordinary elastic loom requires about a 3/4 horse-power motor.

On the elastic looms the motor is kept running, and the loom is started and stopped by means of a friction pulley. The starting torque required of the motor to get these looms in operation is so high that it would be practically impossible to start and stop the motor with the loom unless an exceptionally large motor was furnished, which would have poor efficiency and also low power factor; besides, the first cost would be exceedingly high, and the advantages to be gained would not compensate for the difference.

The wiring for the individual drive should be so arranged that there will not be more than ten motors on one circuit. Each motor is protected with its own set of fuses, and can thereby be cut out of the circuit should change be necessary.

In choosing a generator to supply current to these individual motors, particular attention should be paid to the power factor of the circuit, which is, normally, around 55 per cent. This low power factor does not necessitate the burning of any more coal, but does call for a larger generator than would be necessary for a motor load having a power factor of 85 per cent.; and, unless the generator is designed to take care of this condition, it will become overheated.

In the beginning of this article it was stated that the direct current is best suited for silk printing machines. This is true, because a great variation of speed is required. The alternating current two or three-phase motor cannot be adapted efficiently to meet this requirement.



Method of Mounting Motor to Loom

Among those in charge of silk printing establishments, there are a few who realize the many advantages of the electric drive on printing machines. There are two methods of driving these machines: one by armature and field control, and the other by the Ward-Leonard system.

The armature and field control method is the cheaper to install, as the speed variation necessary is obtained by resistance inserted in armature and field circuits, and only one generator for the total number of printing machines is essential. The speed is controlled by the ordinary type of rheostat placed on the frame of the machine, easily accessible to the operator.

The Ward-Leonard system is a method of motor control in which the speed variation is obtained by changing the strength of the generator field, which causes the voltage of the circuit to vary accordingly. The speed of a direct current motor will vary directly and almost in proportion to the voltage across its terminals. This system of driving necessitates a separate generator for each motor, which makes it decidedly more expensive to install, but it has advantages over the armature and field control system, and the most important one is the speed regulation, for, by the Ward-Leonard system, the finest increments of speed change can be obtained. The controller can be placed on the machine in a manner similar to that followed for the armature-field control system, or it can be placed on the ceiling or wall near the printing machine and a push-button block mounted on the machine

This push-button block has four buttons—accelerating, decelerating, stop and lock. By pushing the accelerating button the motor will start and accelerate in speed until the button is released, when it will run at a constant speed. Should the operator find his speed excessive, by pushing the decelerating button the speed is gradually lowered, and when released the motor will run at constant speed, as in the case of accelerating.

By pushing the stop button the circuit is entirely broken and the machine brought to rest.

There are two push-button blocks, usually about 4 in. by 6 in. each, mounted one in front and the other at the back of the printing machine. Should the operator at either the front or back of the machine desire to work around its moving parts, he may push the lock button, which prevents the motor from being started until the button is released, thereby preventing a possible accident to himself.

With the Ward-Leonard system a switchboard with removable plugs should be provided, so that any motor can be operated by any generator to best suit the working conditions of the whole department. The motor is usually mounted on the ceiling and belted to the printing machine. No definite statement can be made regarding the power necessary to drive these printing machines, as it may vary from 3 horse-power to 15 horse-power, depending on the number of color rolls used and the degree of tightness at which these rolls are set. The most suitable voltage for this work is 220 volt direct.

The electric drive of printing machines gives better speed regulation, saves space, improves the quality of, and turns out less damaged goods, since the machine can be stopped in less time than with engine drive.

There is just one more important factor in the power of silk mills to which the writer desires to call attention, and that is the advantages of the central station supply. By central station is meant the local light and power company. A silk mill, or, in fact, any mill, is a very desirable load for a central station, and in some localities central stations quote very low prices for power, as this service loads up their generating apparatus at a time when it would be otherwise running light. Most central stations can afford to sell power cheap during the ordinary working hours of a silk mill, as their operating expenses are approximately the same, with or without this load.

In comparing cost of power from central station against that of the isolated plant, it must be borne in mind that the central station delivers power right to the motors, which is different from indicated horse-power of the engine in the isolated plant, as all losses in engine and principal belt drives in the mechanically driven mill, and all losses in the engine and generator in the electric isolated plant, are eliminated.

The advantages of a central station supply may be summarized as follows:

Reduction in initial expenditures, or an equivalent increase in productive machinery.

Greater security of supply, due to the extra spare units which are invariably installed in a central station.

Freedom from the fluctuations of the coal market.

Privilege of operating any particular department without running the entire line shafting in the mechanically driven mill, and the power-house equipment in the electrically driven mill.

The writer has endeavored to treat the power question of silk mills in a general way, without going into details, but he would be glad to furnish any reader with detailed information, as he has records from actual tests taken on most of the different machines used in this industry.

THE ELECTRIFICATION OF THE CASCADE TUNNEL OF THE GREAT NORTHERN RAILWAY COMPANY

By W. I. Slichter

The Great Northern Railway Company has adopted electric traction on a section of its main line which includes the tunnel through the summit of the Cascade mountains. This tunnel has become the limiting feature of the railway's capacity for through traffic, owing to the difficulty of handling the heavy trains on the steep grade through it.

As these conditions are common to most of our trunk lines, and the electric installation has successfully overcome them, the Great Northern's electric system is of interest as an object lesson, to show the ability of electric traction to increase the capacity of sections of railroads where, owing to certain physical conditions, operation with steam locomotives has reached its limit.

The conditions which prevailed previous to the electrification were as follows:

The heavy freight trains, coming from the western terminus, on reaching the steep grades of the mountain section, required the service of from two to four of the heaviest locomotives, and even these could not haul the trains faster than about seven or eight miles per hour.

When the tunnel itself was reached the operation became still more difficult; the grade was steep; the smoke and steam from the locomotives coated the rails with a damp greasy soot which caused the wheels to slip; and the locomotives filled the tunnel with the noxious gases of combustion which would nearly suffocate the train crews and made the operation positively dangerous.

It was attempted to mitigate these conditions by using special locomotives and specially selected coal for the tunnel; but even then the conditions were far from satisfactory, and the capacity of the whole road was limited to the ability to get the trains over this short section.

To meet this condition of affairs it was proposed to haul the trains through the tunnel by electric locomotives, as this would completely eliminate the delays due to the bad atmospheric condition in the tunnel, while in addition, a further gain would be made owing to the greater power of the electric locomotives, which would be able to haul the trains at double the speed of the steam locomotives.

The Cascade tunnel is 104 miles east of Seattle on the main line of the Great Northern Railway. From Seattle eastward the line is practically level for forty miles; for the next forty miles to Skykomish the ruling grade is one per cent. From Skykomish to the tunnel there is a practically continuous grade of 2 per

Power House and Tower

cent. and a ruling grade of 2.2 per cent. From the tunnel eastward for about thirty miles there is an average of 1.7 per cent. down grade.

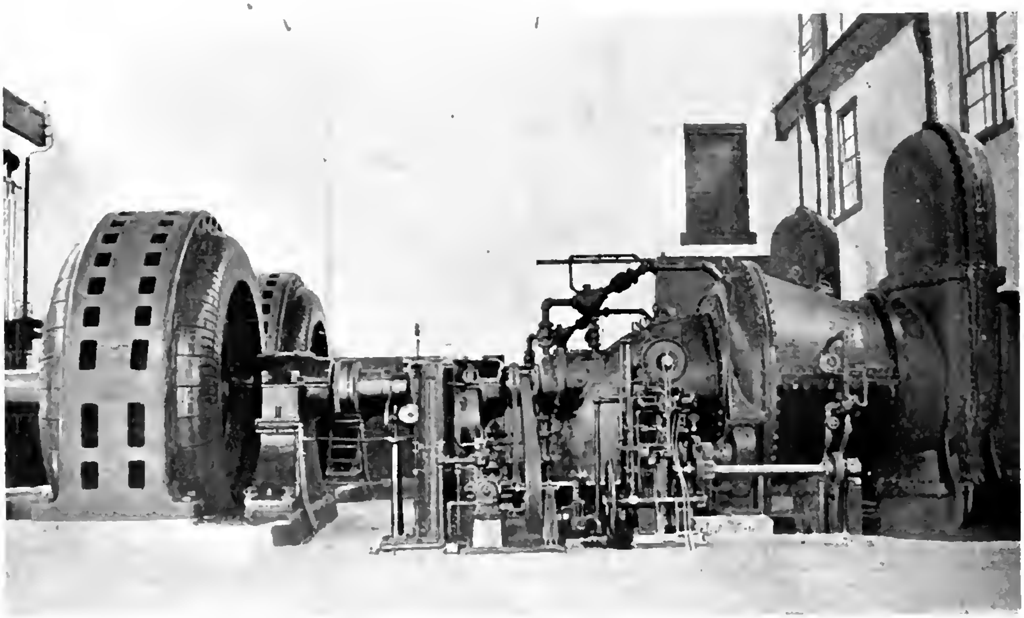
The tunnel itself is about 14,000 ft. long, perfectly straight, and has a uniform grade of 1.7 per cent. In the yards at each end of the tunnel there are grades of 2 and 2.2 per cent. on which all the trains must be started.

In the preliminary study of the proposition the project of equipping the whole section, from Skykomish to Leavenworth, 57 miles, including the worst grades, was kept in mind, as it is considered probable that this extension will be made in the near future. For the present, only the tunnel and its approaches are equipped, involving about

21,000 ft. of the right of way and about six miles of single track, including sidings.

The territory through which the railway passes includes many water falls suitable for power development, and a number of these are controlled by the railway company. This in itself naturally makes the adoption of electric traction attractive.

The main features of the scheme of electrification are a hydro-electric power house at Leavenworth, operating under a head of 180 ft., having a present capacity of 5000 kw. and an ultimate capacity of 7500; a three-phase 33,000-volt transmission line, 30 miles in length; a step-down transformer substation at Cascade; a three-phase distributing system operating at 6600 volts, and four three-phase electric locomotives. The following description of the system is taken largely from a paper on "The Electric System of the Great Northern Railway" read before the A.I.E.E. by Dr. Cary T. Hutchinson.



Water Turbine and Generator Units in Power House

Power House

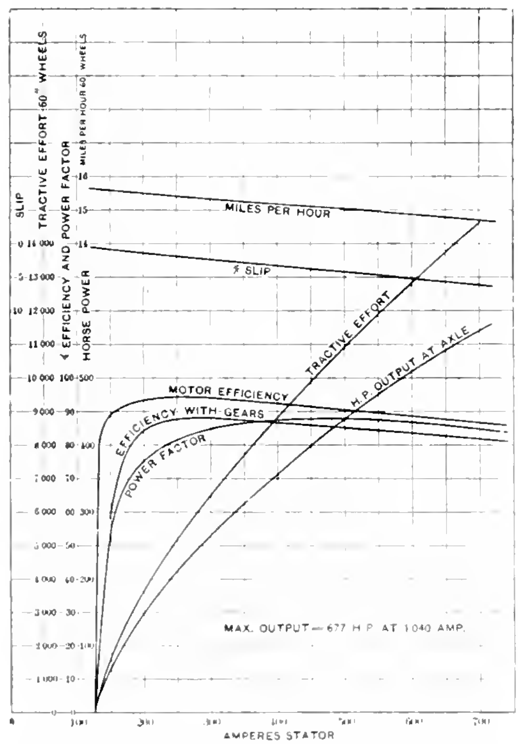
The power house at present contains two 4000 h.p. water wheels built by the Platt Iron Works of Dayton, Ohio, which operate at a head of 180 ft. Each water wheel is directly connected to a General Electric alternating current 2500 kw., 6600 volt, three-phase, 25 cycle generator running at 375 r.p.m. These generators are designed to operate at 80 per cent. power factor and, in conjunction with a voltage regulator, to give a constant voltage with a great variation in load and power factor. This combination has worked so well that it has fallen to the lot of the regulator to take care of the drop in speed of the water wheels. It has proved itself capable of maintaining normal voltage at the terminals of the generator when the speed of the water wheel has dropped to 80 per cent. of normal, and when full load is drawn from the generator at a power factor of approximately 80 per cent.

There are two 125-kw. exciters, each driven by its own water wheel, the current in the fields of these exciters being controlled by the voltage regulator. One exciter is of sufficient capacity to supply the excitation for both generators, leaving the other exciter as a reserve and to supply the auxiliary power of the station.

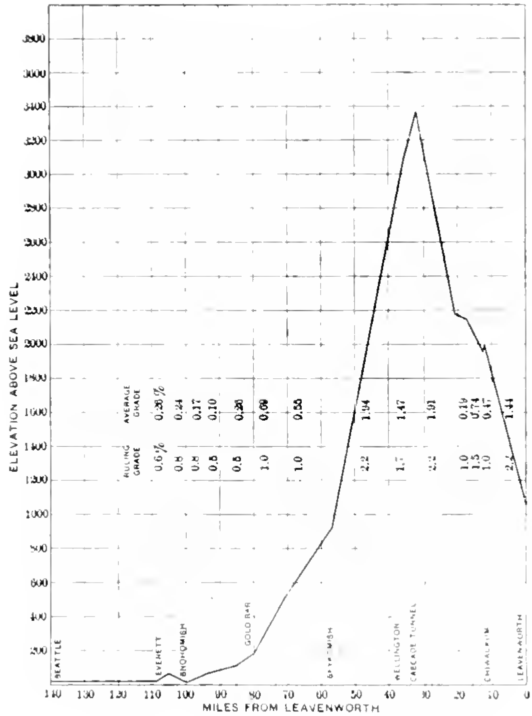
The power station is situated on the right of way about 30 miles east of the tunnel. The railway at this point is not equipped for electric operation, although it is intended to be so equipped later. For the present, all the power is transformed from 6600 to 33,000 volts by a bank of four water cooled, 25 cycle, 850 kw., 6600/33000 volt transformers, three of which are used in normal operation, the fourth being maintained as a spare. These transformers and the high tension switching apparatus are contained in a special room of the power station, separated from the main generating room by a fireproof wall.

The cables from the generators are run in conduits beneath the floor from the generators to the switchboard. From the step-up transformers there are two three-phase outgoing lines which are protected by electrolytic cell lightning arresters placed on the end wall of the building.

The power station also contains two water rheostats intended to absorb the energy which is generated by the locomotives when descending grades at times when there is no demand upon the system. These water rheostats consist of two concrete tanks in each of which three tubular electrodes are suspended in such a manner that they may be raised and lowered automatically in accordance with the load to properly regulate the system. These water rheostats are controlled by a centrifugal governor, driven from the main shaft of the generators, which causes the electrodes to be lowered into the water box whenever the speed of the generators increases above the normal value due to the generators acting as synchronous motors when the locomotives are regenerating. This governor is designed with a positive action so that there is no tendency of the system to hunt, due to the water rheostat overshooting its position.



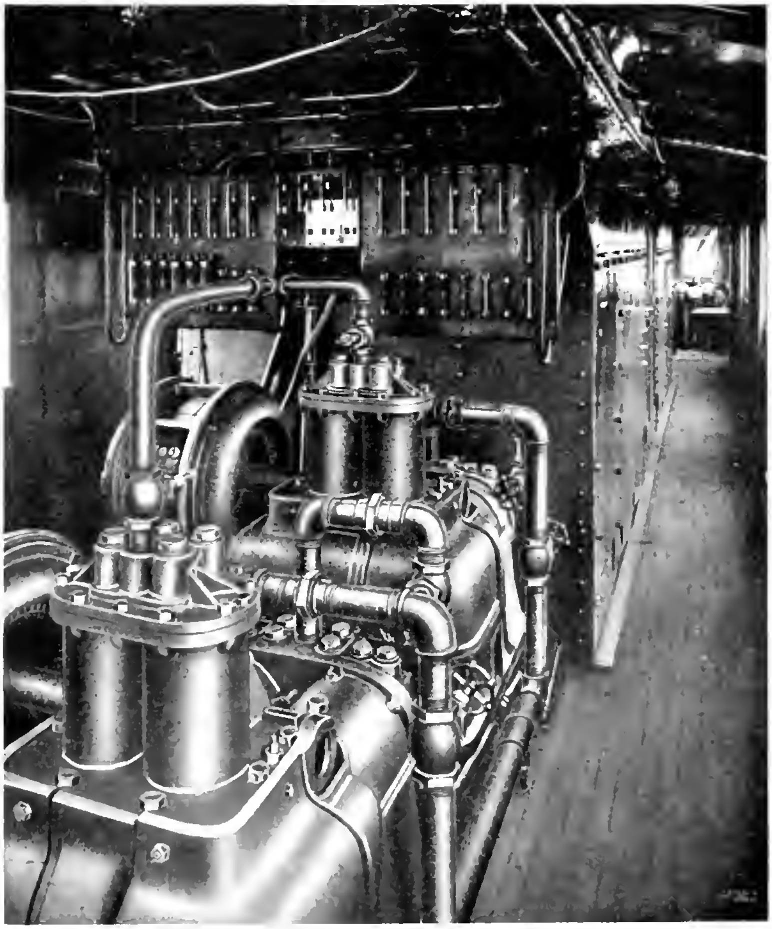
Characteristic Curves of Great Northern Three Phase, 475 H.P. 25-Cycle, 500-Volt Motor. Gear Ratio 4.26; 60 In. Wheels



Profile of Great Northern Railway—Leavenworth to Seattle

Transmission Line

The transmission line is 30 miles in length and consists of two circuits, each including three No. 2 B.&S. stranded hard-drawn copper wires. Each circuit is in a vertical plane at one side of the pole, thus permitting the use of short cross-arms. Provision has been made for a ground wire to be strung at the top of the pole which, however, has not yet been installed. A telephone line is carried on the same poles. The transmission line is not transposed but the telephone line is transposed at every fifth pole. The poles are 40 ft. long, placed 6 or 7 ft. in the ground, the tops being from 10 in. to 12 in. in diameter. The line is divided into three sections by two out-of-door switches, each near a station and under the supervision of a station agent.



Interior of Locomotive

Sub-Station

The sub-station is at Cascade, practically at the east portal of the tunnel. This sub-station contains four single-phase transformers similar to those in the power house; three of these are connected in a bank, the fourth serving as a spare. These transformers reduce the voltage from 33,000 to 6600 volts, three-phase, in which form power is fed to the distributing system. The low pressure bus-bars at the sub-station are connected directly to the line at Cascade and there is also a feeder running from the sub-station through the tunnel to the extreme end of the Wellington yard.

Distribution System

Power is distributed by means of two overhead wires and the track, the latter serving as the conductor for the third phase. The outside overhead construction consists of bracket or cross-catenary, depending upon the number of tracks, but in the tunnel the wires are supported at intervals of 50 ft. by means of clamps attached by swiveled connection to a stud, which is in turn swiveled to the middle point of a turnbuckle. The two eyes of the latter each connect, by means of strand wire, to a link and a petticoat strain insulator arranged in series, the two petticoat insulators being secured to the roof of the tunnel by means of two expansion bolts. Anchors and side braces for the wires in the tunnel are located at intervals of 3000 ft.

In the tunnel the wires are 17 ft. 4 in. above the top of the rail. They are spaced 8 ft. apart to permit the trainmen to operate the hand brakes, or to walk on the tops of the freight cars. In the open the wires are 24 ft. above the top of the rail, are 5 ft. apart, and are supported at intervals of 100 ft. At anchorages and switching points heavy steel bridges are used. Lightning arresters are connected to the trolley wires at several points in the system.

On account of the variation in the spacing of the trolleys, current is collected by the ordinary swiveling trolley pole and wheel instead of a bow collector.

Where wires of opposite phase cross at turnouts they are insulated from each other by an insulated crossing, which is built up of four wooden insulators, each about 5 ft. in length and radiating from a central crossing pan.

Locomotives

Each of the four locomotives has a total weight of 230,000 lb., all on drivers, and has two trucks connected by a coupling, each truck having two driving axles. A three-phase motor is connected by twin gears to each axle. The two trucks are coupled together in such a manner that each tends to guide the other around the curves. They also tend to support each other vertically and are somewhat similar in mechanical design to the Mallet type of steam locomotive. One truck is side equalized while the other contains a three-point suspension. The springs are thereby equalized in groups and the groups are so arranged as to eliminate all skew or twisting stresses in the truck frame.

The wheels are 60 in. in diameter with removable steel tires $3\frac{1}{2}$ in. thick. The wheel centers are steel castings. The gears are shrunk on an extension of the wheel hub, thus eliminating the torsional stresses from the locomotive axles. The motors are connected through gears at both ends, that is, they are twin-geared to the driving wheels, thus having the advantage of maintaining accurate alignment between the axle and armature shafts.

The cab, which is made of No. 10 steel plate, extends the entire length of the platform. The greater part of the control apparatus is placed in a separate compartment 60 in. wide and 22 ft. long, located in the middle of the cab and enclosed by steel partitions extending directly up to the monitor roof. This leaves two open operating spaces at the ends of the locomotive, connected by two side aisles 30 in. in width. This center compartment is divided into three parts by steel plate partitions; the middle part containing the high tension apparatus including the switchboard, and the end parts, which are duplicates, each containing one transformer and the contactors for two of the motors. The rheostats are placed in the monitor at the top of the cab. The air for ventilation, after passing through the transformers, cools the rheostats and then escapes to the atmosphere.

The motors, of which there are four per locomotive, are of the three-phase induction type designed for operation at 25 cycles and wound for a primary voltage of 500. They are similar in their construction to standard stationary type induction motors, but are adapted in the details of their design to traction purposes. The rotors, or secondaries, are wound with definite poles and the terminals are carried to collector rings, by means of which the starting resistance is connected into the circuit. The ratings of the motors are given in the table of data following, and the power factor and efficiency are shown in the characteristic curves. Each motor can exert a maximum tractive effort of 19,000 lb. at rated voltage, and the transformer which reduces the line voltage from 6000 to 500 is provided with a 625-volt tap to which the motors may be connected in case the line drop becomes excessive.

The control system of each motor is separate; the circuits branch from the transformer, two motors being fed from each transformer. The speed and tractive effort of the motors are controlled by varying the resistance in their secondaries. There are 13 steps in the resistance and these are obtained with 9 contactors by a scheme of dividing the resistances into two or three groups, each having its contactor. These groups are brought into different combinations so that each group is used repeatedly, sometimes in series and sometimes in multiple with the others, and is not merely employed for one step. The control is designed to allow of a train being accelerated at an average tractive effort of 37,500 lb. without exceeding a maximum of 41,000 lb. or falling below a minimum of 35,000 lb. The application of the power is continuous throughout the whole range of the controller.

No provision is made for connection in concatenation or changeable pole connection to permit of running at fractional speeds without resistances, but the resistances are so proportioned that the locomotive can run for 15 minutes at full rated tractive effort without overheating the resistances. The first step on the control gives a tractive effort of 10,000 lb. at standstill, and the second step 20,000 lb.

A separate and independent set of resistances is provided for the secondary of each motor to avoid the tendency of the motors to exchange current and "buck," which would occur if the driving wheels were not of exactly the same diameter and one set of resistances was used for all the motors.

The principal data of the locomotive are given in the following table:

Great Northern Locomotive Data

Total weight	230000 lb.
Weight on drivers	230000 lb.
Number of driving axles	4
Number of other axles	0
Diameter of wheels	60 in.
Gear ratio	4.26
Number of motors	4

Output of motor for one hour (nominal)	400 h.p.
Output of motor for one hour (test)	505 h.p.
Rise in temperature	75 deg.
Output of motor for three hours (nominal)	250 h.p.
Output of motor for three hours (test)	397 h.p.
Rise in temperature	75 deg.
Forced ventilation (cu. ft. per min.)	1500
Number of poles on motors	8
Frequency	25 cycles
Synchronous speed of motors	375 r.p.m.
Voltage between terminals	500
Synchronous speed of locomotive	15.7 m.p.h.
Number of transformers	2
High potential voltage of transformers	6000
Rating of transformers (3 hours)	400 kv-a.
Forced ventilation (cu. ft. per min.)	1500
Number of step in control	13
Method of control. Resistance in Secondary	
Continuous rating locomotive, lb. tractive effort	25000
Accelerating rating locomotive, lb. tractive effort	38000
Momentary rating locomotive, lb. tractive effort	56000
Maximum rating locomotive, lb. tractive effort	72000
Length overall locomotive	44 ft. 2 in.
Total wheel base	31 ft. 9 in.
Rigid weel base	11 ft. 0 in.

Distribution of Weight

2 Trucks	81,500 lb.
1 Cab	30,000 lb.
44 Motors	48,800 lb.
8 Gears and gear cases	11,000 lb.
2 Transformers	20,800 lb.
2 Air compressors	5,800 lb.
1 Blower	1,300 lb.
40 Rheostats	10,200 lb.
56 Contactors	3,200 lb.
Miscellaneous	17,400 lb.
Total	230,000 lb.
That is,	
Total weight per axle	57,500 lb.
Dead weight per axle	18,500 lb.

Operation

The original problem was to provide equipment to handle a train having a total weight of 2000 tons, excluding the electric locomotives, over the mountain division from Leavenworth to Skykomish, a distance of 57 miles. The system was to be first tried out at the Cascade Tunnel.

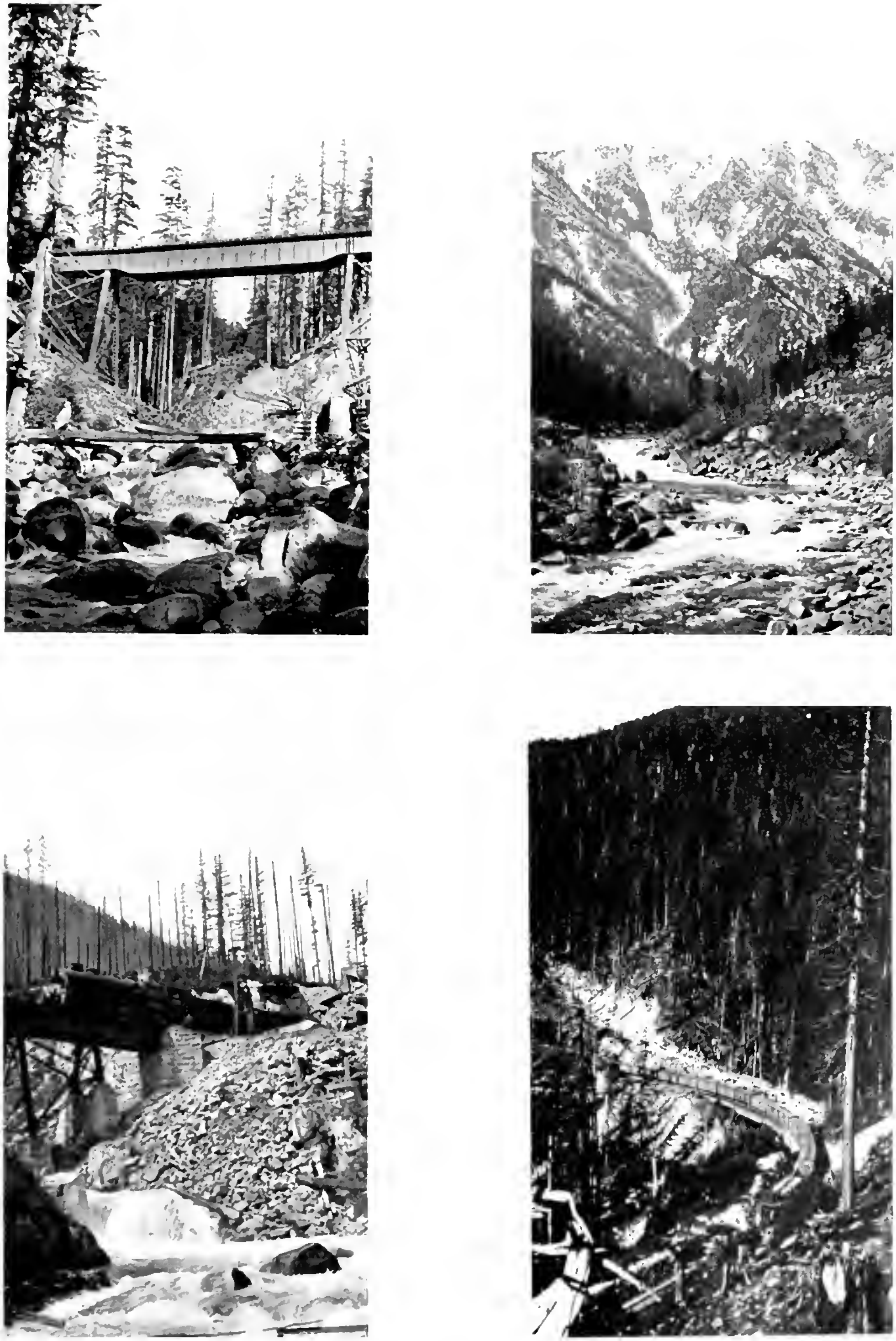
The tractive effort required to accelerate a train having a total weight of 2500 tons on a 2.2 per cent. grade, using 6 lb. per ton for train resistance and 10 lb. per ton for acceleration, making a total of 60 lb. per ton, is 150,000 lb.; this would require four locomotives of a tractive effort of 37,500 lb. each. The railway company's engineers limited the weight on a driving axle to 50,000 lb.; therefore, four driving axles per locomotive are needed, giving a coefficient of adhesion of about 19 per cent. This is a measure of the maximum power required. The locomotive, therefore, was designed to give a continuous tractive effort of approximately 25,000 lb., and it was expected that four of them would be used with a train of maximum weight. However, the locomotive as built greatly exceeds this specification.

The specification of the motor required an output of 250 h.p. continuously for three hours, with 75 deg. C. temperature elevation, when supplied with not more than 2000 cu. ft. of air per minute. The test results of the motor show a continuous output of 375 h.p. at 500 volts with 1500 cu. ft. of air, and 400 h.p. at 625 volts, with the same amount of air; the one-hour rating of the motor at 500 volts with 1500 cu. ft. of air per minute is 475 h.p.; the ratio of continuous output to the hour-rating with 1500 cu. ft. of air is therefore 79 per cent. The continuous output at 500 volts corresponds to a tractive effort of 9350 lb. per motor, and the one-hour output to a tractive effort of 11,900 lb. per motor. The locomotive, therefore, will give 37,400 lb. tractive effort in continuous duty, or 47,600 lb. tractive effort for one hour. The characteristic curves of the motor at 500 volts are shown in cut on page 351.

The locomotives have shown themselves capable of hauling 885 tons trailing load each, if the power requirements are continuous; but, as there are necessarily stops, their actual rating is somewhat greater than this.

The locomotive has been tested to a maximum tractive effort of nearly 80,000 lb., corresponding to a coefficient of adhesion of nearly 35 per cent.; with 60,000 lb., or 29 per cent., each locomotive can accelerate the train of 885 tons trailing on a 2.2 per cent. grade, using 60 lb. per ton as the total tractive effort; or, in other words, the train that a locomotive can haul, as determined by the average duty and safe heating limits, is just about equal to the train that it can accelerate on the maximum grade; that is, the average capacity of the locomotive and its maximum capacity are in the same proportion as the average duty and maximum duty.

The electric service was started on July 10, 1909, although one or two trains had been handled previously. From that time until August 11, practically the entire eastbound service of the company has been handled by electric locomotives.



Scenes Along the Great Northern Railway

During this period of 33 days there were 212 train movements of which trains 82 were freight, 98 passenger and 32 special. In each case the steam locomotive was hauled through with the train. The tonnage handled was as follows:

Freight tonnage	171,000 tons
Passenger tonnage	88,500 tons
Special tonnage	15,500 tons
Total	275,000 tons

This is an average of 8350 tons per day, all eastbound.

The average freight train weight was as follows:

Cars	1480 tons
One Mallet locomotive	250 tons
Three electric locomotives	345 tons
Total train weight	2075 tons

The maximum weight of cars was 1600 tons; the minimum, 1200 tons.

The representative passenger train handled is made up as follows:

Coaches	426 tons
One steam locomotive	250 tons
Two electric locomotive	230 tons
Total train weight	906 tons

The maximum passenger train was about 125 tons greater.

It was found that the frictional resistance of the Mallet locomotives which were hauled through with the trains was about 47 lb. per ton, so that the work performed by the electric locomotives is considerably greater than is shown by the actual weights of the trains.

Using 20,000 lb. as the pull required for a Mallet locomotive on the 1.7 per cent. grade, the total tractive effort for the average freight train is:

Cars	1480 tons × 40 = 59,200 lb.
One Mallet	250 tons × 80 = 20,000 lb.
Three electrics	345 tons × 40 = 13,800 lb.
	93,000 lb.

This is equivalent to 31,000 lb. for each locomotive.

Regeneration

A number of tests were made to determine the power returned when regenerating. A representative test on a ten car passenger train weighing 950 tons gave 597 kw., showing that one ton descending the 1.7 per cent. grade at 15 m.p.h. will deliver 0.67 kw. to the system.

Efficiency

The losses in the system when delivering 4000 kw., equivalent to supplying four locomotives, at the west end of the Wellington yard are:

	Kw.	Per Cent.
Power house	4740	100
Sub-station	4250	89.8
Trolley wheel of locomotive	4000	84.5
Driving axles	3320	70

At the average load the efficiency is higher.

General

In the paper above referred to, Dr. Hutchinson assigned the following reasons for the choice of the three-phase system as compared with the direct current or single-phase systems:

1. The three-phase motor and control are distinguished by the greatest electrical and mechanical simplicity; the motors will stand any amount of abuse and rough use.

2. Greater continuous output within a given space than can be obtained with any other form of motor.

3. Uniform torque. This is an advantage over the single-phase system.

4. Possibility of using 25 cycles. The single-phase system would probably have involved a lower frequency.

5. Regeneration on down grades. This is accomplished in the three-phase system with no additional complication or apparatus on the locomotive.

All of the electrical apparatus in the power house and sub-stations, together with the locomotives, was supplied and manufactured by the General Electric Company.

COMMERCIAL ELECTRICAL TESTING

Part X

By E. F. Collins

Double Pitot Tube, or Government Method of Testing

This test is made in accordance with Government specifications* issued by the Navy Department under the cognizance of the Bureau of Construction and Repair.

Use of Air Table

When making a fan test the temperature of the air near the fan should be taken by two Fahrenheit thermometers, one hanging free in the air and the other with the bulb wrapped in thin cloth, this cloth being saturated by having its lower end placed in a small receptacle filled with water. The water must be at the maximum temperature which it will naturally attain in the room. Corrected barometer reading must also be recorded on the test sheet.

The method of finding the weight of air from the air tables (mentioned in the specifications) is as follows: On the page containing the dry bulb reading, as given by the test sheet, is noted the corresponding barometer reading. In the column under the dry bulb temperature and opposite the barometer reading, the corresponding weight of air is given. The weight of air found in the table must then be corrected to correspond with the corrected barometer reading found in test; this correction being found in the second line from the top of the page. Correction must also be made for the difference between the wet and dry bulb temperatures by adding to the weight of air already obtained the number corresponding to the numerical difference between the wet and dry bulb reading, found in the third sub-division under dry bulb temperature. The numerical differences are tabulated in the second sub-division of the column.

Example:

Given barometer reading	30.15 in.
Dry bulb reading	67° F.
Wet bulb reading	59° F.

Under the column showing the dry bulb temperature of 67° and opposite the barometer reading of 30.1, the weight of air is given as 0.07517. The addition for each 0.01 of an inch of barometer is given as 2.6 in the second line from the top of the page. Multiplying this by 5; *i. e.*, by the excess of the corrected barometer reading over that selected in the table, the result is 13, which number must be added to the weight of air previously found.

* General Specifications, Appendix 8. Instruction for Calculating and Testing Ventilation Systems.

The wet bulb depression is the difference between 67° and 59°; *viz.*, 8°. The number opposite 8 is 23, which must also be added, making the total weight of air 0.07553. All pressure readings should be corrected for standard air (see page 359) by multiplying the actual pressure obtained by the ratio of the weight of standard air to the weight of air at the time of test. The readings of horse-power input to the fan should also be multiplied by this ratio.

Pressure and Horse-Power Curves by Double Tube Method

A pressure curve may be taken by the double tube method as follows:

The opening at the outer end of the discharge pipe should be closed and pressure and power readings taken. Under this condition the static and impact pressures should be exactly the same, since no air passes through the fan. Readings should then be taken as the opening is increased by equal increments from closed to wide open, the opening being measured each time. The speed of the fan should be held constant throughout the test, and the air readings and electrical input readings taken simultaneously.

It will be noted that in a test which is made with a pipe on the discharge side of the fan, the reading of the impact tube is always greater than the static reading. If the pipe is on the suction side, the opposite will be true; the difference between the two readings being the velocity head. The Pitot tube should point against the stream of air in both cases.

If readings are taken by means of a U tube, the readings of both sides of the tube should be recorded. It should always be stated whether the readings were taken by the U tube or by a manometer; if by a manometer, the manometer constant should be recorded and should always be used in working up the test.

Calculation of Fan Tests by the Double Tube Method

A fan test of this kind should be worked up in the following form:

Fan Rating

Motor Rating

Double Tube Test, Taken at R.P.M.

No.	[illegible]	h'	h	[illegible]	[illegible]	Q	[illegible]	[illegible]	[illegible]	Air H.P.	Fan H.P.	Eff.
1												
2												
3												
4												

Wet bulb	°F.
Dry bulb	°F.

$$"f" = \frac{L \times h'''}{D \times 39}$$

Effective area of pipe	sq. ft.
Barometer	in.
Wt. of air	lb.
Effective area of pipe =	sq. ft.

The first column gives the number of the reading.

The second and third show the impact and static readings taken from the test sheet and corrected for standard air.

The fourth column shows the velocity head or the difference between h' and h''.

The fifth column is friction, which must be calculated from the velocity head by the formula $"f" = \frac{L \times h'''}{D \times 47}$; where "$f$" is the friction loss in inches of water, L the length of pipe between the fan and the Pitot tube, D the diameter of the pipe, if round, or the average of the width and depth, if square or nearly square. L and D must always be of the same denomination. The friction loss should be added to both the static and impact readings before the curves are plotted, but it does not affect volume.

The sixth column gives the air velocity and may be obtained from the formula

$$V = 1097\sqrt{\frac{h'''}{w}}$$

The volume must be given in the seventh column. It is obtained by multiplying the velocities given in the sixth column by the effective area of the pipe; *i.e.*, 0.91.

The horse-power in the air can be calculated from the formulæ:

$$\text{Air horse-power} = \frac{P \times Q}{33000} \text{ or } \frac{p \times Q}{5367} \text{ or } \frac{h \times Q}{6346}$$

The horse-power input to the fan is the horse-power output of the motor.

Unless instructions are issued to the contrary, all fan tests for government work should be plotted with pounds per square foot, horse-power input to fan, and efficiency, as ordinates; and volume in cubic feet per minute as abscissæ. Both static and impact pressure should be plotted.

Cone Method of Test

In the cone method of test an adapter is used, where necessary, to change the fan outlet from rectangular to circular, a cone being placed on the circular end. This cone is made up of sections about one foot in length, the sides of which slope about two inches to the foot. Readings are taken by a single Pitot tube, the open end of which is held flush with the opening in the cone and pointed against the stream of air. Pressure is registered as before by a manometer or U tube. The readings are taken, one at the top, one at the bottom, and one at each side of the cone, at a distance from the edge of the pipe of about 1/6 of the diameter of the opening. A reading is also taken in the center of the cone opening. The average of these five readings represents the impact pressure produced by the fan, and is taken as the velocity head. The velocity may be obtained from the formula given for the double tube test.

The static pressure may be obtained as follows: Divide the volume as figured for each opening by the area of the fan outlet, thus obtaining the outlet velocity V_1. The corresponding velocity head can then be obtained from the formula. The velocity head subtracted from the impact pressure gives the static pressure, which should be plotted as well as the impact pressure.

These tests should be plotted with pressures in inches of water, horse-power input to the fan, and efficiencies, as ordinates; and volumes as abscissæ.

The following form should be used for tabulating the results of calculations:

Fan Rating
Motor Rating
Cone Test taken at R.P.M.

No	h''	V	Ac	Q	V_1	h''	h'	Air H.P.	Fan H.P.	Eff.
1										
2										
3										

Wet bulb	°F.
Dry bulb	°F.
Barometer	in.
Wt. of air	lb.

After the curves are plotted, the efficiency as given by the calculations should be checked with the efficiency obtained from the curves. This will correct any discrepancy between the efficiencies as obtained from the curve and as calculated.

The Box Method

The fan is arranged to discharge directly into a box of sufficient capacity to reduce the air velocity to a minimum. Cones similar to those used in the cone test are attched to an opening in the side of the box at right angles to the opening into which the fan discharges. Readings are taken in the same manner as in the previous test, and a record is also made of the box pressure by a U tube connected to a pipe inserted through a hole in the side of the box. This end of the pipe should be flush with the inside of the box to avoid eddy currents. The pressure shown by this pipe will be somewhat higher than that registered at the end of the cone, and both pressures should be corrected for standard air and plotted on the final curve sheet.

The volume must be calculated as in the cone test, but the pressure obtained in the box is taken as the static pressure produced by the fan, since the velocity head is lost in the box. To obtain the impact pressure, the volume obtained should be divided by the area of the opening of the fan, and the corresponding velocity head figured from the formula. This velocity head should be added to the static pressure shown by the cone readings. For transformer ventilation it is customary to calculate the pressure in ounces, measured at the cone opening.

The following form should be used in tabulating the calculations:

Fan Rating
Motor Rating
Box Test taken at R.P.M.

No.	h'	p	V	A_e	Q	V_1	h'''	h''	Air H.P.	Fan H.P.	Eff
1											
2											
3											
4											

Wet bulb °F.
Dry bulb °F.
Barometer in.
Wt. of air lb.

Air horsepower should be calculated from the static pressure and the efficiency obtained will be the static efficiency.

Formulae for Blower Tests

H = Head of air in feet.

h = Head of water in inches shown by manometer.

h' = Static head; h'' = impact head; $h''' = h'' - h'$ − velocity head.

Weight of water = 62.4 lbs. per cu. ft. at 62° F.

Weight of column of water ft. sq., 1 in. high, 5.20 lbs. at 62° F.

Weight of cu. ft. of air at 30 in. Bar., 70° F., 70 per cent. humidity = .07465 lb.

This is taken as "Standard Air."

Weight of air under other conditions, neglecting humidity =

$$\frac{.07465 \times B \times 530}{30(460+t°)} \text{ for Fahrenheit,}$$

or

$$\frac{.07465 \times B \times 294.1}{30(273+t°)} \text{ for centigrade.}$$

V = Velocity of air in feet per minute.

v = Velocity of air in feet per second.

Q = Volume in cubic feet per minute.

P = Pressure of air in lbs. per sq. ft.

p = Pressure of air in ounces per sq. in. $= \frac{h}{1.732} = .577\ h.$

"f" = Loss of head in inches due to friction in pipes $= \frac{L \times h'''}{D \times 47}$

L = Length of pipe between the fan and the Pitot tube.

D = Diameter of pipe, if it is round; or = the average of the width and depth, if it is square or nearly square.

$P = 5.20 \times h = 9\ p.$

A = Area of pipe in sq. ft. A_e = Effective area of pipe $= A \times K$.

$$H = 5.20 \times \frac{h}{w} = 69.73 \times h \text{ for standard air.}$$

$$v = \sqrt{2gH'''} = 8.02\sqrt{H'''}$$

$$= 8.02\sqrt{\frac{5.2 \times h'''}{w}} = 18.28\sqrt{\frac{h'''}{w}}$$

$$V = 481.2\sqrt{H'''} = 1097\sqrt{\frac{h'''}{w}}$$

$$= 4015\sqrt{h'''} \text{ for Std. Air.}$$

$$Vol. = 1097\sqrt{\frac{h'''}{w}} \times KA$$

$$= 3654 \times A\sqrt{h'''} \text{ for } K = .91;$$

$$= 3774 \times A\sqrt{h'''} \text{ for } K = .94;$$

for Std. Air.

K = .94 for the Cone Method.

K = .91 for double Pitot tube or Navy method.

For a given opening pressure varies as the square of the speed of the blower.

Volume varies as the square root of the pressure, hence, directly as the speed.

Air horsepower varies as the cube of the speed.

$$\text{Eff.} = \text{Efficiency} = \frac{\text{Air Horsepower}}{\text{Fan Horsepower}}$$

APPLIANCES FOR ELECTRICAL MEASUREMENTS*

Part I

By C. D. Haskins

Manager Lighting Department, General Electric Company

All military operations of the future and all peace service of the army must deal with electrical questions in a very comprehensive way, and in a rapidly increasing ratio from now onward.

Not less than one officer in seven in the regular establishment, and, perhaps, we may predict not less than one officer in fifteen of the entire commissioned force on a war basis, must have a reasonably complete working knowledge of applied electrical engineering under future conditions of the service.

This statement applies particularly to the Corps of Engineers, to the Signal Corps and to the Artillery Corps, and to less degree to the cavalry, infantry and other field services, inasmuch as all of these arms must come into contact constantly or intermittently with the operation of electrical appliances.

The quartermaster's department and regimental quartermasters will, at some very early date, be constrained to equip themselves with a working knowledge of electrical engineering, and it is with the positive conviction of these necessities, and with a knowledge of their acceptance by the great military nations of Europe, that the following notes have been prepared.

It has been my valued privilege to present at various post-graduate schools of the service a number of lectures devoted to what might be termed "military electrical engineering," and since the more practical considerations surrounding electrical measurements are amongst the more important functions of adequate equipment in electrical engineering necessary to the military electrical engineer, my notes on this occasion are to be devoted to a consideration of the more useful and essential facts in relation to the common appliances for electrical measurements.

In laying this material before you I realize that it is not a topic pertaining particularly to the Signal Corps, but no officer of the Signal Corps who is engaged in devoting his attention to the electrical branch can properly conduct his work without a thorough comprehension of the governing considerations in connection with measuring appliances, and I conceive, therefore, that a proper treatment of this subject must necessarily be useful.

In the consideration of this subject, it is by no means my intention to deal with the highly sensitive devices which are found in the electrical laboratory. Military electrical engineering can have little connection with or occasion to deal with such instruments. They constitute a highly specialized study, and are well dealt with in the text books of the art.

There are, however, three general classes of electrical measuring devices with which the electrical engineer officer of every branch of the service should be intimately familiar, since they fill an important part in the execution of all electrical work with which the military profession is likely to bring its members in contact. These three groups are:

Switchboard instruments
Portable testing instruments
Recording and integrating meters.

Two of these groups are, of course, confined to what might be termed fixed installations, while the group of portable testing instruments is equally important to the fixed or mobile equipment.

Switchboard Instruments

With a continuous current system the two essential instruments are the ampere meter (ammeter) and the volt meter (voltmeter).

In the earliest days of the electric lighting art an incandescent lamp commonly served the purpose of the voltmeter, and the practiced eye was expected to determine, from the brilliancy of the lamp, the correct or incorrect voltage of the system; in short the lamp itself was utilized as a crude voltmeter.

Since the good or poor service of an electric lighting system is entirely dependent upon the maintenance of a reasonably uniform voltage, the voltmeter is obviously of paramount importance, and, during the early history of the art, a very great amount of attention was devoted to the design of structures for the accurate and reliable indication of voltage.

It is interesting to note in connection with the electrical measuring device art, especially in the field of switchboard and recording instruments, that probably no class of mechanical or electro-mechanical

* Paper read before The Army Signal School, Fort Leavenworth, Kan.

devices have been worked out along so many entirely different lines of underlying physical principles as have these.

The problem in indicating instruments (in which class we must place, of course, all switchboard instruments and all portable testing instruments) is to devise a structure which shall indicate upon a scale the current, voltage, or other electrical value under measurement, in its appropriate unit, with the greatest promptness and accuracy, under all the ordinary conditions of use.

The motion of indication must be accomplished with the minimum amount of power waste consistent with positiveness and reliability, and the structure must be such as to be as nearly as possible independent of all external influences.

Following the use of the pilot lamp in its function of voltmeter, we find in the early records of the art a general use of thermal instruments; structures dependent upon the expansion and contraction of metal with variations of temperature, the familiar Cardew voltmeter of the text books being a type of this class.

The position of the needle in such an instrument was determined by the amount of current passing through a controlling wire, the temperature of that wire varying with the amount of current passing through it, and the length of the wire with the temperature.

Such instruments are now relatively rare in the art. They are substantially never used in connection with continuous current systems, but are still used at times in connection with alternating current measurements, because of the fact that they are entirely independent of frequency, and may be used indifferently upon systems of varying frequency.

Thermal instruments are likely to be of especial importance in the future to the Signal Corps, since they constitute the one group of indicating devices for potential measurement which may be regarded as independent of frequency changes, and since the work of the Signal Corps in the future must be closely interwoven with the application of alternating currents of greatly varying frequencies, these instruments are likely to become vitally important in connection with this work as the art progresses.

In considering voltmeters for the switchboard, the practical engineer of today should give due regard to the consideration of accuracy. In writing specifications it is customary to specify that switchboard voltmeters shall be accurate through the upper half of the scale within 75 per cent.

I wish to place emphasis upon the limitation of this demand to the upper portion of the scale, and to emphasize the fact that no indicating instrument should be relied upon in switchboard practice at values below one-third scale. The active forces of coercion and control are so relatively minute in relation to the variables of friction and external influences at the low values as to destroy the reliability of the indications.

It has been customary at times, in writing specifications fixing the accuracy of voltmeters to be used on continuous current service, to limit the amount of energy to be expended in actuating the structure. Such specifications are of doubtful advisability and menace the permanency of accuracy, since the actuating forces are small at best, and it is highly desirable in all measuring structures that constant forces should be large in relation to the variable forces.

It is consequently desirable that the coercive forces shall be relatively high, and that the restraining forces against which such coercive forces are balanced shall also be relatively high.

It is probably safe to indicate a current of ten to fifteen milli-amperes as about the correct value at full scale of a voltmeter destined for use on continuous current.

Having given due consideration to the forces which make for accuracy, it is next necessary to determine, in connection with switchboard voltmeters, those characteristics which make for freedom of sensitiveness to external influences.

Under conditions of continuous current service, the commonest disturbing influence is that of stray fields, which, of course, includes the earth's field and fields induced by neighboring conductors.

The thermal instruments, commonly known as "hot wire" instruments, above referred to, are, of course, free from such disturbances, but such structures have today largely given place to magnetic mechanisms of which the D'Arsonval and the Thomson structures are typical.

The D'Arsonval structure consists of a magnetic mechanism of constant magnetic flux, and of a movable coil so situated in the field of that structure as to take a position in the field in opposition to the torsion of a spring, the position being determined by the amount of current passing through the movable coil.

It is obvious that such a structure is in some measure susceptible to variation by the modification of the field flux, due to external causes.

The density of the field in such an instrument is generally so considerable as to be unaffected by the earth's field within practical limits, but so great is the value of projected fields from heavy bus-bars or other heavy conductors that at times they have an appreciable bearing upon the accuracy of the instrument, by increasing or decreasing the gross flux of the coercive field.

This is a matter which should be considered with care in providing switchboard instruments for most systems. There are three remedies: First, to make the permanent point of use of the instrument so remote from external influences as to minimize the influence of stray fields; second, by shielding the instrument with an iron casing of such a character and in such a manner as to short circuit the lines of force projected by the stray field through a path external to the instrument itself; or third, by resorting to instruments of astatic construction.

Astatic instruments are, for all practical purposes, independent of stray fields, since their coercive and restraining forces are equally and oppositely influenced by varying and irrevelant external magnetic influences.

Astatic instruments are, generally speaking, of somewhat greater first cost than otherwise equally accurate instruments in which this feature is not embodied, but it is probably desirable in most cases to specify an astatic instrument where the conditions of service demand the use of switchboard instruments in close juxtaposition to conductors or in the presence of considerable masses of structural iron and steel work.

If astatic instruments are not utilized it is customary to determine by actual test the general sensitiveness of the instrument in use to projected fields.

Closely correlated to error incident to projected fields is the not altogether uncommon phenomena of permanent derangement due to heavy projected fields, caused by the permanent change of flux in the permanent magnet used in these instruments. Radical examples of such derangement are relatively common.

It will be readily appreciated that any structure of this character dependent upon a permanent magnet must in some measure be subject to loss of accuracy by exposure to a field external to itself.

Modern instruments have been so highly perfected that the external field must be of high value in relation to the flux of the instrument itself to have a permanent effect; nevertheless such high value is met with in switchboards carrying very heavy currents, and freedom from its effect can be insured only by highly developed shielding or by the utilization of electro-magnetic elements; when, of course, it is necessary to resort to a structure in which the coercive and restraining forces both vary with fluctuations in field strength.

Voltmeters of the electro-magnetic type are used in the art from time to time in forms which involve less costly and complex structures than those here dealt with. For example: structures utilizing a simple solenoid and iron core, the pull of the solenoid acting against the force of gravity or a spring; or structures involving the use of a fixed coil and a movable magnetic vane or arm, acting against the force of gravity or a spring; or, in some cases, structures involving the use of one fixed and one movable coil, without the use of magnetic material.

Solenoid and coil instruments and coil and vane instruments are obviously far more susceptible to error due to external influences, especially stray fields, than are instruments with a substantially closed magnetic circuit; but, because of their simple structure and low first cost, they are much used for rough measurements such as the measurements of voltage across batteries, etc., or in connection with small electric lighting or power systems, where high accuracy is not required of the switchboard instruments.

All commercial voltmeters for use on continuous current are subject to slight temperature errors. This is due to the fact that their indications are dependent upon the amount of current passing through a fixed resistance.

Numerous alloys or combinations of pure metals and alloys have been resorted to to minimize this error, and indeed it is theoretically possible to substantially eliminate it; but in ordinary practice variations in room temperature do cause a variation in the resistance of the voltmeter circuit, and consequently a variation in the accuracy of the indications of the instrument. Good modern practice prescribes that the accuracy of the instrument shall not vary more than .02 per cent. degree centigrade, normal accuracy generally being fixed at 25 per cent. centigrade in commercial calibration.

The second important instrument in connection with continuous current switchboards is the ammeter.

Elementally the mechanical structures employed for ammeters parallel those employed for voltmeters. A voltmeter is indeed an ammeter measuring the amount of current passing through a fixed resistance.

In direct current switchboard practice, it was customary, in the early days, to take the entire current to be measured through the instrument; but such practice was both costly and cumbersome, and presented no advantages adequate to justify the continuance of the practice.

In all ordinary switchboard practice today it is usual to measure the drop of potential across a fixed resistance; that is, the modern ammeter is connected in shunt to a resistance and consequently the commonly used modern switchboard ampere meter is in reality a voltmeter and subject to all the conditions and limitations laid down in connection with voltmeters.

No more common error has characterized the recent art than the misdirected effort to cut down the resistance of the shunt (and consequently the loss) to so low a point as to reduce the coercive force in the instrument to a value materially below that necessary to secure positive and permanently accurate operation.

It is safe and conservative, in connection with modern practice, to call for the use of ammeter shunts for direct current service having a drop of 60 milli-volts at their rated capacity.

As voltmeters vary with fluctuations of temperature, so also do ammeters, for obviously not only does the resistance of the circuit of the ammeter itself change with temperature, but also that of the shunt, and in the case of the shunt this change is accentuated by the fact that the shunt is itself heated by the current passing through it; but the utilization of special alloys has largely obviated this difficulty.

Great attention has been given both to the determinating of the proper compromise as between the proper drop and coercive force of the instrument on the one side, and a safe limitation of resistance to the point where excessive heating is not involved on the other. Much thought, too, has been given to the design of shunts in relation to the provision of ample radiating surface.

It is ordinarily conservative to specify that the variation in accuracy in a shunt type ammeter of the kind commonly used on switchboards shall not exceed 0.15 per cent. per degree centigrade in room temperature. It should be borne in mind that the accuracy of the shunt ammeter is absolutely at the mercy of the character of the connections between the shunt and the main circuit and the shunt and the instrument.

If the connections between the shunt and the main circuit are imperfect, then the resistance of these connections will cause excessive heating of the shunt, with a consequent increase in resistance and false indications of the ammeter. This point is to be carefully watched in all installations, and in writing specifications it is desirable to carefully cover this point.

Again, if the connections between the instrument and the shunt are imperfect, the resistance of the instrument circuit is greater than that contemplated, and since the total resistance of an ordinary ammeter such as is commonly used in switchboard practice is only about 20 ohms, the resistance of a bad contact may change the total resistance of the instrument circuit by a high percentage, and give a series of false indications which may be well nigh disastrous. Circuits have been overloaded and generally destroyed by such defects.

Poorly drawn specifications frequently seek to achieve economy by utilizing a single ammeter for the measurement of current values upon several circuits, this being accomplished by the use of a similar shunt in each of the circuits to be measured, successively connecting the ammeter to No. 1, No. 2 and No. 3 shunt by switching or plugging.

This practice is exceedingly bad because of the variation in the contact resistance of the various switches and the error incident thereto.

Specifications calling for such arrangement should be condemned since they sacrifice accuracy to a dangerous degree in an endeavor to secure an economy which is in reality trivial. It is far better to be without an ammeter on a circuit than to attempt to measure under conditions involving so high a degree of unreliability.

It is desirable to make it clear that the objection to switching or "plugging over" a single ammeter onto two or more circuits is broadly pertinent only to ammeters used in connection with shunts, or, to state the case more literally, to voltmeters (for that is what such ammeters are) in which the needle, when at the highest point of the scale, is actuated by, let us say, 15 milli-amperes at 0.06 volts across the two terminals.

With the exception of integrating and recording instruments, the ammeter and the voltmeter comprise substantially all the instruments commonly used on continuous current circuits.

In the field of alternating current switchboard measuring appliances we find a very much larger field of conditions to be dealt with, and we must give consideration to all of the following mechanisms: the voltmeter, the ammeter, the indicating wattmeter, the polyphase indicating wattmeter, the synchronism indicator, the frequency indicator and the power factor indicator.

The alternating current voltmeter in ordinary practice today takes two forms: a structure having a fixed coil and a free coil, moving in relation to one another and against the restraining force of a spring or of gravity; or a fixed coil and a moveable magnetic vane, also moving against the restraining force of a spring or gravity.

The type of instrument in which the moving vane is utilized is capable of somewhat less precise accuracy than that involving the fixed and movable coils. It is, however, satisfactory for general voltage determination, and is the form commonly used.

The higher grade alternating current voltmeters, and indeed ammeters and other instruments of their general structure and characteristics, are very commonly made in such physical form as to permit of the use of a vertical pivot.

This structure is resorted to primarily because moving coil instruments of types in which no highly concentrated magnetic field is used have a high ratio of weight of moving element to torque, and by the use of the vertical pivot or step bearing the ratio of torque to friction is improved in the ratio of about two to one, as compared with similar mechanisms utilizing horizontal bearings.

We may compare this modification to a top revolving upon a vertical bearing, as compared with the same top spinning between horizontal bearings of highly perfected construction.

Instruments with vertical pivots must obviously, for the sake of convenience, have horizontal scales, which, however, chance to coincide with convenient arrangement. The most commonly used instruments in alternating current service are known as horizontal edgewise instruments.

Alternating current voltmeters are generally required to indicate at the generating plant the secondary voltage of the system, and they are consequently not ordinarily connected directly and physically to the generating circuit or feeder, but to the secondary of a transformer, the primary of which is connected to the generating circuit and the ratio of which is similar to that of the transformers in use on the circuit outside.

This statement applies, of course, only to systems where distribution is accomplished through step-down transformers, which method is, however, substantially universal.

The principal purpose of this so-called step-down transformer is, of course, to secure a voltage corresponding with that of the applied system, but incidentally it should be noted that with rare exceptions no instruments whatever should be connected directly and physically to the circuit when that circuit is of high potential. There are exceptions to this rule, but above 2500 volts it should be carefully observed, even on small systems, for in small structures like instruments it is difficult to provide insulation which will insure permanent isolation of the electrical parts of the instruments from the circuit, and obviously a ground on an instrument might be fatal to human life.

For high grade alternating current practice it is entirely proper to specify an accuracy between one-half scale and full scale within one per cent. of actual.

Alternating current voltmeters are subject, as are direct current voltmeters, to changes in room temperature, and in addition they are subject to other conditions of a more elusive character. Thus in some types a very noticeable error may be introduced by the use of the same instrument on circuits deriving their energy from machines giving different wave forms, and the same is true of changes in frequency. These deviations, however, if pursued, would carry the subject into a highly specialized branch of study.

Alternating current ammeters have, in a large measure, the same physical characteristics of mechanical construction as have voltmeters. They are commonly used, however, not in connection with shunts but in connection with so-called series or current transformers, that is, transformers, the secondary current of which varies in direct ratio to the variations in the current of the primary.

Such transformers are in reality step-up transformers with a very small number of turns in the primary (sometimes only a fraction of one turn) and a relatively large number of turns in the secondary. These devices obviously serve the same economic purpose in connection with alternating current as do the shunts in direct current service. The same kind of care must be exercised in making connections to them as to shunts. This is particularly true with the primary or high current connections, but not so radically true with the secondary or low current connections.

Current transformers are generally manufactured commercially for use interchangeably with ammeters of appropriate capacity and suitable type. They are not as a rule accurately reliable through a range exceeding ten to one, and it is preferable to so arrange the system as to rely upon them only through a range of five to one.

It is good practice to specify that the ratio error of current transformers shall not vary more than $1\frac{1}{2}$ per cent. with a change in secondary load from one-tenth to normal full load. This latter stipulation is pertinent to the utilization of the same current transformer for the excitation of the actuating coils of several instruments, as for example, the current coil of a voltmeter, the current coil of an ammeter and the current coil of an integrating meter, all in the same circuit.

It is customary at times to specify the net accuracy of the ammeter and the current transformer, considered as a unit, in which case a variation of 2 per cent. from zero at all points between one-half scale and full scale is permissible.

Whilst the ammeter and the voltmeter may be regarded as the fundamental indicating instruments for all systems, and the only really necessary ones for continuous current service, the use of alternating current has rendered it desirable, and even necessary, to place upon most, if not all, switchboards, a number of other indicators reading in other units.

First among such instruments we must consider the indicating wattmeter.

Alternating current systems operating at unity power factor are practically never found in modern practice Any distribution system serving devices involving iron in their circuit, such as transformers, arc lamps, fan or other motors and the like, is subject to phase displacement between the current and potential waves, and, as a consequence, the product of volts and amperes is not a true measure of the power output of the system, since the measured amperes and the measured volts are not concurrent.

It is therefore necessary to provide an instrument which will indicate the true watts upon the circuit. This instrument is the indicating wattmeter.

Physically, such instruments, whilst capable of being made in numerous forms, are substantially never found today save in one general form, namely, a moving coil rigidly attached to the indicating mechanism, excited through a fixed resistance across the system, and responding to fluctuations of potential; and a fixed coil, creating the field in which the potential coil moves, varying in its strength with fluctuations in current.

The mechanical combination of these elements may be greatly varied, but the resultant phenomena of torque and motion varying with the voltage multiplied by the current must be always the same.

In modern practice the potential coil of such instruments is usually attached to the secondary of a potential transformer, as in a voltmeter (indeed, the moving coil is essentially a voltmeter) whilst the fixed current coil is attached to the secondary of the current transformer, as in the case of an ammeter.

Two-phase and three-phase indicating wattmeters are commonly manufactured for such systems, and, whilst necessitating greater complexity of construction, involve similar principles. Such instruments are generally known by the name of polyphase wattmeters. There is another form of indicating wattmeter perhaps less commonly used, which involves the use of no moving wire, but the motion of which is dependent upon the torque produced by the induction of foucault currents in a disk by a mechanism whose inductive effect is dependent upon the watts in the system. Such a disk armature has a turning torque dependent upon the watts, and tends to turn against the restraining force of a spring. This mechanism is a modification of the familiar integrating induction type recording wattmeter, which will be dealt with later.

Whilst it is possible to determine the power factor of the system or the wattless component by comparing the volt-amperes (voltmeter, ammeter) with the true watts as shown by the wattmeter, it is common and good practice to place power factor indicators upon each outgoing line or at least upon those involving the larger power loads, which are, of course, the larger inductive loads.

The purpose of this instrument is to show from week to week, rather than from moment to moment, the condition of the circuit, indicating when the inductive load of that particular circuit has been run up too high for economy, and pointing to the desirability of the correction of this condition, as by the introduction of synchronous motors or rotary condensers, or by the re-arrangement of the circuits. The power factor indicator is to be regarded as a technical luxury rather than a necessity.

This is also true of the frequency indicator, the function of which is to indicate upon a scale, as its name indicates, the frequency or alternations upon the system. This instrument serves to constantly inform the operator of the speed accuracy of his apparatus, as the efficiency and good behavior of most of the apparatus on the system is in some measure dependent upon the maintenance of proper frequency.

It would be undesirable to leave the subject of switchboard instruments without making some reference to electrostatic voltmeters, which are quite commonly used, especially in connection with high potential systems, where for various reasons it may be undesirable to introduce potential transformers between the system and the measuring device.

Electrostatic voltmeters actuate the needle in its movement across the scale by the electrostatic attraction or repulsion of one or more fixed vanes upon one or more movable vanes attached to the spindle and needle.

Numerous variations of construction may be and are resorted to in connection with such mechanisms, and these variations will be dealt with in another portion of this paper.

The principle of the electrostatic voltmeter is utilized in operating so-called ground detectors—instruments whose function it is to show upon a scale the presence of and to measure the resistance of a ground on a circuit or system, as well as to indicate the wire upon which the ground is present.

A common way of accomplishing this upon a single-phase system, for example, is to attach each of two fixed vanes or sectors to each of the two outgoing wires and a third fixed vane or sector to earth. A movable vane or vanes attached to the needle will, with no ground on the system, stand at such a position as to hold the needle in the center of the scale, but, should a ground occur upon either leg of the line, then the permanently grounded sector and the temporarily grounded sector will become essentially one, and the movable vane will take a position calculated to bridge through the shortest path between the ungrounded sector, and the grounded section of the system.

Before leaving switchboard instruments, a moment of consideration must be given the question of damping.

Substantially all indicating mechanisms have a most trying tendency when under rapid fluctuations of load to vibrate with such violence and for so considerable a time as to render any reliable readings substantially impossible.

If the moving element is light and of small inertia this motion is of small amplitude and of high frequency, resulting in vibrations of the needle which result in little more than a blur of the needle, whilst if the moving element be of relatively high inertia the motion is of large amplitude, longer period and at least equally difficult to interpolate.

Three common means have been resorted to for correcting this difficulty. In the early days of the art perhaps the most common means and certainly the simplest was to attach an air vane or an air dashpot of some form to the moving element. This served reasonably well in the days of small coercive forces, and vibrations of relatively large magnitude, but it was obviously inadequate for certain classes of instruments, which led to the introduction of fluid dashpots, one form of which consisted in attaching to the moving element a disk shaped hollow cylinder containing some viscous fluid as, for example, glycerine.

Such construction was open to objection, first because of excessive weight of moving element, and second because of the tendency of the fluid to cling to the interior of the moving cylinder and throw the mechanism out of balance.

In modern practice where a strong and relatively dense magnetic field constitutes a portion of the structure, it is easy to place a disk or cup or other similar element in this field, attached to the moving spindle in such a way that the motion of the spindle moves this foucault element through the field, resulting in the induction of foucault currents therein, thus damping the motion admirably, and rendering the instrument, in the phraseology of the art, "dead beat."

Where concentrated magnetic fields are not available, through the inherent principles of the instrument, the air vane is maintained as the preferable method, and has been developed to a high degree of perfection.

(To be Continued)

READVILLE REPAIR SHOP OF THE N. Y., N. H. and H. R. R.

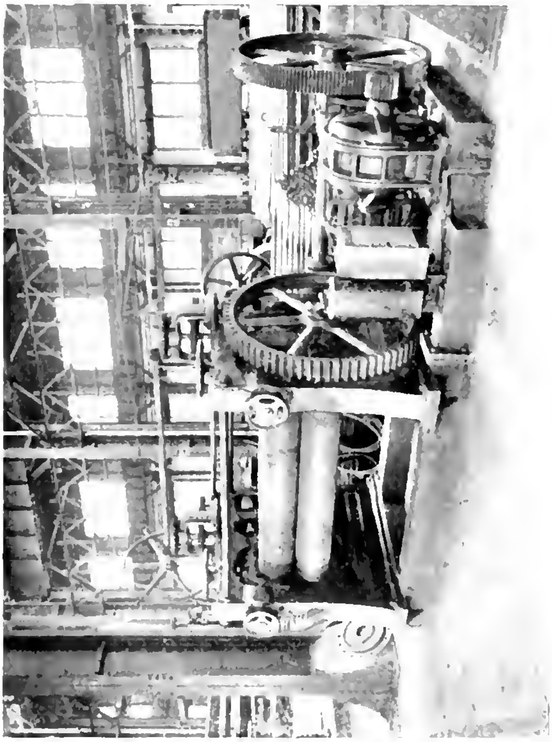
By A. I. Totten

The main building of the Readville Shops of the New York, New Haven and Hartford Railroad is 904 ft. 6 in. long by 150 ft. wide and comprises a machine shop, an erecting shop, a boiler shop, and a tank shop. This building is of brick and concrete construction, with structural steel frame, and has a roof covered with 5-ply asphalt and gravel. A great deal of attention was paid to the construction of the concrete floor, which is laid in squares with strips of tar paper separating the various sections.

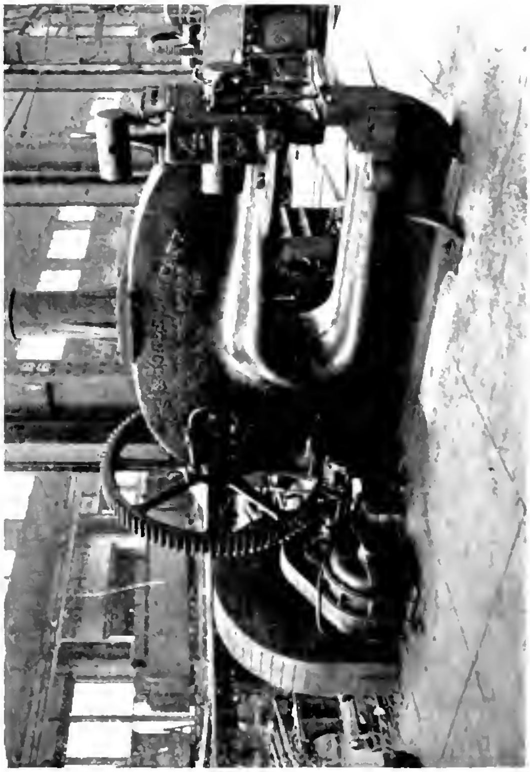
The erecting shop occupies half the width of the building and two-thirds of its length; it is built on what is known as a longitudinal design, will house 36 locomotives, and can make heavy repairs to 45 locomotives per month. The three longitudinal tracks are spaced on 23 ft. centers, the two outside tracks being used for engine repairs and the middle track for stripping and erecting, also for the storage of driving wheels during the period that the engines are in the shop. Stripping and erecting pits 150 ft. long are located under the center track at each end of the erecting shop, and between the central and outside tracks are storage pits which extend the full length of this shop. These pits are covered with 4 in. by 12 in. yellow pine plank, every tenth plank being provided with heavy malleable iron handles to facilitate its removal.

At the end of the erecting shop and occupying about 300 ft. of the total length of the building, is the boiler shop. These two shops are served by two 60 ton and two 20 ton cranes, the former being used for handling locomotives and the latter for handling boilers and the lighter work in connection with stripping, erecting, and transferring the various parts. These cranes, as well as all other cranes in the shops, are operated by

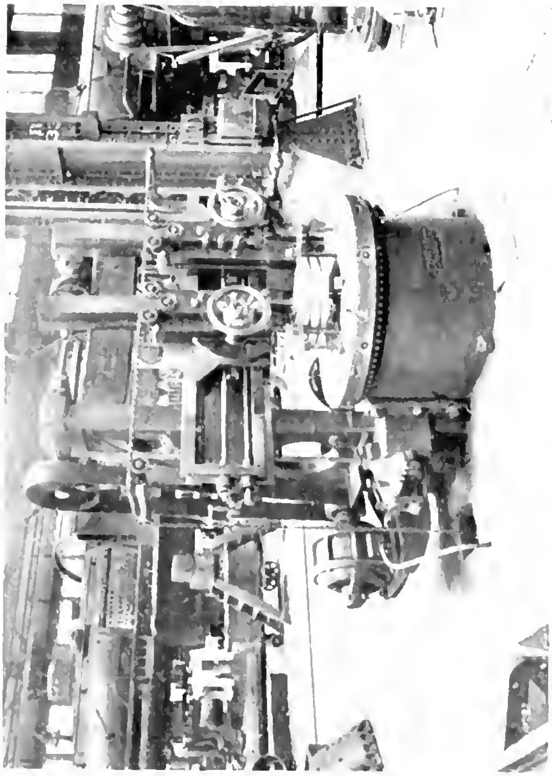
Portion of Machine Shop on the Right; Erecting Shop on the Left



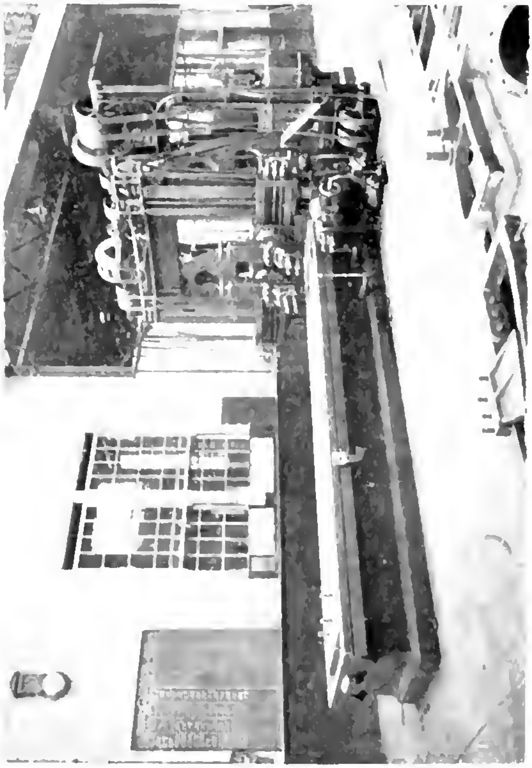
Straightening Roll Driven by 10 H.P., 450 R.P.M., 550 Volt, Form M Induction Motor



Shear Driven by 10 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor



[illegible]1 In. Boring Mill Driven by [illegible] H.P., [illegible] R.P.M., 550 Volt, Form K Induction Motor



[illegible] Ft. x 20 Ft. Planer Direct Connected to 35 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor alternating current induction motors. At one end of the erecting shop are placed driving wheel lathes, large boring mills, etc., to avoid

6 Ft. Radial Drill Geared to 5 H.P., 1500 R.P.M., 550 Volt Form K Induction Motor

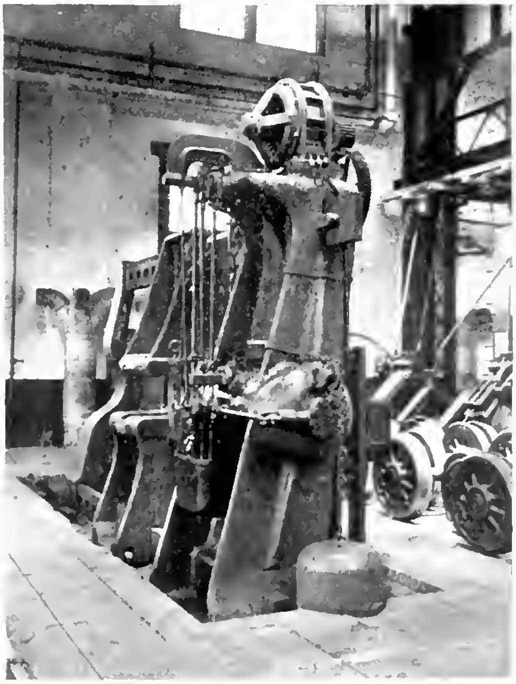
the necessity of handling driving wheels and the heavier locomotive parts between the erecting shop and the machine shop.

The machine shop is of the same length as the erecting shop and occupies the opposite half of the building. In addition to the ground floor space in this department, there is also a gallery 35 ft. wide, the full length of the building. This gallery is used for brass work, bolt work, lubricator and injector repair work, electrical repair work, tin and copper work, and cab work. Hatches are located at intervals in the floor and an I-beam trolley is used both for transferring material in the gallery and for raising material from the ground floor to the gallery floor through the hatches. In the gallery are located two Sturtevant indirect radiation heating systems which provide heat for the whole building. The gallery floors are of 2 in. by 6 in. spruce laid diagonally on 8 in. by 16 in. joists and covered with 1 in. by 1 in. maple. At each end of the gallery are locker rooms with suitable lavatory accommodat ons and immediately below these locker rooms are others similarly equipped.

The heavier tools on the ground floor of the machine shop are located outside of the gallery and served by three 10-ton cranes. In addition to the traveling crane service, the more important machines have each an independent jib crane, so that material can be handled in and out without the necessity of waiting on the traveling cranes.

Beneath the gallery are located the lighter tools, which are operated in groups from line shafting running the full length of the shop. This line shafting is divided into sections, each section being operated by an independent motor. At the dividing point between any two sections is placed a flange coupling with the bolts removed. In case it is desired to take any motor out of service for repairs or other reasons, the bolts can be inserted in the flange coupling and two sections of the shafting run by a single motor; or, by connecting the flange couplings at each end of the section, two motors can be made to operate three sections of shafting.

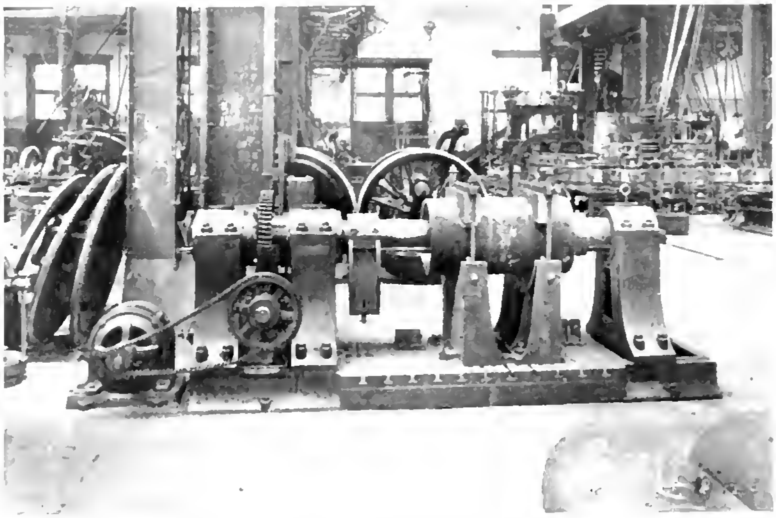
The majority of large tools are independently motor driven, and tests on a large number of



90 In. 600 Ton Wheel Press, Operated Through Gearing by 25 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

these motors, as well as tests on some of the group drive motors, may prove of interest and are included at the end of the article.

These tests, in so far as they refer to individually driven machines, were taken under average conditions; the groups, however, were not working up to their full capacity when the tests were made. While it is true that the results of these tests would not indicate the capacity of motor best suited to a given requirement, it can be inferred that the horse-power in the majority of cases varies in almost direct proportion to the metal removed, and it can therefore readily be ascertained whether or not the motors are of the proper size.



Cylinder Borer Driven by 7½ H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

There is what might be termed a manufacturing tool room in the gallery, and immediately beneath this is a corresponding room on the ground floor for the distribution and grinding of tools. A central station for a complete shop telephone system is located in the distributing tool room, this arrangement saving the time that would be necessary for mechanics to go to and from the tool room. When any special tool is desired, it is called for by telephone and delivered by messenger, who takes a check as a receipt.

The blacksmith shop is in a separate building paralleling a portion of the erecting shop, but there are few points of special interest to be described in connection with this department.

The power plant contains the following equipment:

Six 400 h.p. Babcock & Willcox boilers, five of which are equipped with mechanical stokers, the remaining one being arranged for burning shavings and refuse from the planing mill. These boilers are provided with Sturtevant economizers.

Three 400 kw., 150 r.p.m., 600 volt, 25 cycle G.E. generators direct connected to Hooven Owens Rentschler Company's cross compound 18 in. by 28 in. by 30 in. non-condensing engines.

Two 50 kw., 280 r.p.m., 125 volt exciters driven by simple Watertown engines.

Two 12-B brush arc generators direct connected to one 200 h.p., 250 r.p.m., 550 volt motor.

One 12-B brush arc generator direct connected to one 100 h.p., 500 r.p.m., 550 volt motor.

One 24 panel blue Vermont marble switchboard, equipped with General Electric Type TA voltage regulator.

One Franklin cross compound air compressor with a capacity of 1700 cubic ft. of free air per minute.

Two Franklin air compressors with a capacity of 1100 cubic ft. of free air per minute.

The piping, both that in the power plant and that connecting the power plant with other buildings of the shop, is painted in different colors, according to the purpose for which it is used. A table, as

24 In. Planer Driven Through Gearing by 7½ H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

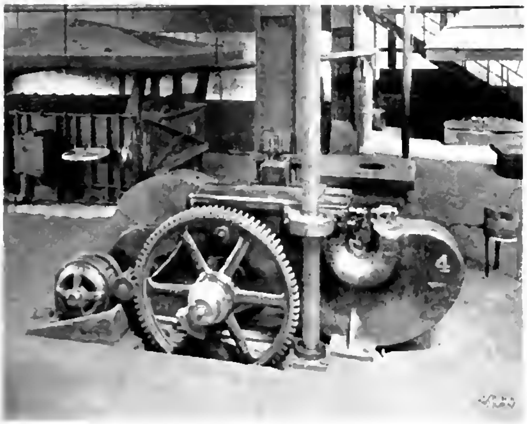
shown below, is provided at various points for the instruction of those interested:

White—High pressure steam.
Yellow—Exhaust and low pressure steam heat.
Black—Water, including boiler feed and feed water heater.
Green—Air
Blue—Drip and return.
Red—Fire service.

In addition to the building described above, there is a car department, which was, however, built a number of years ago. The machinery in this department is operated throughout by motors receiving current from the power plant described.

This entire plant is operated by 25 cycle alternating current, the only direct current apparatus being the exciters for the alternating current generators.

In the various departments are installed 173 motors with a total capacity of 3160 h.p., all of which are of General Electric manufacture. The average motor load at the switchboard varies from 600 to 700 kw., the average lighting and power load combined varying



Punch Driven by 10 H.P., 750 R.P.M., 550 Volt Form K Induction Motor

from 800 to 900 kw. It is therefore seen that the percentage of average load to total capacity of motors installed is about 30 per cent. The power factor throughout the day time is about 69 per cent., increasing to 71 or 72 per cent. when the lights are placed in operation.

TESTS

80 IN. DOUBLE WHEEL LATHE (Putnam)
10 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor.

Load	Kilowatt Input
Rolling axle, speed 15 feet per min	0.5–2.0
Turning axle, 1/64 in. cut, 1/32 in. feed Speed 15 ft. per min.	0.6–1.6

90 In. DOUBLE WHEEL LATHE Putnam
50 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Running light	2.4
Full load	28.

Load consists of two heavy cuts on driving wheels, 3/8 in. feed, 3/8 in. cut, cutting speed 12 ft. per min. Kind of tool steel—Mushet high speed.

7½ H.P., 750 R.P.M., Form K Induction Motor

This motor is used to move tail stock.

Load	Kilowatt Input
Moving forward	1.8
Moving backward	1.8

600 TON, 90 In. WHEEL PRESS (Pond)
25 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Running light	1.4
Pressing 6 in. crank pin from driving wheel	
Average load	2.3
Maximum load when pin started	3.5
Maximum pressure when pin started 260 tons.	

36 IN. X 12 FT. PLANER (Putnam)
10 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Running light	1.8
Forward, no load	2.8
Reverse	22.
Back	4.4
Reverse	18.
Forward under load	3.6

Load: One 1/64 in. cut, 1/16 in. feed on cast iron, Tool steel, Midvale
One 1/32 in. cut, 1/16 in. feed on steel. Tool steel, Syrian
Forward 35 ft. per min.
Backward 70 ft. min.

48 IN. X 16 FT. DOUBLE PLANER (Woodard & Powell)
25 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Running light	2.
Forward, no load	4.
Backward, no load	4.
Forward, under load	13.

Load, two 5/16 in. cut, 1/32 in. feed on cast steel
Tool steel—Mushet high speed
Cutting speed 45 ft. per min.

72 IN. X 12 FT. PLANER (Pond)
25 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Running light	1.7
Reverse	20.
Forward, no load	2.1
Backward	5.
Reverse	10.
Forward, under load	1.8

Load, 1 cut ½ in. with 1/8 in. feed on cast iron
Tool steel—Mushet high speed
Cutting speed—18 ft. per min.
Return speed—54 ft. per min.

72 IN. X 30 FT PLANER (Putnam)
35 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Running light	3.4
Forward, no load	4.8

72 IN. X 30 FT. PLANER (Putnam) Concluded
35 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input	
Reverse	32.	5 tons
Backward	9.2	on bed
Reverse	14.8	
Forward, under load	6.4	

Load, one $\frac{1}{4}$ in. cut, $\frac{1}{16}$ in. feed on cast iron
Tool steel—Mushet
Speed forward—30 ft. per min.
Speed backward—65 ft. per min.

CYLINDER BORER
$7\frac{1}{2}$ H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Running light	0.76
3 cuts $\frac{1}{8}$ in. by $\frac{1}{16}$ in. feed	4.8
5 cuts $\frac{1}{8}$ in. by $\frac{1}{16}$ in. feed	5.6

On 3 cuts, cutting speed 17 ft. per min. Tool steel unknown

On 2 additional cuts, cutting speed 25 ft. per min. Tool steel, one Mushet high speed; one Syrian

6 FT RADIAL DRILL (Bickford)
5 H.P., 1500 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Running light	0.9
$\frac{7}{8}$ in. hole in cast steel	1.9

Feed, $\frac{1}{2}$ in. per min.
Speed of drill, 74 r.p.m.

5 FT RADIAL DRILL (Bickford)
5 H.P., 1500 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input	Speed of Drill
Running light	.48	
One $\frac{5}{8}$ in. hole in steel, feed 0.45 in. per min.	1.3	52 r.p.m.
Two $\frac{1}{2}$ in. hole in cast iron, feed 0.16 in. per min.	1.5	24 r.p.m.
Two $\frac{3}{4}$ in. hole in steel, feed 0.375 in. per min.	2.4	20 r.p.m.

51 IN BORING MILL (Bullard)
$7\frac{1}{2}$ H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Running light	1.8
Two $\frac{1}{4}$ in. cuts, $\frac{3}{32}$ in. feed, 40 ft. per min. on cast iron	4.6

Tool steel—Mushet high speed

47 IN BORING MILL (Baush)
10 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Running light	1.9
One $\frac{7}{32}$ in. cut, $\frac{1}{32}$ in. feed, 35 ft. per min. cast steel	3.
One $\frac{1}{16}$ in. cut, $\frac{1}{64}$ in. feed, 40 ft. per min. cast steel	3.5
One $\frac{3}{16}$ in. cut, $\frac{1}{16}$ in. feed, 50 ft. per min. cast steel	4.

Tool steel—Mushet high speed

BUFFER & GRINDER (Rawson)
3 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Running light	0.4
Grinding 6 in. steam pipe to surface	0.5

COLD SAW (Newton)
3 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Running light	.6
Cutting 6 in. cast iron	3.2

Slow feed 0.45 in. per min.
Saw 16 in. dia., $14\frac{1}{2}$ r.p.m.

FLUE CLEANER (Ryerson)
25 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Rolling	7.2
Lifting	17.

Loaded with 308—2 in. dia. tubes, 12 ft. long.

No. 5 PUNCH (Hilles & Jones)
5 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input	
Running light	0.7	
Punching $\frac{9}{16}$ in. hole in $\frac{1}{4}$ in. boiler plate	1.3	Max.
Punching $\frac{9}{16}$ in. hole in $\frac{3}{16}$ in. boiler plate	1.2	Max.
Punching $\frac{9}{16}$ in. hole in $\frac{5}{16}$ in. iron	1.5	Max.
Punching $\frac{9}{16}$ in. hole in $\frac{1}{2}$ in. steel	2.32	Max.

22 Punches per min.

NO 4 PUNCH (Hilles & Jones)
10 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Running light	.5
Punching $\frac{13}{16}$ in. hole in $\frac{1}{2}$ in. flange steel	4. (Max.)

NO. 9 PUNCH & SHEAR (Hilles & Jones)
15 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input	
Running light	3.	
Punching 2 in. hole in $\frac{1}{4}$ in. boiler plate	5.	Max.
Punching 2 in. hole in $1\frac{1}{2}$ in. wrought iron	22.	Max.
Shearing 4 in. by $2\frac{1}{2}$ in. hammered iron	10.	Max.

NO. 3 SHEAR (Hilles & Jones)
5 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input	
Running light	0.3	
Shearing round steel $\frac{1}{2}$ in. dia.	0.8	Max.
Shearing round steel $\frac{3}{4}$ in. dia.	1.1	Max.
Shearing boiler plate $\frac{5}{8}$ in. by $2\frac{1}{2}$ in.	2.	Max.
Shearing boiler plate $\frac{3}{8}$ in. by $1\frac{1}{2}$ in.	1.2	Max.

SPLITTING SHEAR (Lenox Machine Co.)
$7\frac{1}{2}$ H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Running light	0.4
Cutting $\frac{1}{4}$ in. boiler plate	1.7

Cutting speed 7.2 ft. per min.

10 FT. BENDING ROLLS (Hilles & Jones)
10 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Running light	1.2
Bending $\frac{1}{2}$ in. boiler plate. Av.	2.8; Max 4.4

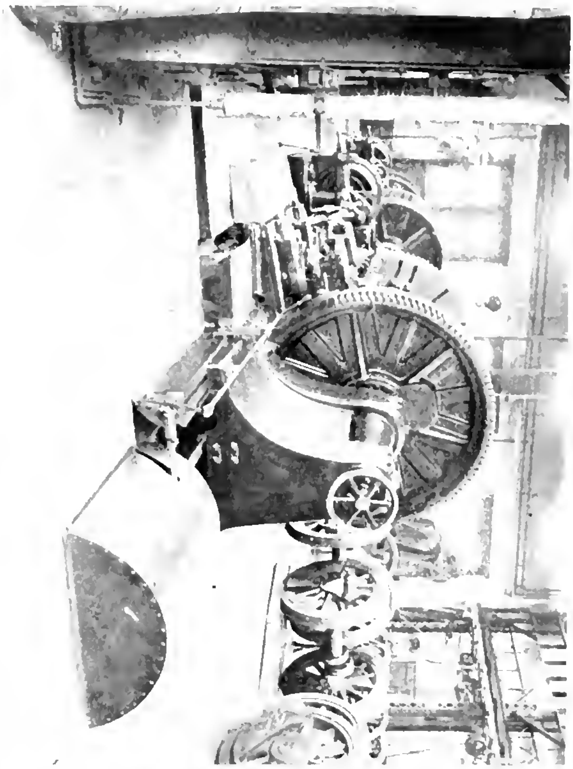
Boiler plate was $6\frac{1}{2}$ ft. wide and was bent to a radius of 30 in. in 5 rollings

Rolling speed 5.6 ft. per min.

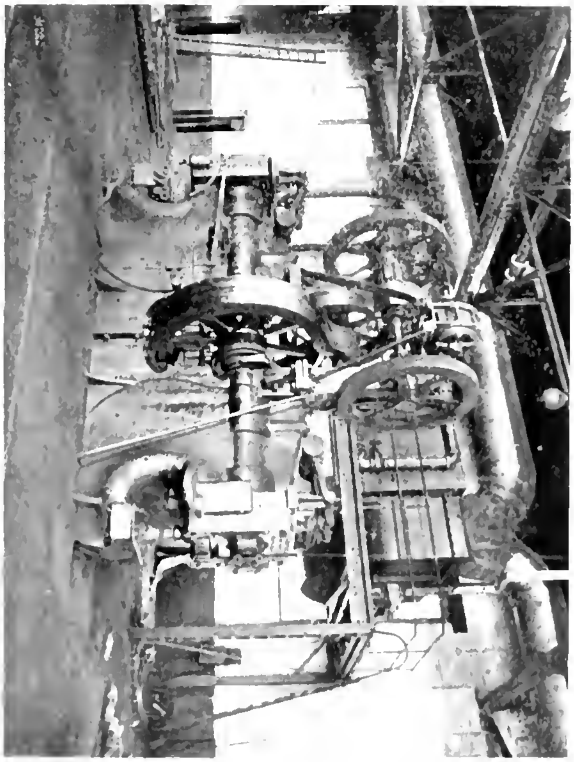
63 IN BOSTON CUPOLA & FORGE BLOWER
30 H.P., 750 R.P.M., 550 Volt, Form L Induction Motor

This blower furnishes air for one flange fire, two flue fires, and a four burner Ferguson annealing furnace, made by the Railway Materials Co.

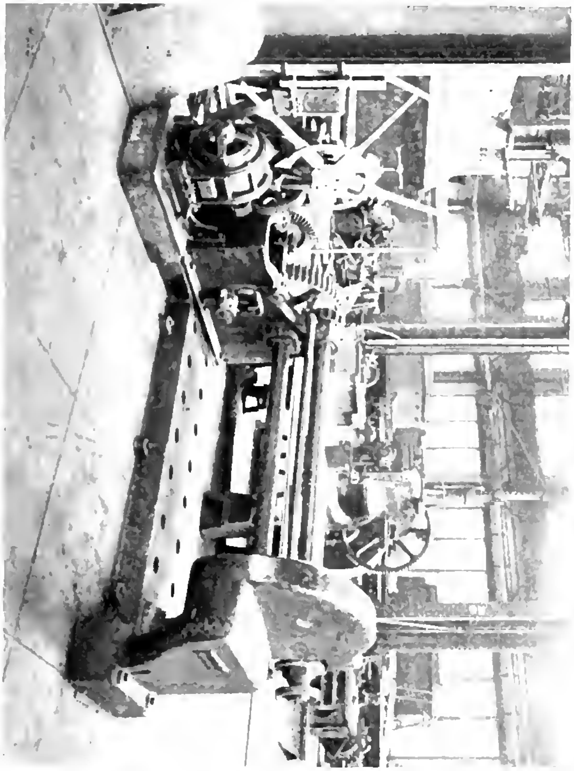
Load	Kilowatt Input
All full blast	13.8
Two flue fires only	9.5



90 In. Double Wheel Lathe Geared to 75 H.P., 715 R.P.M., 550 Volt, Form K Induction Motor



Punch and Shear Driven by 15 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor



Splitting Shears Driven by 7½ H.P., 715 R.P.M., 550 Volt, Form K Induction Motor

Rail Bender Driven by 10 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

NO. 7 BLOWER (Sturtevant) BULLDOZER (Ajax)

35 H.P., 500 R.P.M., 550 Volt, Form K Induction Motor

Blower furnishes air for 5 furnaces

Load	Kilowatt Input
Blower with 3 furnaces operating	16.3
Blower & Bulldozer	28.3 Max.

Bulldozer was making 2–90 degree bends on $\frac{3}{4}$ in. by 3 in. iron

STURTEVANT BLOWER

35 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Blower furnishes air for
One double furnace
Four single furnaces
Five double forges

Load	Kilowatt Input
3 single furnaces at work 1 double furnace at work	17.6
3 single furnaces at work 1 double furnace at work 1 double forge full vent	18.6

BLOWER (Buffalo) EXHAUSTER (Buffalo) For 20 forges and 2 furnaces

50 H.P., 500 R.P.M., 550 Volt, Form L Induction Motor

Load	Kilowatt Input
11 forges and 2 furnaces in operation	21.5

NO. 3 SHEAR (Hilles & Jones)

10 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input	
Running light	1.	
Shearing $1\frac{1}{2}$ in. wrought iron	5.5	Max.
Shearing $2\frac{3}{4}$ in. wrought iron	6.	Max.

5 FT., 6 IN. RADIAL DRILL (Niles-Bement & Pond)

5 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Running light	1.2
Drilling $\frac{3}{4}$ in. hole in steel, feed 0.67 in. per min.	1.5
Drilling $2\frac{1}{2}$ in. hole in steel, feed 0.075 in. per min.	1.8

MILL SHOP NO. 1

SWING CUT-OFF SAW (Rogers)

3 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Running light	0.74
Cutting 2 in. by $12\frac{1}{2}$ in. spruce	2.4

Size of saw 19 in.
Speed 2080 r.p.m.

SWING CUT-OFF SAW (Rogers)

3 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input	
Running light	0.9	
Cutting 5 in. by 8 in. hard pine	6.	Max.
Cutting 2 in. by 10 in. hard pine	5.	Max.

Size of saw 18 in.
Speed 1840

RAIL SAW (Newton)

$7\frac{1}{2}$ H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Running light	0.56
Sawing 6 in. steel rail	Av. 1.6 Max. 2.4

Feed 0.21 in. per min.
28 in. saw
5.15 r.p.m.

RAIL BENDER (Watson & Stillman)

15 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Running light	1.
Bending 79 lb. rail to 24 ft., $11\frac{1}{4}$ in. radius	8.

Speed of rail 100 ft. per min.

15 IN. SLOTTER (Dill)

5 H.P., 1500 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Running light	0.4
One $\frac{3}{8}$ in. cut, $\frac{3}{64}$ in. feed on steel	0.9

Tool steel—Mushet high speed
Strokes per minute, 23

ELEVATOR

5 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Motor running light	0.56
Elevator up with one man	Pump back on line
Elevator down with one man	4.2
Elevator up with 1400 lbs.	1.2
Elevator down with 1400 lbs.	2.2

24 IN. EXTRACTOR

3 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Load	Kilowatt Input
Extractor filled with oily waste	0.96–0.88

Speed of extractor, 1080 r.p.m.

NO. 3 GAINER (Wood)

0 H.P., 750 R.P.M., 550 Volt, Form L Induction Motor

Load	Kilowatt Input
Running light	2.4
$\frac{1}{2}$ in. by $1\frac{1}{2}$ in. gain in hard pine	4.4
2 in. by $4\frac{1}{2}$ in. gain in hard pine	7.2

NO. 2 FORGING MACHINE (Ajax)

10 H.P., 750 R.P.M., 550 Volt, Form L Induction Motor

Load	Kilowatt Input
Running light	1.6
Punching $\frac{7}{16}$ in. hole in a $1\frac{9}{16}$ in. rivet	5.0 Max.

NO. 5 FORGING MACHINE (Ajax)

20 H.P., 750 R.P.M., 550 Volt, Form L Induction Motor

Load	Kilowatt Input
Running light	3.7
Loaded	16.1 Max.

Load consisted of gathering a $1\frac{7}{8}$ in. hemispherical head on a $1\frac{1}{8}$ in. rivet.

GROUP (Gallery)

$7\frac{1}{2}$ H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Machines	Load	Kilowatt Input
1 Two spindle irregular moulder (Carey)	Running light	7.
1 $39\frac{1}{2}$ in. band saw (Carey)	Running	
1 Double saw table (Carey)	Running	

When test was made saw was ripping 2 in. pine and saw bench ripping 2 in. oak.

GROUP

10 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Machines	Load	Kilowatt Input
4 Flue cutters	2 Running light 2 Running	4.
1 Flue welder	Running	

GROUP

10 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Machines	Load	Kilowatt Input
1 28 in. Vertical drill (Blaisdell)	Running	
1 40 in. Vertical drill (Bement)	Running	
1 38 in. Vertical drill (Prentice)	Running	
2 34 in. Lathes (Putnam)	1 Running	6.2
5 22½ in. Vertical drills (Barnes)	1 Running	

GROUP

15 H.P., 750 R.P.M., 550 Volt, Form K, Induction Motor

Machines	Load	Kilowatt Input
3 24 in. Lathes (Reed)	2 Running	
1 40 in. Vertical drill (Bement)		
1 42 in. Boring mill (Bullard)	Running	
1 24 in. Shaper (Stockbridge)		
1 15 in. Slotter (Betts)		8.
1 18 in. Slotter (Putnam)	Running	
1 30 ton arbor press (Chamsberberg)		

GROUP

15 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Machines	Load	Kilowatt Input
2 30 in. by 8 ft. planers (Woodward & Powell)	2 Running	
1 26 in. by 10 ft. milling machine planer type (Becker Brainard)		
1 5 ft. radial drill (Bickford)	Running	8.
2 No. 2 horizontal boring mills (Betts)	2 Running	
1 25 in. vertical drill (Barnes)		

GROUP (Gallery)

15 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Machines	Load	Kilowatt Input
1 24 in. lathe (Fitchburg)		
2 20 in. lathes (Schumacher)	1 Running	
4 18 in. lathes (Prentice)	2 Running	
5 18 in. lathes (Schumacher)		
4 2 ft. by 24 in. flat turret lathes (Warner & Swasey)	2 Running	
2 2 ft. by 24 in. flat turret lathes (Jones & Lampson)	1 Running	Av. 12. Max. 24.
1 40 in. vertical drill (Bement)		
1 25 in. vertical drill (Barnes)		
1 3 in. bolt cutter		
1 1½ in. bolt cutter (Acme)		
2 double bolt cutters (Acme)	2 Running	
1 double bolt cutter (Niles, Bement & Pond)	Running	

GROUP

15 H.P., 750 R.P.M., 550 Volt, Form L Induction Motor

Machines	Load	Kilowatt Input
1 Trip hammer (Bradley)	Running	
1 No. 2 emery grinder (Diamond Machine Co.)	Running	
2 40 in. vertical drills (Bement)	2 Running	
1 Grindstone		Av. 13.
1 Hammer (Bradley)		Max. 19.
1 No. 2 shear (Hilles & Jones)		
1 1½ in. forging machine (Ajax)		
1 2 in. forging machine (Ajax)	Running	
1 3½ in. forging machine (Ajax)	Running	

GROUP

25 H.P., 750 R.P.M., 550 Volt, Form K Induction Motor

Machines	Load	Kilowatt Input
2 30 in. boring mills (Bullard)	1 Running	
2 24 in. lathes (Reed)	2 Running	
2 18 in. lathes (Reed)		
1 24 in. turret lathe (Gisholt)	Running	
1 30 in. planer (Woodward & Powell)		
1 16 in. shaper (Gould & Erbhardt)		16.
1 24 in. shaper (Stockbridge)	Running	
1 16 in. shaper (Stockbridge)		
1 30 in. planer (Putnam)		
1 42 in. vertical milling machine (Hilles & Jones)		
1 Double rod borer (Newton)		

GROUP

30 H.P., 750 R.P.M., 550 Volt, Form L Induction Motor

Machines	Load	Kilowatt Input
1 No. 300 Hollow mortiser (Wood)	Running	
1 No. 225 Hollow mortiser (Greenlee)	Running	Av. 22.2
1 30 in. Single planer (Rogers)	Running	Max. 30.3
1 30 in. Single planer (Fay) Heavy load	Running	

GROUP

35 H.P., 500 R.P.M., 550 Volt, Form K Induction Motor

Machines	Load	Kilowatt Input
2 Irregular moulders (Wood)	2 Running	
1 60 in. three drum sander (Fay)	Running	
1 42 in. three drum sander (Fay)	Running	
2 Grindstones	Running	
1 42 in. band saw (Fay)	Running	26.3
2 Turning lathes (Wood)		
1 Dowel machine (Fay)		
1 Rip saw	Running	
2 Copper sheathing machines Heavy load		

GROUP

40 H.P., 750 R.P.M., 550 Volt, Form L Induction Motor

Machines	Load	Kilowatt Input
1 No. 214 jointer (Invincible)		
1 Universal jointer (Fay)	Running	
1 Saw table (Rodston Engine Works)		
1 End tenoner (Berry & Orton)		20.3
1 5 spindle borer (Wood)	Running	
1 5 spindle borer (Greenlee)	Running	
1 Self feed rip saw (Wood)		

GROUP

50 H.P., 500 R.P.M., 550 Volt, Form L Induction Motor

Machines	Load	Kilowatt Input
1 Chain mortiser (New Britain)		
1 Buzz planer and drill (Fay)		
1 18 in. band saw (Fay)	Running	
1 10 in. outside moulder (Wood)	Running	18.3
1 36 in. band saw (Atlantic)		
1 Tenoner (Fay)		
1 Double cabinet saw (Carey)		
1 Tenoner		

THE EFFECT OF SUPERHEAT, VACUUM, INITIAL PRESSURE AND FEED WATER TEMPERATURE ON THE WATER RATE AND COAL CONSUMPTION OF TURBINES

By Dr. Ernst J. Berg

By referring to the equations given in the first paper† or to the tabulation of theoretical water rates, the theoretical water rate can be determined for any values of initial pressure, superheat, and vacuum.

So for instance with 200 lbs. absolute initial pressure, dry saturated steam, and 28 in. vacuum, the theoretical water rate is 10.2 lbs. per kilowatt hour. At 29 in. vacuum it is 9.6 lbs. per kilowatt hour, and at 27 in. vacuum, 10.75 lbs.; therefore, using 28 in. vacuum as a basis for comparison, there is a decrease in water rate of 5.9 per cent. when increasing the vacuum 1 in. and an increase in water rate of 5.4 per cent. when lowering the vacuum by 1 in.

Thus on an average, we conclude that around 28 in. vacuum each inch of vacuum changes the water rate by about 5.7 per cent.

With steam at 200° F. superheat, the theoretical water rate at 28 in. vacuum is 9.1 lbs. per kw-hr.; at 29 in. vacuum it is 8.55 lbs. per kw-hr.; and at 27 in. vacuum, 9.6 lbs.; thus the average change in water rate per inch of vacuum is also 5.7 per cent.

Therefore, in general we can state that, disregarding the condition of the steam (at about 200 lbs. absolute initial pressure and 28 in. vacuum), there is a change of water rate per inch of vacuum of about 5.7 per cent. With lower initial pressure, as for instance 140 lbs. absolute, the average change of water rate is 6.4 per cent. per inch of vacuum, or considerably greater than at the higher initial pressure, as could be expected.

The effect of superheat on the water rate can also be determined from the equation of available energy, or by referring to the table. For instance, at 200 lbs. absolute pressure and 28 in. vacuum, the theoretical water rate is 10.2 lbs. with saturated steam. With steam at 200° F. superheat, it is 9.1 lbs.; thus the decrease in water rate is 10.8 per cent., for each per cent. decrease in water rate requires 18.5° superheat. This value remains practically the same whether the vacuum is 27 in. or 29 in. It is also practically the same for all commercial initial pressures.

It is an interesting fact, however, that while the gain in water rate by vacuum is practically that demanded by theory, the gain by superheat is almost 50 per cent. greater. The fact that the gain by vacuum is as much as theory demands is interesting, since it indicates that the operation of the lower stages must be very efficient with high available energies, and corresponding high steam speeds, as the lower, or indeed the last stage, is practically the only one affected by the change of vacuum and may with high vacuum convert far more energy than each of the upper stages.

The large gain by superheat is no doubt due to the fact that the rotation loss is less than with initially saturated steam. It has been found that this loss is a function of the quality of the steam. A mixture of steam with a considerable amount of water acts to some extent as a water brake.

The great saving effected by the use of high vacuum is in the coal consumption; the per cent. saving corresponding practically to the gain in the water rate by increased vacuum. For instance, assuming the efficiency of the turbine to be the same when operating at 27 in. vacuum and at 28.5 in. vacuum, the gain in water rate at average commercial initial pressure is 9 per cent. and 9 per cent. in water means substantially a saving of 9 per cent. in coal.

The gain in water rate by superheat only slightly affects the coal consumption. As an example, the relative coal consumption will be determined for a turbine operated at 200 lbs. absolute initial pressure with dry saturated steam and 28 in. vacuum, and again with the same pressure, but 100° F. superheat.

The total heat per pound of saturated steam at 200 lbs. pressure is 1198.3 B.t.u.; the heat corresponding to 100° superheat (assuming Cp as .5) is 50 B.t.u.; and thus the increase in heat with superheat is

$$\frac{50}{1198.3} = .0417, \text{ or } 4.17 \text{ per cent.}$$

The available energy in the superheated steam between 200 lbs. and 1 lb. is 275,200 foot pounds; in saturated steam it is 261,000 foot lbs.; and thus the increase in available energy is 5.37 per cent., and the gain in coal $5.37\% - 4.17\% = 1.2\%$. As stated above,

* The second of a series of three papers read before the employees of the Commonwealth Edison Company, Chicago.
† July, 1910, Review

the gain in water rate is considerably greater than that which corresponds to the gain in available energy, and is about 8 per cent.; thus, in practice the gain in coal saved by 100° F. superheat is 8% − 1.17%, or 3.83%. In this calculation it has been assumed that the flue gases leave at the same temperature, and that the thermal efficiency of the boiler in one case and boiler with superheater in the other is the same. In all probability this is not quite the case; nevertheless, there is a decided gain.

The initial pressure bears an important relation to economy, but the gain by increasing the initial pressure is very small compared with that derived by a few inches of vacuum.

Referring again to the tabulation of the theoretical water rates:

At 200 lbs. pressure, saturated steam, and 28 in. vacuum, the theoretical water rate is 10.2 lbs. per kilowatt hour; at 175 lbs. absolute and the same vacuum, it is 10.45 lbs.; thus the gain in water rate by raising the initial pressure 25 lbs. is 0.25 lbs. or 2.5 per cent. for 25 lbs., or 1 per cent. for each 10 lbs.

Effect of Feed Water Temperature on Steam Economy

It is generally recognized that it is well to supply steam boilers with water of as high temperature as possible. There are many good reasons for this practice outside of the gain in economy, but it is well worth doing on that score alone.

To illustrate this, a few typical cases will be considered.

1. When there is *no feed water heating*, which case might exist in a plant using electrically driven auxiliaries only.
2. *Exhaust from the auxiliaries is used to heat the feed water.*
3. *Feed water is heated partly by live steam and partly by the exhaust from the auxiliaries.*
4. *Feed water is heated partly by the exhaust and partly from a turbine which is "bled."*

No Feed Water Heating

We will consider a plant with main turbines of 540 kw. capacity and auxiliaries requiring 40 kw.; thus the useful output is 500 kw.

It will be assumed that the turbine is supplied with dry saturated steam at 165 lbs. absolute pressure, that the vacuum is 28 in., and that the water rate 19 lbs. per kilowatt hour. The flow per hour is then 19×540 = 10,250 lbs. At 28 in. vacuum the temperature of the condensed steam is 102° F.; at the boiler it is 366° F. Thus we need to supply 366 − 102 = 264 B.t.u. as liquid heat per lb. of water. The latent heat at 165 lbs. pressure is 855.6 B.t.u.; thus each pound of the flow requires 855.6 + 264 = 1119.6 B.t.u. and the total heat required is:

1119.6×10,250 = 11,500,000 B.t.u.

Engines or Turbines Driving the Auxiliaries and their Exhaust (at Atmospheric Pressure) used to Heat the Feed Water

As in the first case, it will be assumed that the useful output is 500 kw., at a water rate of 19 lbs. It will be of interest to determine the water rate of the small engines or turbines, which at 40 kw. output will give sufficient exhaust steam at atmospheric pressure to raise the temperature of the feed water to 212° F. Since the temperature of the condensed steam from the main turbine is 102° F., we will require 212 − 102 = 110 B.t.u. per pound of steam; thus, since with 500 kw. output at a water rate of 19 lbs. the flow is 9500, the heat required is 9500×110 = 1,045,000 B.t.u.

Assuming that the exhaust from the auxiliary engine contains 4 per cent. moisture, the heat input is the latent heat of 96 per cent. of the flow.

Let f be the flow from the auxiliary engine, and a the latent heat at atmospheric pressure, which is 965.8 B.t.u.

We have then, $965.8 \times 0.96\ f$ = heat input = 1,045,000 B.t.u.

Thus the flow f = 1130 lbs., which corresponds to a water rate of the auxiliaries of 1130 ÷ 40 = 28.2 lbs. per kilowatt hour.

This water rate is far better than could be expected from small non-condensing turbines or engines; thus the heat in the exhaust is more than enough to bring the temperature of the feed water to 212° F. Some of the steam would have to exhaust into the atmosphere and would be lost.

If the water rate were 40 lbs. per kilowatt hour, which is likely, then the amount of surplus steam would be 40(40 − 28.2) = 470 lbs. This steam would have to be supplied from the source of water, which might have a temperature of 60° F., but before entering the boiler it would be heated to 212° F. Thus the total heat necessary to be supplied is:

For that part of the water which has to be drawn for the water supply:

	B.t.u.
Liquid heat = 470(366 − 212) =	72,409
Latent heat = 470×855.6 =	103,000
	175,400

For the rest of the flow (9500+1130=10,630 lbs.)

	B.t.u.
Liquid heat = 10630(366−212) =	1,638,000
Latent heat = 10630×855.6 =	9,110,000
	10,748,000

Thus total heat = 11,223,400 B.t.u.

In this case then, when a considerable portion of the exhaust steam is wasted, the gain is only slight, being about 2.4 per cent.

In large stations where the amount of power taken by the auxiliaries is a much smaller percentage of the useful power, the gain is very considerable. For instance, if the auxiliaries required only 5.6 per cent. of the useful power instead of 8 per cent., as was the case above, then no exhaust steam would go to waste and the total heat required would have been 10,748,000 B.t.u.

The saving in coal would then have been 6 per cent.

In very large stations the amount of exhaust steam is frequently insufficient to raise the temperature of the feed water to 212°. It is then of interest to inquire whether any economy would result if live steam was delivered to the feed, or if steam at substantially atmospheric pressure was drawn from the turbine.

As an illustration it will be assumed that the auxiliaries require only 4 per cent. of the main flow, that the water rate of the main turbines is 15 lbs. per kilowatt hour, and that the vacuum is 29 in. For the sake of simplicity we shall make the calculations for each 1000 kilowatts of output of the main turbines. The temperature of the condensed steam is 80° F. and the amount of condensed steam, 15,000 lbs. per hour. The mixture of the condensed steam and the exhaust will take a certain temperature t, which is higher than 80° and lower than 212°.

The heat required is the liquid heat between temperatures t and 80° F.; thus the heat required in B.t.u. units is $15{,}000(t-80) = 15{,}000\,t - 1{,}200{,}000$. The amount of the exhaust steam is $0.04 \times 15{,}000 = 600$ lbs. Thus the heat given by the exhaust is:

Liquid heat $= 600(212-t) = 127{,}200 - 600\,t$.

Latent heat $= 0.96 \times 600 \times 965.8 = 557{,}000$.

Thus $15{,}000\,t - 1{,}200{,}000 = 127{,}200 - 600\,t + 557{,}000$; thus $t = 121°$.

The heat required is:

	B.t.u.
Liquid heat for a flow of 15,600 lbs. = 15,600(366−121) =	3,820,000
Latent heat for a flow of 15,600 lbs. = 15,600×855.6 =	13,350,000
	17,170,000

To raise the temperature of the feed water to 212°, we obviously need:

15,600(212−121) = 1,420,000 B.t.u.

With p pounds of live steam supply, we get from the latent heat 855.6 p(B.t.u.).

From the liquid heat $p(366-212) = 154\,p$.

Thus a total amount of heat of 1009.6 p.

Thus $1009.6\,p = 1{,}420{,}000$ B.t.u.

or $p = 1410$ lbs. per hour.

In this case, then, the total flow will be

15,000+600+1410 = 17,010 lbs.

and the heat required:

	B.t.u.
Liquid heat 17,100(366−212) =	2,620,000
Latent heat 17,100×855.6 =	14,550,000
	17,170,000

Thus there is no gain or loss except in so far as it is better to supply the boiler with the hotter water.

As was shown above, to raise the feed water temperature to 212° will require 1,420,000 B.t.u.

The second stage of the turbines usually has about atmospheric pressure; thus, since the latent heat at atmospheric pressure is 965.8 B.t.u., we require:

$$\frac{1{,}420{,}000}{965.8} = 1{,}470 \text{ lbs. of steam.}$$

At atmospheric pressure (since the steam probably contains 4 per cent. moisture)

$$\frac{1{,}470}{0.96} = 1{,}530 \text{ lbs. per hour.}$$

This steam has done some work in the main turbine, the amount of work being governed by the ratio of the available energy in the steam between the initial pressure and atmospheric pressure, to the total available energy. As can readily be calculated from the equation for the available energy and as can be seen from the tabulation of theoretical water rate, the available energy in the steam between the boiler pressure and the atmospheric pressure is approximately one-half of the total it would have had had it expanded to 29 in. vacuum.

Thus the water rate for that part of the steam which passes through the upper part of the turbine only and which is exhausted in the feed water is, say, $\frac{15}{0.5} = 30$ lbs. per kilowatt hour. The output of 1,530 lbs. is, therefore, $\frac{1{,}530}{30} = 51$ kw.

Therefore the steam which goes through the entire turbine need give only 949 kw.

Thus the total flow of steam is:

	Lbs.
Main turbine (in its entirety) $949 \times 15 =$	14,240
Main turbine, non-condensing part =	1,530
Flow from auxiliaries =	600
	16,370

Thus the heat required is:

	B.t.u.
Liquid heat $16{,}370(366-212) =$	2,500,000
Latent heat $16{,}370 \times 855.6 =$	14,000,000
Total heat =	16,500,000

The saving effected by bleeding the turbine is thus $17{,}170{,}000 - 16{,}500{,}000 = 670{,}000$ B.t.u. or 3.9 per cent.

In general it is safe to say that the most economical way of operating the auxiliaries is either to use a high class reciprocating engine which has a low water rate or else to have them electrically driven, and in the latter case, supply the necessary heat to the feed water by bleeding the turbine. The installation of small inefficient turbines for driving the various auxiliaries is not good engineering and the loss incidental to their use even if all the exhaust steam can be used for heating the feed water, amounts frequently to several percent of the total output. This is evident from the fact that there is practically as much heat from the exhaust of an efficient turbine at atmospheric pressure as from an inefficient turbine, and consequently the difference in output in the two types of turbines is a net gain to the general station output; therefore, if the total auxiliaries in a large plant amount to say, 200 kw., and these auxiliaries are driven largely by small turbines, it is safe to say that at least 100 kw. out of the 200 kw. could be saved by using electrical drive instead of turbine drive. The necessary mechanical arrangement for bleeding the turbines is so simple that there is practically no complication involved in its use. I relaize, of course, that there are frequently good reasons why steam driven auxiliaries should be given preference to motor driven auxiliaries, but I think that very frequently an unnecessary amount of small steam driven auxiliaries are used, and their justification has been the erroneous assumption that the efficiency of the small auxiliary is immaterial as long s its exhaust can be used to advantage to heat the feed water.

LUMINESCENCE*

By Dr. Charles P. Steinmetz

Since the old primeval days, when fire was first used for heat, light and as a protection against animal foes, down to the present, the art of illumination has been advancing - very slowly at first, then more and more rapidly; developing from the wood fire, through the torch, the candle, and the oil burners to the gas and electric lights.

Light which is produced by heat, or temperature, we call incandescent light. The heat energy which a current of electricity produces in the resistance of the filament must escape from it, and this appears as radiation. Light, and radiation in general, are forms of energy differing from heat, but by the interception of the radiation by some opaque body, heat is produced. For instance, if you place your hand so that the radiation energy impinges upon it, this energy is destroyed as radiation and becomes heat.

By raising the temperature we obtain more rapid vibration and higher frequencies, until ultimately frequencies are reached that produce visible radiation, or light. In the lower frequencies that produce light, this light appears red. Increasing the temperature further, the amount of radiation increases and we have rays of orange, yellow, green, blue, violet and ultra violet; the color of light changing with increasing temperature from red to orange, to yellow, to yellowish white, and then becoming whiter and whiter.

If the temperature could be increased beyond that at which white light is produced, the light would become bluish, or ultra-violet, but long before this we are close to the limit of temperature which even the tungsten lamp can stand, because the filament will melt. If we wish to use a still higher temperature, we start an arc between two carbon terminals. As the current passes through the stream of vapor between these two terminals, the stream is at the boiling point of carbon (about 3700° C.) and heats the terminals to this point, thus producing a light that is whiter than that seen in the tungsten lamp. The arc lamp operates at the highest temperature—the boiling point of carbon—and gives the most efficient incandescent light. Thus the efficiency increases, and the colors change with the increase in temperature.

*Lecture delivered before the Schenectady Section A.I.E.E.

The total range of radiation, from the lowest frequency to the highest, compasses something like 12 octaves, of which something less than one octave is visible—all the other being invisible. It should be understood that the lowest frequency within these 12 octaves is still hundreds of millions of cycles per second.

Most illuminants give a yellow light, because the temperature is naturally lower than that necessary to obtain a white light. Green light it is impossible to get, with a temperature radiation, green being in the middle of the visible range. The color of ordinary incandescent light is seen in the light produced in the candle—the most reliable illuminant which human ingenuity has ever devised.

If we take an alcohol lamp, and hold in the flame a piece of platinum wire which has been dipped in thallium chloride, the flame assumes a green color. Now this color is not due to incandescence or temperature radiation, since it is a green, a color, which, as stated, can not be obtained from temperature radiation. If instead of thallium chloride, the platinum wire is dipped into lithium chloride, the flame assumes a bright red color. Again using sodium chloride we get a yellow light. It is a curious thing that we can get green, red and yellow lights in the same flame, the temperature being the same in all three cases. Here we find a kind of radiation which is not due to incandescence. It is not temperature radiation, for with it we cannot obtain a green light; furthermore we get different colors at the same temperature, whereas in temperature radiation the color is a function of the temperature, and ranges from red to white according as the temperature is low or high.

If we take some calcium nitrate and expose it in the alcohol flame, the flame becomes yellow. Again, if we take the same calcium compound and put it in the carbon arc at 3500° C., we shall see the same yellow light. Thus at the low temperature of the alcohol lamp, which does not exceed 1000° C., and at the very high temperature of the carbon arc, the color remains the same. We have, therefore, different colors at the same temperature, and also the same colors at different temperatures. This, however, is not always the case. Some compounds change the color of the light with changes of temperature, but the change of color does not follow the regular law of incandescence.

In the mercury vapor lamp the temperature is relatively low—not much above the boiling point of water—still we get an intense light—a green light. If we increased the temperature, the mercury light would change in color from bluish green, which it has at low temperature, to a whiter color, and at extremely high temperature it becomes a pinkish-red. In the mercury arc the average frequency decreases with increase of temperature, which is just the reverse of the case of temperature radiation.

If a platinum wire with thoria at the end of it is held in the flame, it grows much brighter and glows with a greenish light; whereas some platinum gauze held in the flame glows with the yellow light of incandescence. The temperature of the flame being relatively low, the platinum gives incandescent radiations of yellow, orange and violet. If now we take the gauze of thoria and platinum together we shall see the two different colors produced at the same temperature, again showing that it has nothing to do with temperature radiation.

There is, therefore, the possibility of producing light radiations which do not follow the temperature laws. The interesting feature of this is that while we can produce light from incandescence, we are limited in color. Excepting at extremely high temperature, we cannot get a white light. Green we cannot get at all. Red we can get only at relative inefficiency, as it is produced only at very low temperature radiation, where the efficiency is low. Furthermore, even at the highest temperature allowable, the efficiency is relatively low.

As we have shown, however, we can get radiation and not follow the temperature laws, but get different colors at the same temperature, or the same colors at different temperatures, as well as different colors at different temperatures.

It is worth while to investigate and find out whether with radiation that does not follow the temperature law and that is not due to incandescence, but which we call luminescence or selective radiation, we could reach efficiencies higher than those possible by incandescence.

The color of luminescent radiation is not a function of the temperature, but depends upon the material which luminesces. Thallium, in the alcohol flame, produces a green light; sodium, a yellow light, and lithium a red light—all at the same temperature. Barium produces a yellowish green.

If the color is a function of the material, this means that the frequency of radiation obtained depends upon the kind of material used. Suppose a material were found in which those particular frequencies at which luminescence takes place were in the visible range that the eye can see, that material would give 100 per cent. efficiency in light production. Again, in another material, if the radiation of luminescence was in the invisible range, that would be a very inefficient light producer.

The light, and, in general, the radiation, given by a vapor conductor between terminals is due to luminescence, or the transformation of the electric energy into radiation. The frequency of radiation in the arc stream is not due to temperature, but the frequencies are determined by the chemical nature of the luminescent body, or arc stream. Thus the light efficiency does not depend upon the highness of temperature, as in temperature radiation, but rather the reverse. The arc of lowest temperature, the mercury arc, is one of the most efficient. The color of the light depends upon the character of the material which luminesces. However, in luminescent radiation the temperature is of importance, not that we want very *high* temperature, but rather the *right* temperature; the one that is suited to the particular material used. The change of colors in luminescence do not follow a definite law, as in temperature radiation.

In the titanium arc the light is white, the lines in the spectrum being quite uniformly distributed over the entire visible range. The light from the ordinary iron arc is also white and very brilliant, the lines of the spectrum being similarly distributed. If we greatly increase the temperature of this iron arc, by using a condenser discharge between the terminals, the arc gives little visible light but gives a large amount of ultra-violet radiation.

In selective or luminescent radiation there is the possibility of producing light at higher or lower frequencies and getting different colors, depending upon the material used. The question is, how does this radiation come about; how is luminescent radiation produced, and how can we picture this?

We assume that all materials are composed of smallest parts—molecules, atoms, or whatever they may be. If we take a piece of graphite, carbon or titanium and heat it, the molecules or atoms will be set in motion; they will vibrate and communicate their vibration to the ether. This produces the ether waves, and the energy sent out we see, at the proper frequency, as light. Consider the molecule or atom or particle, whatever it is, vibrating. It has definite mass, definite force, and therefore the conclusion is that it would vibrate at a definite frequency—just like a tuning fork or any other body vibrating at a definite frequency. If we heat a tungsten filament, we set the molecules vibrating. We do not, however, get a definite frequency of radiation, but a mixture of an infinite number of frequencies over a wide range of many octaves. What is the cause of this? We know the tuning fork will vibrate at a definite tone and definite frequency. The air in the organ pipe, when set in motion, will vibrate at a definite frequency—so also should the atom or molecule. If we take a mound of sand, however, and attempt to set it in vibration, each particle of sand will vibrate at a definite rate, depending on its mass and the forces acting upon it; but as a part of the mound it cannot vibrate freely because its vibrations are continually interfered with by the other sand particles. The continual interference of the other particles prevents the particle from properly completing its vibration, and instead of the whole mound of sand vibrating at a definite rate, there are all kinds of frequencies; each grain of sand having a different rate from the other grains, depending upon the interference of the particles around it.

If we look at the energy distribution in the spectrum of a radiating body, like tungsten filament, what we see is the probability curve of vibrational frequency for any single molecule. What it amounts to is that each individual molecule would, if by itself, vibrate at a definite rate. In the solid mass, however, due to interference between molecules, there can be no uniform vibration, but a mixture of all possible rates of vibration—all possible frequencies.

The problem is to find a material in which the atoms, or molecules, or whatever the radiating particles may be, are free from interference with each other. In solids and liquids there is this interference, which practically destroys the individual vibration of the particles and gives only the total. Some solids there are, however, which to some extent give their specific vibration, as for instance some of the rare earths, thoria and ceria. The particles do not so completely interfere as to wipe out entirely the individual vibration. These materials do not follow the temperature law; they radiate light at an abnormal efficiency. Thoria alone does not give the selective radiation to any great extent, but combined with ceria in the Welsbach mantel produces an efficiency of light many times higher than the gas flame alone could give. The specific vibrations of thoria in the Welsbach mantel are very prominent at low temperature. Once the vibration gets energetic enough, due to high temperature, the independent vibration of the particles, even of the Welsbach mantel, practically ceases. The vibrations at higher temperatures are more energetic, extend over wider distances, and the chance of interference is greater.

If the problem of selecting a material with which to produce luminescence or selective radiation depends upon finding one in which the particles do not interfere with each other, a gas or vapor might be used. In this the molecules are so far apart as not to interfere, and for this reason it would be an ideal material for the purpose. In a solid if particles are set in vibration by heat it becomes incandescent. If we heat a gas or vapor we get motion of the molecules it is true, but not as in a solid, for instead of getting radiations, we get pressure. If then, temperature does not produce luminescence in a gas but at the same time the gas or vapor would be the ideal material for luminescence, we must find some other way of producing vibration. There are two convenient ways: chemical excitation and electrical excitation. The chemical method is that of bringing the luminescent material into the focus of intense chemical reaction; the electrical, that of using it in the vapor state as a conductor of electric current. Both methods of producing luminescence have found commercial applications.

Chemical Excitation

If we take materials like the salts of which I have spoken, and in the flame vaporize them or split them up into their elements, the atoms are set in motion, and in vapors they are free to vibrate without interference; so that they have a definite frequency and give color to the light, independently of the temperature.

A gas flame gives relatively low light efficiency. By increasing the temperature of the gas flame, we get a more rapid rate of combustion but no more light; but if we use this temperature to heat the thoria and oxides of the Welsbach mantel to a high temperature, then the flame is luminescent, and gives an efficiency several times higher than the gas flame.

Chemical luminescence is a very convenient method of producing colored lights of very high intensity, and is used industrially in fireworks, and in colored signal lights. To a considerable extent it is used for purposes of amusement.

Electrical Excitation

As stated, electrical excitation consists in using the material as a conductor of electric current. There are two possibilities: we may use gases as radiators by having them conduct the electric current (as in the Moore tube, in which the gas is a conductor of electricity, carries the current and is made to luminesce) or we may use electrode vapor.

Gases are extremely poor conductors. In the Geissler tube, if the voltage drops below a certain value there is no current, and thus a high voltage is required. Of the gases which have been investigated, nitrogen gives the best efficiency; this is not quite as good as that of the tungsten lamp, but is high compared with the gas flame or ordinary incandescent lamp.

Good conductors, however, are the metal vapors in the arc stream. The arc has first to be started between the terminals—a conducting bridge must be produced by the expenditure of energy. There are several ways of starting the arc conduction, such as bringing the terminals together, closing the circuit, and then separating them; or by raising the voltage between the terminals so high that a static spark passes between them; or again by the supplying a vapor stream from another arc, etc. The current, having started its own conductor by evaporation of the electrode material, maintains it by maintaining a supply of conducting vapor. The color is therefore that of the electrode material, and not that of the gas which fills the space in which the arc is produced; the nature of this gas has no effect on the arc.

The three materials which give an efficiency of light production which is many times higher than can be reached by incandescence are mercury, calcium and titanium. Mercury gives a bluish-green light, because the visible radiation is mostly in blue and green. Calcium, which is used in the flame arc, gives an orange-yellow light, because most of the visible radiation is in the orange and yellow. Titanium gives a white light, the visible radiation being scattered uniformly all over the visible range. These three materials seem to give fairly closely the same efficiency. Possibly titanium is highest—all three are used. The mercury vapor lamp is not used as much as it deserves because in the bluish-green color people do not look pretty.

Luminescence is used to produce colored lights, and to produce higher efficiencies. Luminescence was the first step in advance in the method of light production through all the ages, from the wood fire of the primeval savages down to modern times, replacing incandescence by selective radiation, or luminescence.

We are only at the very beginning or entrance to the field of luminescence—especially on the electrical side. On the chemical side, in the Welsbach mantel, much has been accomplished. There is the possibility in the future of light efficiency which we have never dreamed of, and which in incandescent material we could not hope to even approach.

AN INTERESTING METER INSTALLATION

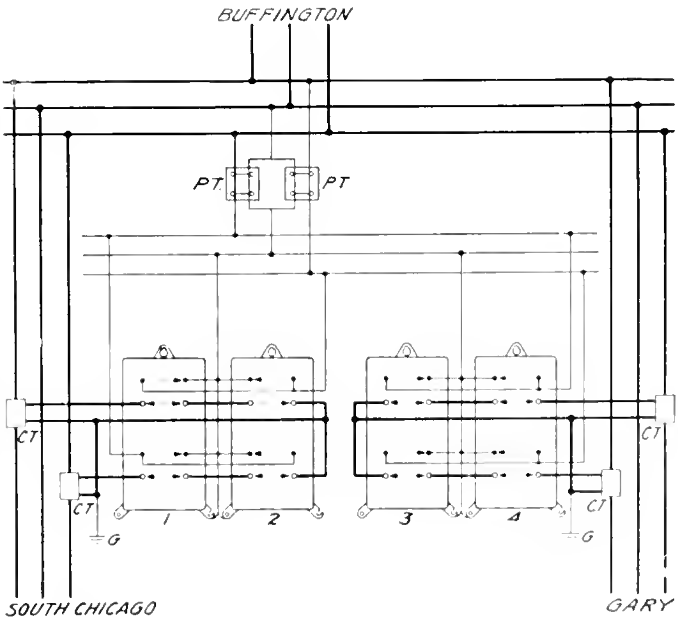
By B. E. Semple

The Illinois Steel Company, South Chicago, Ill., generates its power at 2200 volts, 3-phase, 25c cyles; the Indiana Steel Company, Gary, Ind., generates its power at 6600 volts, 3-phase, 25 cycles. These two plants are about sixteen miles apart and operate in parallel with each other through a 22,000 volt line, suitable step up transformers being in use at each station.

The plant of Universal Portland Company is located at Buffington, Ind., about five miles from Gary and eleven miles from South Chicago, and receives its power from the 22,000 volt line connecting South Chicago with Gary.

At times Gary furnishes power to South Chicago and also to Buffington, and at other times to South Chicago alone or to Buffington alone. Likewise South Chicago at times furnishes power to Gary and Buffington, or to either separately.

This state of affairs demanded a system of metering whereby the proper billing amounts could be arrived at, and it was found that by using four three-phase, three-wire meters at the Buffington sub-station, connected as shown in the accompanying diagram, the correct amount of energy consumed by the Buffington plant, coming either from South Chicago or Gary, could be recorded, as well as the amounts of energy passing from one generating station to the other.



All four meters are equipped with ratchet devices so arranged as to move the recording hands only when the rotating elements are revolving in the proper direction; the meters being free to rotate in either direction, depending on the direction in which the current is flowing.

When South Chicago is feeding Gary and no energy is being used at Buffington, meters No. 1 and No. 3 are registering, since they are connected in series.

When Gary is feeding South Chicago and no energy is being used at Buffington, meters No. 2 and No. 4 are resistering, since they also are connected in series.

When South Chicago is feeding Buffington alone, no energy being sent to Gary, meter No. 1 registers.

When Gary is feeding Buffington alone, no energy being sent to South Chiacgo, meter No. 4 registers.

In billing, therefore, the amount shown by meter No. 1, less the amount shown by meter No. 3, is charged to Buffington, and credited to South Chicago; the amount shown by meter No. 2 is charged to South Chicago and credited to Gary; the amount shown by meter No. 3 is charged to Gary and credited to South Chicago; and the amount shown by meter No. 4, less the amount shown by meter No. 2, is charged to Buffington and credited to Gary.

BOOK REVIEW

THE COPPER HANDBOOK, VOL. IX

1628 Pages Price $5.00 (Sent on Approval)

The ninth annual edition of the Copper Handbook, edited and published by Horace J. Stevens, of Houghton, Michigan, lists and describes over 7,000 copper mines and copper mining companies throughout the world; the descriptions being the same as in the preceding volume, except that over eight hundred titles have been added to those contained in previous editions.

The book also contains a number of miscellaneous chapters covering the history, chemistry, mineralogy metallurgy and uses of copper; other chapters being devoted to substitutes, alloys, brands and grades. The chapter of statistics, containing upwards of forty tables, has been fully revised and, as nearly as possible, brought to date.

Anyone interested in the subject of copper, as producer, consumer or investor in shares, should find the Copper Handbook of much interest.

OBITUARY

Clinton Charles Burr, Chief Engineer of the Northern Electrical Manufacturing Company, Madison, Wisconsin, died at Lincoln, Nebraska, May 28th. Mr. Burr had been in failing health for some months past, and in March last went to Lincoln for treatment; then his health improved for a time, but finally failed gradually until the end came.

He was born at Albion, Michigan, December 30th, 1870; prepared for college at the Albion High School, and later entered the University of Michigan at Ann Arbor, where he took the course in electrical engineering. He then entered the employ of the General Electric Company at Schenectady and while still in their service, went to Quito, Ecquador, where he superintended the installation and starting of a large hydro-electric plant, continuing in charge of its operation through the years 1899, 1900 and 1901. Returning to this country, he was identified for a period of one year with the Lincoln Traction Company, Lincoln Nebraska, leaving there to enter the engineering department of the Ft. Wayne Electric Works, where he remained until the year 1905. He then became Chief Engineer of the Phoenix Electric Company, Mansfield, Ohio, and later of the Mechanical Appliance Company at Milwaukee, entering the employ of the Northern Electrical Manufacturing Company at Madison in 1908. Very shortly thereafter he was appointed Chief Engineer of the Northern Electrical Manufacturing Company, which position he occupied at the time of his death.

Mr. Burr was a man of wide experience and acquaintance in the electrical field where, and because of his technical ability, his unfailing courtesy and cheerful disposition, he was held in the highest esteem by all those with whom he came in contact.

GENERAL ELECTRIC REVIEW

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Detroit River Tunnel Electric Locomotive Hauling 1400 Ton Freight Train

GENERAL ELECTRIC REVIEW

ECONOMICS OF RAILWAY ELECTRIFICATION

It is generally recognized that the next distinct advance in the electric railway field will be the electrification of certain portions of our steam main lines. With increasing congestion of single track mountain divisions, still greater train weights and higher speeds must become operative. The limits of steam locomotive construction have been nearly reached, and while the introduction of refinements in construction and auxiliaries may offer a means of obtaining increased output and better economy over present practice, the steam locomotive as a type of motive power still falls far short of what the electric locomotive can accomplish in meeting the requirements of the operating department for main line service. The alternative is offered of double tracking or electrifying, and the paper presented by W. B. Potter before the joint meeting of British and American Mechanical Engineers and reprinted in this issue, treats in considerable detail with the general subject of the economies of railway electrification.

It is admitted that the cost of installing electric locomotives, motor cars and auxiliaries, on a steam line is an item for consideration. That an attractive return on the first cost of installation is effected, however, by the economies and flexibility of operation introduced by the adoption of the electric motor is the history of every installation where the apparatus has been properly selected to meet the service requirements.

Granting the benefits of electrification, the first question asked is, what is the cost? This leads immediately to a consideration of the type of apparatus best suited to meet the particular requirements. It is not surprising, therefore, that a large part of Mr. Potter's paper is devoted to giving, in commendable detail and clearness a general comparison of installation and operating figures of the several systems of operation available for steam line electrification. In fact, the author starts out with the assumption that any reasonable service may be successfully operated with any of the several systems. By thus eliminating the question of purely electrical engineering, Mr. Potter is able to devote his attention to setting forth the economic comparison of the alternating current—direct current situation.

In consideration of trunk line electrification, it is evident that the source of power supply and its frequency will have much to do with the determination of the system of operation. Such large generating and distributing systems have been built up in the past few years that they will enter as a factor when considering the question of generating or purchasing power for a given installation. Large alternating current motors operate best at a frequency of 15 cycles. The alternating current system would, therefore, suffer a handicap in efficiency and first cost if considerations of frequency or balanced load on a polyphase supply system necessitated the use of frequency changers.

While 1200 volts offers many advantages as a standard trolley potential for interurban roads having city connections, it is not necessarily the economical limit of direct current apparatus design. We may expect, therefore, to see direct current potential of 1800 or 2400 volts proposed for trunk lines where the service conditions demand a large kilowatt train input.

While in Mr. Potter's paper no figures are given of operating results of any specific road, the data presented represents the experience accumulated from observing the operation of a majority of all the alternating current and 1200 volt direct current roads operating in this country. This data is presented in tables giving comparative first cost of installation and cost of operation obtained from interurban road records.

Though last in the field, the 1200 volt direct current system has made a most admirable showing. Costing but slightly more than 600 volt apparatus, the 1200 volt car and substation equipments have given equal satisfaction in operation and at practically the same cost of upkeep. Here then is a system admirably adapted to the needs of motor car operation over interurban lines. The question of feeder copper is largely eliminated with the possibility offered of locating substations 25 to 30 miles apart. No sacrifice in motors or equipment is necessary to permit of running over 600 volt city tracks. Substation equipment may comprise two 600 volt converters in series for 1200 volts, or a single rotary converter may be wound for the higher potential, both methods being proven entirely satisfactory.

The 1200 volt direct current system, therefore, receives the approval of Mr. Potter, to the extent that he expresses the opinion that it will entirely supersede the alternating current system, for interurban service, unless some marked advance in the art affords the means of considerably reducing the motor equipment cost of the latter.

Undoubtedly part of the favorable attitude toward electrification now displayed by railroad managements is due to the preparedness of the manufacturers to furnish reliable apparatus. Selection of a proper system of operation is therefore most likely to rest in individual cases upon questions of reliability and pas. performance, rather than adherence to any proposed arbitrary standards.

FIRE-DAMP PROOF APPARATUS

Throughout the coal mines of the United States the number of men killed each year has been steadily increasing. During the decade from 1895 to 1905, the number almost exactly doubled, while in 1907 the casualties reached a total of 6861 killed and injured. That the greater production of coal and the employment of a correspondingly larger number of miners does not account for the increase in these fatalities, is shown by the fact that for each 1000 men employed, the number killed was 2.67 in 1895, and in 1905 this ratio had increased to 3.53. In all the European coal producing countries, on the other hand, where the output of coal has likewise greatly increased, the number of deaths per 1000 miners has steadily diminished. In Belgium, for example, this number decreased from 1.40 in 1895 to 0.91 in 1905 In England from 1.49 in 1895 to 1.35 in 1905 In Prussia from 2.54 in 1895 to 1.80 in 1904 In France from 1.03 in 1901 to 0.84 in 1905

The advantages that these countries can claim over the United States in this respect are due to the exhaustive investigations that they have carried on regarding the causes and prevention of accidents, and the resulting stringent laws that have been enacted and are being enforced.

A large number of these fatalities are caused by explosions of gas or coal dust and very many more by falls of roofs and coal, which, in turn, are frequently due to past explosions that have weakened the walls or roofs.

In 1907 the importance of this subject as a whole was brought forcibly before the public by a series of disastrous explosions that occurred in the coal fields of Pennsylvania and West Virginia. The first of these took place on December 1st at the Naomi mine, 34 men being killed and injured. Less than a week later the most disastrous explosion in the history of American mining occurred at the well laid out and comparatively new mine at Monongah, West Virginia. In this explosion the fan was entirely wrecked, the engine house demolished, and, as nearly as is known, 361 men lost their lives. Within two weeks a third explosion wrecked the Darr mine at Jacobs Creek, Pa. In point of fatality, this explosion was second only to that at Monongah; of the 239 men in the mine, but one escaped with his life.

Since that time the United States Government has been carrying on extensive investigations as to the conditions existing in mines; e g. the origin of the gas, and the laws governing its outflow into the mines, the danger of explosions due to coal dust, etc., etc. To this end, the Mine Accident Division of the United States Geological Survey has opened an experimental laboratory in Pittsburg, where the actual mine gases are available for experiment.

As with the European countries, these investigations will eventuate in legislation looking to the prevention of explosions and similar accidents, and in supplying electrical machinery for mine use, it will be necessary to have it so designed as to preclude the possibility of its causing mine explosions.

In this issue of the REVIEW, we print what we believe to be the first article that has been published in English on the subject of Fire-Damp Proof Apparatus The author gives the different methods of protection against fire-damp and discusses the results and conclusions arrived at through the various investigations.

ECONOMICS OF RAILWAY ELECTRIFICATION*

By Wm. Bancroft Potter

Engineer Railway Department, General Electric Company

1. National prosperity and importance are largely proportional to facilities for intercommunication, and since overland transportation is to so large an extent dependent on railways any development providing for better railway service is of paramount importance. Steam locomotives and electric motors are the two recognized means of applying power which are available for practical railway requirements. The fundamental principles which underlie the problem of train movement are the same in either instance, but a true comparison of their relative advantages can only be made by a study of each particular method.

Fig. 1. Three-Phase Locomotive Used at the Cascade Tunnel of the Great Northern Railway

Trolley voltage	6600
Frequency, cycles	25
Total weight, lb.	230,000
Weight on drivers, lb.	230,000
Maximum rated draw-bar pull	77,000
Continuous rated draw bar pull	35,000
Speed, mi. per hr.	15

Duty—Three units to haul 1500 ton train up 2.2 per cent. grade.

2. Much that has been written has treated the subject of electrification of steam railways from the general standpoint of averages, but unfortunately the economic application of electricity is not a subject for generalization — unfortunately, because averages are convenient and usually available, but often lead to erroneous conclusions, either for or against electrification. It is a mistake to assume that the average of the expenses for the entire railroad represents the actual expense for the particular conditions usually existing on the division under consideration.

3. On account of the investment already incurred, and because the question is usually one of determining comparative results, the electrification of an existing steam railway is a more complex problem than the electrical equipment of a new road.

4. Electrification, like any other engineering work, involves an investment against which there will be a fixed charge for interest and a liability of depreciation. The interest is a constant and permanent charge which must be met irrespective of any economy which may be secured by intelligent operation. The subject of depreciation is receiving more attention than formerly, the tendency having been to make the operating expenses

* Paper presented before meeting of British and American Engineers, London.

cover this charge. However classified, the depreciation charge must be accounted for, and it is directly influenced by the character of the equipment with respect to reliability, durability, and capacity to provide for future requirements.

5. The utilization of higher trolley potentials, made possible with direct current by the development of the commutating pole motor and with alternating current by the development of the single-phase motor; the higher speeds of rotary apparatus in the sub-stations; and the development of the steam turbine, have effected a material reduction in the investment required and the cost of operation.

6. The different methods of electrification applicable in any instance should be carefully analyzed with regard to interest, depreciation and operating expense, and only the net result should be given consideration in determining the class of equipment. In this connection it is well to bear in mind that the expenditure is a lump sum which can be accurately determined, while depreciation and operating expense can only be approximated. Reference to the corresponding items of expense on railways operating under conditions comparable to those of the line to be electrified, will supply the most reliable figures. Future traffic developments must not be overlooked and the type of initial electrification should be selected with due regard to the ultimate requirements.

7. There would undoubtedly be an advantage in having the character of the energy supplied to the contact conductor uniform, but this is out of the question on account of the great difference in the requirements of specific conditions, such as congested urban or suburban service and comparatively infrequent trunk line train movements.

8. The sub-station and rolling stock may be equipped for operation with direct current or alternating current, single-phase or three-phase, and what is commonly spoken of as "the system" usually refers only to that part of the general scheme of electrification which comprises the sub-station and rolling stock equipment. There are exceptional cases where the power station and transmission lines have direct relation to the rolling stock equipments; but with the development of alternating current transmission, this is less frequently the case than it was a number of years ago when 600 volt power stations supplied power directly for the operation of 600 volt motors.

9. The development of apparatus for higher voltage direct current has so far increased its scope that direct current at either 600 volts or higher may be considered the most economical for city and interurban service, and for the electrification of steam railways where the density of traffic is sufficient to require a relatively large investment for rolling stock, as compared with that required for the secondary distribution system and the sub-station apparatus.

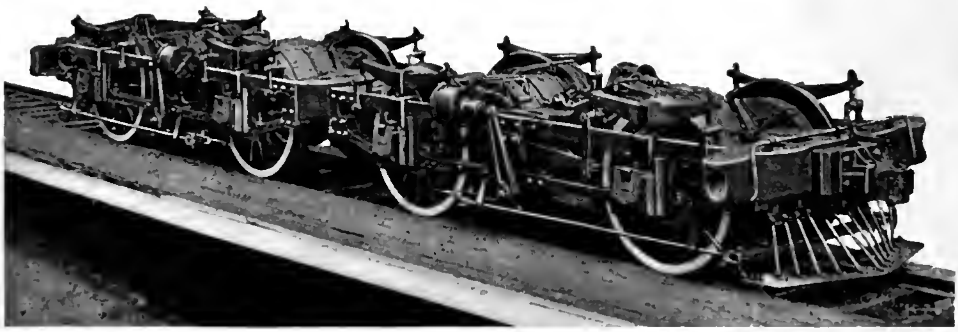

Fig. 2. Trucks for Three-Phase Locomotive, Great Northern Railway

10. Single-phase and three-phase rolling stock equipments are generally applicable only to exceptional conditions. The reason for this is the greater first cost of such equipments. This is especially true when comparing single-phase with direct current. The type of equipment used on the rolling stock may well be a more important factor in the economy of investment and operation than the scheme of power distribution.

11. Under the conditions which exist in America, direct current and single-phase are applicable to either level or grade work; while three-phase will probably be limited

to the latter where its regenerative feature of returning energy to the line may be of value. The relative economy of the different systems of electrification is dependent on the density of traffic and the character of power available, rather than on the length of the railway.

12. In cases where purchased power is used, or is depended on as a reserve, the frequency of the current supplied by the power company will have a bearing on the cost of sub-stations, and will thus affect the choice of the system. For direct current operation, rotary apparatus is used for converting the alternating into direct current, and the frequency of the supply is therefore relatively unimportant. For single-phase operation under the usual conditions, a frequency of not more than 15 cycles is desirable; and to provide this frequency, rotary frequency changers are as necessary as are rotary converters in the case of direct current, since the frequency of existing power companies ranges from 25 to 60 cycles.

13. With power supplied at the proper frequency for single-phase operation, permitting the use of static transformers and dispensing with frequency changers, the amount of energy required for a given trunk line service is in many cases nearly the same as for direct current, the greater weight of the equipped rolling stock, and the lower efficiency of the single-phase equipments, offsetting the rotary converters and trolley line or third rail losses of the direct current.

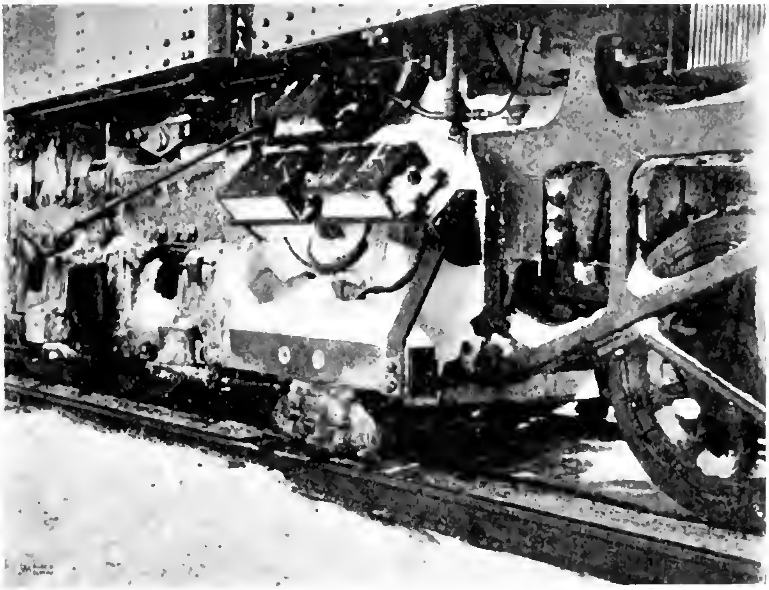

Fig. 4. Portion of a New York Central Locomotive After Running Through Snow

Fig. 3. Locomotive Used in the New York Central Electrification at New York

Voltage	660 d.c.	Maximum rated draw bar pull, lb.	47,000
Total Weight	230,000	Continuous rated tractive effort, lb.	7,250
Weight on drivers, lb.	141,000	Speed, mi. per hr.	60

14. The principal conditions which determine railway equipment are:

a Profile of road.
b Transportation required, *i.e.*, weight of trains or seating capacity of cars.
c Frequency of trains.
d Length of individual runs or distance between stops.
e Schedule required.
f Length of railway to be electrified.

15. In the selection of the electrical system best adapted to a particular set of conditions there are three items to be considered: (*a*) sub-stations, (*b*) contact conductors, (*c*) rolling stock. A comparison of these items determines the relative economic values of the systems. There are certain features under each of these items which may properly be examined. For trunk line service the values in Table I will be found within reasonable limits for the usual requirements.

16. We will consider briefly the effect of changes in the data sheet items (Par. 14):

a *Profile:* From a level country to a limiting grade of 1 or 1½ per cent. there will be little difference in the relative values of the systems. With steeper grades the conditions will be more favorable for alternating current.

b *Traffic Requirements:* Heavy individual train units favor the alternating current system with exception of the locomotives; light trains or multiple unit operation favor the direct current system.

c *Frequency of Trains:* Infrequent service with a relatively small number of locomotives favors the alternating current, frequent service the direct current. With increase in number of trains, the direct current systems gain relatively faster than the alternating current in economy of operation, due to relatively decreased sub-station operation, increased sub-station efficiency, and lower cost of equipment maintenance. It is therefore well to consider what the ultimate traffic density may be and select the system best suited to meet these requirements.

d, e *Distance between Stops and Schedule Required:* Variations in these will not affect the relative value of systems unless extreme requirements, such as high schedule speed with short runs, make the use of direct current imperative.

f *Length of Road:* For a similar character of service throughout, the railroad may be of any length without affecting the relative desirability of the various systems. What is suitable for the first fifty miles will be equally suitable for any extension.

An examination of these variables will show that a change in the conditions to be met will radically change the relative economic value of the systems of electrification.

17. The single-phase system, by reason of the apparent simplicity of its elements and the utilization of higher potential for the contact conductor than is possible with direct current, is admittedly very attractive. There is the other side of the question, that the single-phase commutating motor is much higher in first cost and maintenance than the direct current motor. Over this subject of alternating current single-phase vs. direct current systems there has been a great deal of controversy. It is our opinion that comparative results obtained up to the present time are in favor of direct current.

18. Desirable as would be a standard system for all classes of service, we cannot hope to establish such a standard should it impose an additional expense without adequate return. A summing up of all the elements of each electrical system will generally lead to a definite showing of which system is most desirable to meet specific conditions. For trunk line service a higher potential than 600 volts will unquestionably be used; 1200 volts direct current will prove economical in some cases, but a still higher voltage is required to provide economically for the heavier intermittent service. Whether this potential will be 1800 or 2400 volts direct current or 11,000 volts alternating current cannot be settled arbitrarily.

Fig. 5. Typical American Interurban Car, West Shore Railroad

Interurban Railways

19. Let us consider the interurban railway situation in the United States, particularly in regard to the various available schemes of electrification. These are, 600 volt direct current, 1200 volt direct current, and single-phase, the three-phase being objectionable on

account of the complications of the necessary double overhead distribution system.

20. The application of single-phase to new projects has been practically abandoned, there having been but one or two new installations in the last three years. This arrested development of a system which for a short time held forth considerable promise, has been brought about by a general recognition of its limitations. Experience has shown these to be:

a Excessive weight of rolling stock.
b Excessive cost of rolling stock.
c High cost of equipment maintenance.
d Increased power consumption.
e Rapid depreciation of motor.
f Rapid depreciation of car bodies and trucks.
g Increased cost of maintaining track and roadway.

Moreover it is recognized that any interurban road in the United States must be capable of operating over existing city tracks from 600 volt direct current trolley, a condition which hampers the single-phase system on account of increased complications in the control system.

21. For interurban railways a potential of 1200 volts direct current has been selected, because with the motors wound for 600 volts the car may be operated at the same speed from either 600 or 1200 volt trolley, by connecting the motors all in parallel for 600 volt operation, and two in series with two groups in parallel on a 1200 volt section.

22. To show clearly the relative merits of the systems we have made an analysis of an interurban railroad 100 miles long with cars

TABLE I

Reasonable Values for Trunk Line Service

SUB-STATIONS

	600 V. D.C.	1200 V. D.C.	11,000 V. 1-Phase	11,000 V. 3-Phase
First cost per kw., complete	$26	$28	$11	$12
Comparison of installed kw., %	200–250	100–125	100	100–125
Load factor, machines in service, %	20–40	35–70	40–80	30–60
Average efficiency, %	78–88	87–92	97–98	97–98
Yearly operation and maintenance, each station	$5,000	$5,000	$2,500	$2,500

CONTACT CONDUCTORS *

	Third Rail		Overhead	
First cost, per mile	$5,000 to $7,000	$5,500 to $7,500	$3,500 to $7,000	$4,500 to $8,000
Efficiency, %	88–92	90–96	93–97	93–97
Maintenance per mile per year	$75–$125	$100–$150	$100–$200	$125–$250

ROLLING STOCK †

	600 V. D.C.	1200 V. D.C.	11,000 V. 1-Phase	11,000 V. 3-Phase
LOCOMOTIVES				
First cost, each	$44,000	$47,500	$64,000	$58,000
Weight, tons (2000 lb.)	125	125	160	160
Average efficiency, locomotive wheels to trolley, %	85	85	79	81
Maintenance per locomotive per mile, cents	4	4	8	5
MOTOR CARS (COMPLETE)				
First cost, each	$12,000	$13,500	$20,000	
Weight, tons (2000 lb.)	43	44	54	
Average efficiency, wheels to trolley	82	81	73	
Maintenance per car mile, cents	2	2.2	3.5	

* Variation in cost of third rail due to different weights of rail which may be required. Variation in cost of overhead due to variation in the class of construction, such as with wooden poles or with steel bridges.
† Other weights of locomotives will cost more or less about in proportion to their weights. With gearless direct current locomotives, the average efficiency of locomotive wheels to trolley is approximately 88 per cent.

in each direction every hour. This condition represents practically the minimum car requirements in the United States, and is therefore favorable to the single-phase. It is

Fig. 6. Typical American Overhead 6600 Volt Single-phase Interurban Trolley Line, Baltimore and Annapolis Short Line, Annapolis, Md.

obvious that any increase in traffic density will be relatively more favorable to the direct current system on account of the lower first cost of cars, lower car maintenance and relatively lower cost of sub-station operation.

23. Assume a typical interurban condition.

a Profile: rolling country.
b Transportation required: passenger cars to seat 50 passengers and having baggage compartment, or the equivalent of 60 passengers without baggage compartment.
c Frequency of trains: one every hour in each direction.
d Average distance between stops: 3 miles.
e Schedule speed: 33 miles per hour.
f Length of road: 100 miles.
g To operate on existing 600 volt city tracks.

The general data required are approximated in Tables 2 to 7.

24. There will be an additional cost of operation and maintenance with the single-phase system for the items of track and roadway, due to additional weight of cars, car shop expenses in providing greater facilities for shop inspection and repairs, and greater skill in superintendence of equipment. In a number of instances this has been found to amount to several cents per car mile. A conservative estimate would require at least one cent per car mile to be added for these items.

25. The comparison in Table 7 brings out the fact that even for conditions selected as favorable to the single-phase system, the 600 volt direct current system is the more economical considering operation, maintenance and fixed charges. An examination of the elements which enter into the first cost and operation of a system will show at once that as the density of traffic increases there is a rapid gain in the relative advantage of the direct current over the single-phase system.

Conclusion

26. The saving effected by the 1200 volt direct current system is so marked that a great increase in the adoption of this potential for this class of interurban railroading may be anticipated, and on the other hand it will not be surprising if the single-phase interurban system is entirely discarded in America, unless some improvement is made in the art and a more economical equipment made

Fig. 7. 1200 Volt Direct Current Overhead Line Construction of the Pittsburg, Harmony, Butler and New Castle Railway, Pittsburg, Pa.

available. There is no question regarding the mere movement of trains by any particular system—this may be taken for granted. The study of electrification is really a problem in economic engineering and not simply a technical problem.

TABLES RELATING TO TYPICAL INTERURBAN ELECTRIC SERVICE

TABLE II

GENERAL DATA FOR CARS

	600 V. D.C.	1200 V. D.C.	6600 V. A.C.
Number of cars	15	15	18
Seating capacity, passengers	60	60	60
Distance between stops, miles	3	3	3
Schedule speed, miles per hour	33	33	33
Maximum speed, miles per hour	48	48	55
Weight each car, tons (2000 lb.)	35	36	43
Car miles per day	3000	3000	3000
Miles per car in service per day	300	300	300
Miles per car per day, average*	200	200	166
Estimated maintenance per car mile, cents			
a Electrical	0.70	0.77	1.50
b Mechanical	1.00	1.00	1.25
Total car barn expense	1.70	1.77	2.75
Amperes starting car	520	280	75
Amperes running car	174	94	24
Kilowatt hours per car mile at car	2.8	2.88	3.78
Cost each car complete	$10,000	$11,500	$17,000

* On twelve American single-phase interurban roads the average miles per day called for on the published time tables, divided by the number of cars owned, is 138; on four 1200 volt roads which have been operating over a year this number is 237, the larger number of alternating current cars being required on account of the fact that a greater number are necessarily held in the barn for inspection and maintenance purposes. This explains why in the table above 18 alternating current cars are assumed and 15 direct current cars.

TABLE III

SUB-STATIONS

	600 V. D.C.	1200 V. D.C.	6600 V. A.C.
Number of sub-stations	9	4	2
Estimated momentary demand			
Cars starting	1	1	2
Cars running	1	1	0
Peak load, kilowatts	416	448	670
Average load, each sub-station, kilowatts	52	120	275
Size each unit, kilowatts	300	300	300
Number of units	2	2	3
Load factor (machines in service)	0.17	0.40	0.46
Average efficiency	0.76	0.87	0.96
Cost each sub-station complete	$24,000	$26,400	$10,000

TALE IV

FEEDER COPPER REQUIREMENTS

	600 V. D.C.	1200 V. D.C.	6600 V. A.C.
Maximum momentary demand midway between sub-stations			
Cars starting	1	1	2
Cars running	0	1	0
Amperes	520	374	150
Distance between sub-stations	11.8	28	66.6
Equivalent stub-end feed	2.9	[illegible]	16.6
Feeder required additional to 4/0 trolley	4/0	1/0	none
Cost overhead construction per mile, including both trolley and feeder	$2300	$2100	$1900

Bonding taken as $400 per mile of track

Transmission line taken in each case as [illegible] per mile of track and assumed to run entire length of right of way.

Power house: No power house is included, but it is assumed that power is purchased at the power station bus at [illegible] cent per kw-hr and fed at any convenient point into the transmission line.

TABLE V

POWER CONSUMPTION

	600 V. D.C.	1200 V. D.C.	6600 V. A.C.
Total kilowatt hours per day at cars	8400	8650	11,400
Efficiency, secondary distribution	0.90	0.90	0.94
Sub-stations	0.76	0.87	0.96
Transmission line and power house step-up transformers	0.94	0.94	0.94
Combined efficiency	0.64	0.74	0.85
Kilowatt-hours per day at power house	13,100	11,700	13,400

TABLE VI

Summary of Costs

FIRST COSTS

	600 V. D.C.	1200 V. D.C.	6600 V. A.C.
Transmission	$84,000	$84,000	$84 000
Sub-stations	216,000	106,000	20,000
Secondary distribution	230,000	210,000	190,000
Bonding	40,000	40,000	40,000
Cars	150,000	172,500	360,000
Total	$720,000	$612,500	$694,000

ANNUAL FIXED CHARGES

Depreciation	Life Years	Annuity 5%	600 V. D.C.	1200 V. D.C.	6600 V. A.C.
Transmission	20	30.34	$2,500	$2,500	$2,500
Sub-stations	20	30.34	6,500	3,200	600
Secondary distribution	15	46.34	10,600	9,700	8,800
Bonding	10	79.50	3,200	3,200	3,200
Cars (A.C.)	12	62.83		. .	22,600
Cars (D.C.)	15	46.34	6,900	8,000	. . . .
Total Depreciation			$29,700	$26,600	$37,700
Interest and Taxes					
Interest 5%, taxes 1.5% of cost of electrical material			$46,000	$39,800	$45,000
Insurance					
1.5% of sub-station and car costs			$5,500	$4,200	$5,700
Total fixed charges			$81,200	$70,600	$88,400

ANNUAL OPERATION AND MAINTENANCE

	600 V. D.C.	1200 V. D.C.	6600 V. A.C.
Transmission	$3,500	$3,500	$3,500
Sub-stations	17,000	7,600	500
Secondary distribution, including bonds	9,000	9,000	10,000
Cars	18,500	19,500	30,100
Power at one cent per kw-hr.	47,800	42,700	49,000
Additional cost maintenance of track and roadway, shops and supervision, due to heavier cars and more expert supervision required for the single-phase			10,900
Total	$95,800	$82,300	$104,000

ERRATA SHEET for pages 396 and 397, September 1910 REVIEW

(Corrections are indicated by heavy faced type)

TABLE VI

Summary of Costs

FIRST COSTS

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Secondary distribution	230,000	210,000	190,000
Bonding	40,000	40,000	40,000
Cars	150,000	172,500	**30 600**
Total	$720,000	$612,500	**$640.000**

ANNUAL FIXED CHARGES

DEPRECIATION	Life Years	Annuity 5%	600 V. D.C.	1200 V. D.C.	6600 V. A.C.
Transmission	20	30.34	$2,500	$2,500	$2,500
Sub-stations	20	30.34	6,500	3,200	600
Secondary distribution	15	46.34	10,600	9,700	8,800
Bonding	10	79.50	3,200	3,200	3,200
Cars (A.C.)	12	62.83	...	...	**19,200**
Cars (D.C.)	15	46.34	6,900	8,000	...
Total Depreciation			$29,700	$26,600	**$34.300**
INTEREST AND TAXES					
Interest 5%, taxes 1.5% of cost of electrical material			$46,000	$39,800	**$41,600**
INSURANCE					
1.5% of sub-station and car costs			$5,500	$4,200	**$4,900**
Total fixed charges			$81,200	$70,600	**$80.800**

ANNUAL OPERATION AND MAINTENANCE

	600 V. D.C.	1200 V. D.C.	6600 V. A.C.
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Additional cost maintenance of track and roadway, shops and supervision, due to heavier cars and more expert supervision required for the single-phase			10,900
Total	$95,800	$82,300	$104,000

TABLE VII

COMPARISON OF COST OF SYSTEMS

	600 V. D.C.	1200 V. D.C.	6600 V. A.C.
1 First cost	**$720.000**	$612,500	**$640,000**
2 Fixed charges	$81,200	$70,600	**$80.800**
3 Operation and maintenance	95,800	82,300	104,000
4 Annual cost (Item 2 plus Item 3)	$176,000	$152,900	**$184.800**
Based on 1,095,000 car miles per year, additional annual charge per car mile above the cost for 1200 volts, in cents	2.4	0	**2.9**

TABLE VII

COMPARISON OF COST OF SYSTEMS

	600 V. D.C.	1200 V. D.C.	6600 V. A.C.
1 First cost	$710,000	$612,500	$694,000
2 Fixed charges	$81,200	$70,600	$88,400
3 Operation and maintenance .	95,800	82,300	104,000
4 Annual cost (Item 2 plus Item 3)	$176,000	$152,900	$192,400
Based on 1,095,000 car miles per year, additional annual charge per car mile above the cost for 1200 volts, in cents . . .	2.1	0	3.6

27. Reliability of operation is of the greatest importance, not only to the public but to the operating company, and in this respect the electric motor with its simpler construction, even though the general service is supplied from a central power station, has proved its superiority over the steam locomotive. Except in the case of some extraordinary accident, the power station, substations and transmission line, in their entirety, are rarely rendered inoperative. The liability to interruption is principally centered in the equipment of the rolling stock, and for this reason the mechanical and electrical design of the motors, control and equipment devices, should receive careful consideration.

28. The electrical equipment of motor cars and locomotive is exposed to a large extent to dirt, water and snow; and not being particularly convenient for inspection, it usually receives less attention than the apparatus in the power station and substations. It is the custom on many roads to give the equipments a regular inspection once in a thousand or fifteen hundred miles, depending on experience, and to dismantle them for a thorough overhauling once a year. The character of the rolling stock equipment is a factor of far more importance to the reliability of the service than is often appreciated.

29. The steam locomotive has been brought to its present state of development through many years of experience. It is an exponent of the highest type of mechanical design, and notwithstanding its limitations, is remarkably efficient as a source of power. During the past twenty years the power of the steam locomotive has been practically doubled, but the demand today is for still greater power.

30. The multiple unit idea, to which electric service is so well adapted, was utilized in the design of the Mallet type of steam locomotive where the driving engines of two practically separate locomotives are supplied with steam from a single boiler. Mallet locomotives have been built having a weight of 441,000 lbs. on the drivers, the boiler having over 5800 sq. ft. of heating surface and a grate area of 100 sq. ft. To fire properly a locomotive of this capacity is difficult, and unlike the electric locomotive, its effectiveness depends on the steam from its own particular boiler.

31. With existing road clearances the steam locomotive unit, controlled by a single engineer, seems to have reached nearly the limit of power. The power of a steam locomotive being limited by the capacity of its boiler, an increase in speed can be secured only by a proportional reduction in tractive force. The electric locomotive, on the other hand, is supplied with practically unlimited power from an independent power station, and can maintain a speed and tractive force that would be impracticable with a steam locomotive. The application of electric locomotives to passenger and freight service will result in faster schedules with equal or even heavier trains than are at present handled by steam locomotives.

32 Since the electric locomotive is equipped with a number of independent motor units, controlled by one engineer from a single master controller, it makes no difference considering the complete locomotive as a machine, whether it be built as a single unit, or as two or three units having the same total weight on the drivers. For convenience in operation and repairs, it is probable that a single electric locomotive unit will be limited to a weight between 200,000 and 300,000 lbs. on the drivers, even when built for the heaviest service. There are electric locomotives now under consideration which as single units will exert a maximum tractive effort of 90,000

lbs., and which will be capable of maintaining a tractive effort of 35,000 lbs. at a speed of 30 miles per hour.

33. Many of the terminal and tunnel electrifications have been brought about from the desire to do away with the danger and nuisance caused by smoke and gas. The elimination of smoke has also an economic aspect in the electrification of terminal stations, in permitting material improvement in the character and value of railway buildings. The Quai d'Orsay terminal of the Paris-Orleans Railway in Paris, which has been in operation since May 1900, was the first instance where a steam railway profited by this feature of electrification.

34. The enhanced value of railway buildings is seen to a marked degree when terminals are electrified in large cities in which land values are high. The fact that electric operation will permit platforms on two or more levels adds greatly to the capacity of the station, or conversely, decreases the land area required for given traffic facilities. In the case of the New York Central terminal in New York City, there will be two levels of platforms, the entire suburban facilities being placed below those of the main line. The Pennsylvania terminal in New York is another instance of station design affording facilities for handling traffic that would be impossible under steam operation.

35. The electric locomotive is well adapted for the handling of trains where the character of the service will not permit the operation of individually equipped cars. Where the service is self-contained, individually equipped motor cars, operated in trains with multiple unit control, are recognized as providing for the most efficient handling of traffic.

Fig. 8. 1200-Volt Overhead Line Construction on Steel Trestle, Pittsburg, Harmony, Butler and New Castle Railway, Pittsburg, Pa.

36. Economy in operation will be secured by proportioning the number of cars in a train to the traffic required during different hours of the day. The patronage on which the gross receipts depend will be much encouraged by providing a service with short intervals between trains. In the study of any scheme of transportation, due regard should be given not only to economical operation but also to the method of handling which will insure the maximum gross receipts.

37. The author desires to express his thanks to Mr. C. E. Eveleth for his assistance in the preparation of this paper.

THE STEAM TURBINE*

Part I

By Dr. Ernst J. Berg

The Condition of Steam in Turbines

The relation between the available energy and the pressures and conditions of steam was given in the first of these lectures. It has been shown how, when the steam is expanded, a certain amount of moisture is formed and how this moisture is partly re-evaporated by the internal losses. For instance, in the case discussed, where the final amount of moisture would have been 20 per cent., with 100 per cent. efficiency of the turbine, the actual moisture of the exhaust was only 11.4 per cent. on account of the losses. (See page 295 in July, 1910, Review.)

In a single stage turbine there would be no way to take advantage of this, since the steam is discharged directly into the condenser. In a multi-stage turbine there is, however, a gain (although slight) by the re-evaporation, and as a result we have the apparent paradox that the joint efficiency of all stages is greater than the efficiencies of the individual stages.

As an illustration, assume that a single stage turbine is operated with saturated steam at a pressure of 175 lbs. absolute and 28 in. vacuum; the available energy is then 253,000 ft. lbs. and the final moisture 23.4 per cent. At 70 per cent. efficiency of the turbine the energy available for re-evaporation (neglecting losses by radiation, which are small) is $0.30 \times 253{,}000 = 75{,}900$ ft. lbs. The latent heat at one pound absolute pressure is 1043.1 B.t.u.; therefore to evaporate one pound, $1043.1 \times 778 = 812{,}000$ ft. lbs. of energy are required. Therefore with 75,809 ft. lbs., 0.0935 lbs. of moisture are evaporated. The moisture is therefore:

$0.234 - .0935 = 0.1405$, or 14.05 per cent.

With a four stage machine operated with initially dry saturated steam at 175 lbs. absolute pressure and 28 in. vacuum, the following condition of moisture exists in the different stages when the efficiency of each stage is 70 per cent. and the work per stage is approximately the same.

First stage (63 lbs. pressure), 4 per cent. moisture;

Second stage (19.5 lbs. pressure), 7.8 per cent. moisture;

Third stage (5 lbs. pressure), 11.5 per cent. moisture;

Fourth stage (1 lb. pressure), 11.8 per cent. moisture.

Comparing this with the moisture given in the previous case, 14.1 per cent., we see that the four stage machine has converted more steam to water, or has abstracted more energy. The efficiency corresponding to this moisture is 72.4 per cent. as can readily be determined from the above method.

There is therefore an apparent gain in going to many stages. It might be well, however, to mention that the gain, although considerable between a one-stage and four-stage turbine, is proportionately very much less as the number of stages is increased. The gain is approximately 1.5 per cent. in going from four to twenty stages.

This gain, however, cannot be fully taken advantage of, since with an increased number of stages other difficulties appear, as, for instance, steam leaks around diaphragms, etc.

To illustrate the dependence of moisture on the efficiency, the following tables have been prepared for a single-stage and a four-stage turbine:

Single Stage Turbine

1st. Initial pressure, 175 lbs. absolute; initial condition, dry saturated steam; exhaust pressure, 1 lb. absolute (28 in. vacuum).

Per cent. efficiency of turbine	100	70	50	30
Per cent. moisture in exhaust	23.4%	14%	7.7%	1.4%

2nd. Initial pressure . . . 175 lbs. abs.
Condition of steam . . . 200° F. superheat
Exhaust pressure . . . 1 lb. absolute

Per cent. efficiency of turbine	100	70	50	30
Per cent. moisture or superheat	17.6%	7.05%	0.05%	144° sup.

Four Stage Turbine

1st. Pressure, saturated steam . . . 175 lbs. abs.
Exhaust pressure . . . 1 lb.

Per cent. efficiency of each stage	80	70	60	50	40	30
Per cent. moisture in 1st.	4.9	4	3	2	1.1	.01
Per cent. moisture in 2nd.	9.6	7.8	6.1	4.3	2.6	.08
Per cent. moisture in 3rd.	14	11.5	9	6.5	4.1	1.6
Per cent. moisture in 4th.	18	14.8	11.8	8.6	5.5	2.4

*The last of a series of three papers read before the employees of the Commonwealth Power Company, Chicago. The first and second papers were published in July and August issues of the *Review*.

2nd. Pressure						175 lbs. abs.
Superheat						200°
Exhaust pressure						1 lb.
Per cent. efficiency of each stage	80	70	60	50	40	30
Per cent. superheat in lb. of 1st stage	0.84°	106°	127°	148°	172°	192°
Per cent. moisture or superheat in lb. of 2nd stage	2%	0	44°	85°	126°	168°
Per cent. moisture or superheat in lb. of 3rd stage	7%	3%	.4%	20°	80°	136°
Per cent. moisture or superheat in lb. of 4th stage	12%	8.4%	5%	2%	35°	108°

It is interesting to note that with 200° superheat and dry exhaust the efficiency cannot be higher than about 45 per cent.

Unfortunately, it is very difficult to determine the true conditions of the steam in the exhaust. Practical experience has shown that it is next to impossible to get a true sample.

It is evident, however, that if there were any practical ways of obtaining the percentage moisture in the exhaust of a turbine, its efficiency could be directly told.

At first sight it might be thought that since there is substantially no radiation from the throttling valve, there should be practically no loss in available energy through its use. That it is inefficient, however, is found in practice and theory. We will assume that the boiler gives saturated dry steam at 175 lbs. absolute pressure, and that by throttling the pressure is reduced to 100 lbs. absolute.

The specific heat of superheated steam is not definitely known, but will be assumed as 0.5. We have, therefore, assuming no loss by radiation: total heat of saturated steam at 175 lbs. = total heat of saturated steam of 100 lbs. $+0.t_1$, where t_1 is the amount of superheat.

Total heat at 175 lbs. sat. steam is 1,194.9 B.t.u.
Total heat at 100 lbs. sat. steam is 1,181.9 B.t.u.
Thus $0.5t_1 = 13$, and $t_1 = 26°$ F.

From the equations previously given, it can be determined that the available energy of saturated steam between 175 lbs. and 1 lb. is 253,000 ft. lbs., and that the available energy of superheated steam at 100 lbs. and 26° superheat is 228,100 ft. lbs.

$$\text{Therefore } \frac{228,400}{253,000} = 0.902.$$

or 90.2 per cent. only is available at the lower pressure.

In this connection it may be of interest to discuss the use of the *throttling calorimeter*, and the bearing that the uncertainty of the specific heat of superheated steam has on the deductions.

It will be assumed that the calorimeter is connected to the atmosphere and that the initial pressure is 175 lbs. abs.; the condition of the steam is unknown and the temperature of the superheated steam at atmosphere pressure is 262° F., or 50° superheat.

Since the total heat is assumed to be the same at the two pressures, we get:

Total heat at 14.7 lbs. saturated steam $+ Cp \times 50 =$ (total heat of saturated steam at 175 lbs.) + (heat of the liquid).

Let x be the percentage steam, then $1 - x =$ percentage liquid.

The liquid heat at 175 lbs. pressure is 343.3; therefore we get:

$$1,146.9 + 50Cp = 1,194.9x + 343.3(1 - x).$$

or

$$x = \frac{803.6 + 50\,Cp}{851.6}$$

For $Cp = 0.5$ we conclude a moisture of 2.75 per cent.

For $Cp = 0.6$ we conclude a moisture of 2.1 per cent.

From the equation it is readily seen that with saturated exhaust steam the initial moisture may be 5.7 per cent. or more.

The calorimeter, therefore, cannot record more than 5.7 per cent. moisture under this pressure condition. In reality it is limited to a considerably smaller percentage, on account of the error in temperature deduction, difficulties of getting true samples of the steam when loaded with much moisture, etc.

The Reciprocating Engine

The reciprocating engine, especially when new and properly adjusted, converts the energy of steam into mechanical energy with high efficiency. This is particularly so when operating non-condensing, or with moderate vacuum only. It must be remembered that high efficiency does not mean low water rate in general, but low water rate when considering the energy delivered to the engine in the steam between any given pressure ranges. For instance, an engine operating non-condensing with initially dry steam of 175 lbs. abs. pressure and an efficiency, including generator, of 80 per cent., would have a water rate of 23.6 lbs. per kilowatt-hour. Another engine operating with the same initial pressure and 28 in. vacuum and taking 17.5 lbs. of water, would have an efficiency of 60 per cent.

Due to the number of large cylinders, cylinder condensation, etc., it is evident that the low pressure part of the steam engine is not as efficient as the high pressure part. In the steam turbine, due to the higher rotation losses in the part which has high pressure, the conditions are reversed, the low pressure stages working, as a rule, with higher efficiency than those of higher pressure.

The reciprocating engine can have higher efficiency than the turbine at high pressures, and the turbine higher efficiency at low pressures. An excellent combination is, therefore, a high pressure reciprocating engine in conjunction with a low pressure turbine. This combination is the more attractive from the central station point of view, since it does not mean discarding the available equipment, but only adding such new apparatus as the load requires. This combination is much cheaper than the addition of new high pressure turbines or reciprocating engines with their boilers; it also reduces very materially the coal consumption per kilowatt generated.

Mr. Barrus, in his book on engine tests, shows that ordinarily, condensing only effects a saving of 25 per cent. in water rate in compound engines, and 17 per cent. in single engines.

Based upon these figures and certain assumptions of efficiency it is possible to make a very instructive analysis of the gain that can be made by the installation of low pressure turbines.

As stated, the efficiency of a compound engine, when new and properly adjusted and operating at atmospheric exhaust, is very high; it may be 90 per cent. with ordinary care. However, the efficiency cannot be maintained at this value, but averages probably 80 per cent. which value represents about 75 per cent. efficiency when the losses of the electric generator are included.

The water rate of such a unit operating with initially saturated steam at a pressure of 175 lbs. absolute is $\frac{18.9}{0.75}=25.2$ lbs. per kilowatt hour (See table page 291, July, 1910, REVIEW). At 28.5 in. vacuum, according to Mr. Barnes, we may expect a water rate of $0.75 \times 25.2=18.9$ lbs., which corresponds to an efficiency of $\frac{10.12}{18.9}=53$ per cent. (See table and interpolate between 28 in. and 29 in. vacuum.)

The available energy between 175 lbs. pressure and atmospheric exhaust is 139,500 ft. lbs.; thus energy converted per lbs. of steam in $0.75 \times 139{,}500=104{,}000$. The available energy between 175 lbs. pressure and 28.5 in. vacuum is 262,000 ft. lbs., thus the energy converted is $0.53 \times 262{,}000=139{,}000$. Therefore while operating condensing, the part of the steam engine unit which converts the low pressure steam to electrical energy supplies only $139{,}000-104{,}000=35{,}000$ ft. lbs. per lb. of steam.

Due to the internal losses and the re-evaporation of part of the moisture incidental thereto, the steam contains practically 8.9 per cent. moisture at atmospheric pressure. The available energy of each pound of moisture of steam and water expanded to 28.5 in. vacuum is readily calculated at 130,900 ft. lbs. Thus the efficiency of the low pressure part of the steam engine cycle is only

$$\frac{35{,}000}{130{,}900}=26.7 \text{ per cent.}$$

Depending upon the size, of course, the efficiency of a low pressure turbine set might be from 60 to 70 per cent. Assuming 65 per cent., as a mean value, it is evident that, for the same amount of steam, we can convert 130,900 foot lbs. to 35,000 foot lbs. useful work in one case, and in the other to 91,700 foot lbs. useful work. The total amount of useful energy in the former case is,

$$0.75 \times 139{,}500+0.267 \times 130{,}900=139{,}600 \text{ ft. lbs.}$$

in the latter case:

$$0.75 \times 139{,}500+0.65 \times 130{,}900=189{,}800 \text{ ft. lbs.}$$

Thus the low pressure turbine enables us to increase the output 36 per cent. when using the same flow of steam and the same amount of coal in both cases.

At overloads, the efficiency of the steam engine is usually considerably lower than at full load, so that it is undesirable to operate them at such loads. With the combination of a low pressure turbine, however, it is not the least objectionable to so operate them, since the turbine has a very uniform efficiency over a wide range of loads.

Therefore, not only is the joint efficiency high, but the output can be greatly increased with only moderate increase in steam flow. It is possible to more than double the output with 50 per cent. increase in flow.

(To be continued)

FIRE-DAMP PROOF APPARATUS

By William Baum

In the years 1903, 1904 and 1905 a great number of experiments on fire-damp protection were undertaken in Germany, in which all the prominent electrical manuacturers took part. These experiments had

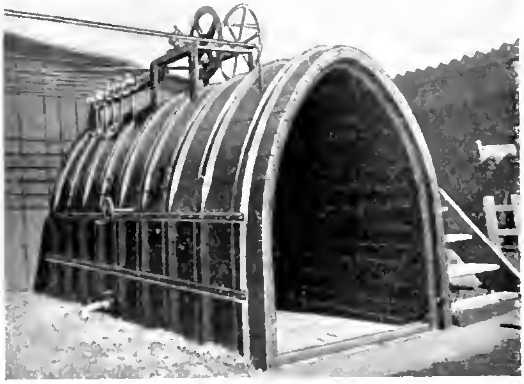


Fig. 1. Tank for Conducting Experiments with Fire-damp

an important final result, their immediate value for the miner and the electrical engineer consisting in the fact that electrical drives have been introduced in fire-damp mines. The experiments acquire an additional value from the fact that they have enlarged our views concerning the phenomena of pressure and current as they are manifested in the ignition of gases.

Fire-damp is a mixture of air and mining gas, and enormous quantities of the latter gas (methan CH_4) are evolved in coal pits, due in all probability to a slow decomposition of coal. Some beds of coal are so saturated with gas that when they are cut it may be heard oozing from every pore of the rock, when the coal is called "singing coal;" and in other cases the gas escapes by what are termed "blowers," the mixture of gases frequently collecting in the old working or unventilated portions of the pit. Not infrequently fire-damp bursts forth in large quantities from the seams of coal, or from the strata of clay which divide them, and is the cause of terrible accidents.

Methan has a specific weight of 0.556 (air = 1), is readily inflammable, and burns with a slightly luminous flame, which in the upper part has a yellow and in the lower a blue color. Fire-damp with 5½ to 13½ per cent. methan must be considered dangerous; the highest explosion pressures and temperatures occuring if the gas contains 9½ per cent. methan. The lowest ignition point is given as 650 deg. C. It may be mentioned incidentally that for human beings, the inhalation of fire-damp is considered harmless.

A few remarks may be in place regarding the experimental laboratory and the manipulation of the experiments.

For reliable tests the substitution of other gases is not feasible, as fire-damp ignites in a manner peculiar to itself. The laboratory was so situated that methan could be received from a coal mine and the gases conducted to a storage tank. In order to obtain the temperature of a mine, steam heating was provided. Fig. 1 shows the experimental tank. The mixture with air took place by means of fans, the volume of the mixture being measured by a gas meter and the character of the gases determined by chemical analysis. For a rough determination a glass tube was filled with a sample which was

Fig. 2. Iron Cylinder Protected by Double Wire Gauze

ignited by an electric spark, a certain power of explosion being thus indicated.

The apparatus to be tested was placed inside the tank and the fire-damp ignited by an electric spark or a platinum spiral brought up to glowing heat by an electric current.

Fire-damp protection may be classified as follows:

(1) Net protection.
(2) Protection by means of solid cases.
(3) Opening protection.
(4) Protection by means of
 (a) Labyrinth.
 (b) Pipes.
 (c) Flanges.
 (d) Plates.
(5) Protection by submerging sparking parts in oil.
(6) Artificial ventilation.

(1) Net Protection.

The best known protection against fire-damp is the wire-basket of the safety lamp invented by Davy. The wire gauze is made of brass or steel wire of 0.0118 in. to 0.0138 in. dia. with 31 meshes per inch. The experiments showed that in selecting a certain wire net surface for a given unit volume of fire-damp the safety of protection was influenced by the location of the ignition point and the general character of the protected space.

Fig. 2 shows an iron cylinder which was sufficiently protected by a double wire gauze of 0.02 sq. inch per cu. in. fire-damp; *i.e.*, when an ignition took place in the center of the cylinder, the surrounding gases did not

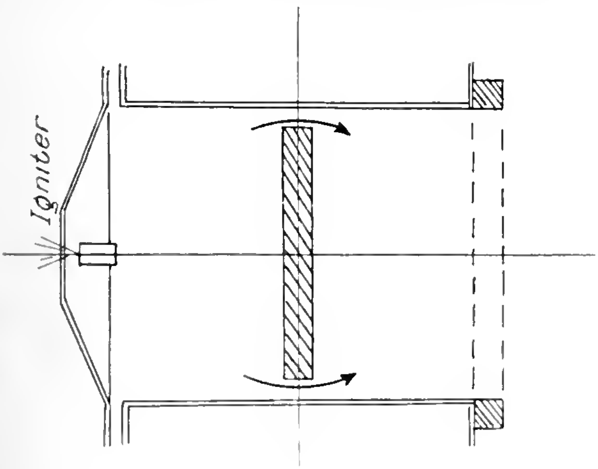


Fig. 3. Iron Cylinder of Fig. 2 Fitted with Wooden Partition

explode. With a single wire gauze, 0.025 sq. in. surface per cu. in. fire-damp was required. However, when th space in the cylinder was divided by a wooden disc with openings, as shown in the sketch (Fig. 3) and the ignition took place in the back part of the cylinder, the external gases were ignited. This process of igniting the surrounding gases, I shall term "puncture." In this case, two wire gauzes were provided having a distance

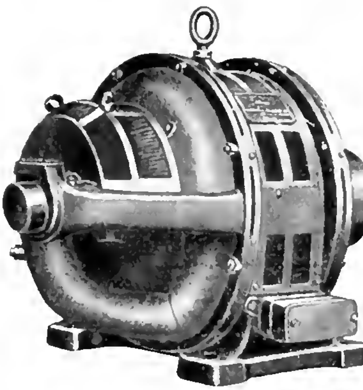


Fig. 4. 6 H.P. 500 Volt Slip Ring Induction Motor. This Motor Caused Ignition of Surrounding Gases, Owing to Large Openings Between the Feet and to Wire Gauze of too Large Mesh

between them of 0.78 in. and representing 0.125 sq. in. surface per cu. in. fire-damp. Reliable protection was secured with three nets.

These experiments showed that when the ignited fire-damp penetrated to confined spaces (as is the case with motors) the danger of puncture was increased. This is readily understood through the higher pressures which arise if the ignition takes place under these conditions. A wire gauze having a surface of 0.25 to 0.1 sq. in. per cu. in. fire-damp may be taken as a safe protection. In most cases, however, the phenomenon of "afterburning" was observed. After an ignition without puncture, fresh gases flew into the protected space and were ignited by the burning gases inside. This "afterburning," also known from the safety lamp, lasted often until all fire-damp in the experimental tank was consumed. It is seen, therefore, that electric apparatus with wire net protection would be destroyed by "afterburning."

Fig. 4 shows a 6 h.p., 500 volt slip-ring motor which punctured at once. There were large openings between the feet (Fig. 5) and the wire gauze was of too large mesh.

The collector of a 23 h.p., 500 volt direct current motor was protected by means of four double nets of 31 sq. in. surface enclosing 110 cu. in. fire-damp (0.282 sq. in. per cu. in.) and after an ignition inside the motor the surrounding gases exploded. This was also the case with a 6 h.p., 500 volt direct current series motor, "afterburning" occurring for a short period.

Poor results were experienced with a 30 h.p., 1000 r.p.m. induction motor with a short

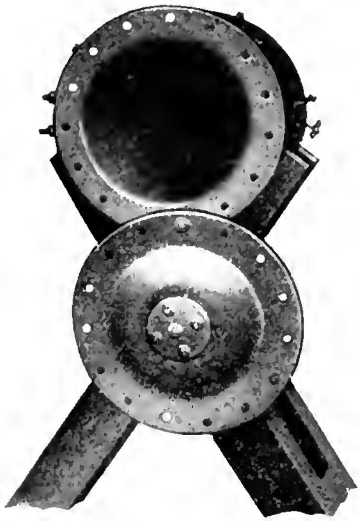


Fig. 5. Gas Tight Iron Cylinder for Determining Pressures Produced by Explosion of Different Mixtures of Methan and Air

circuiting and brush lifting device, this motor puncturing, as the leads were not brought out tightly through the frame. After this trouble was remedied no puncture occurred, but "afterburning" took place, the solder melted, and the brush lifting device was destroyed.

(2) Protection by Means of Solid Cases.

Experiments have shown that totally enclosed motors "breathe" or absorb gases, especially if they are provided with doors or removable covers. Unless an enclosed motor has air-tight bearings, gases will pass into the interior of the machine. When put in operation, a motor "exhales," as the enclosed air heats up and expands. At standstill it "inhales," the enclosed air cooling down.

From the above it is seen that totally enclosed motors should be so designed that the frame and end shields will offer sufficient resistance to the explosion pressure should an ignition take place, since the interior of the motor will, in most cases, be filled with fire-damp.

In order to determine the explosion pressures, a gas-tight iron cylinder (Fig. 5) was filled with different grades of mixtures and ignited, the pressures being read by means of an indicator which registered on a rotating drum. Fig. 6 shows the pressures in atmospheres against per cent. fire-damp. How the burning process took place appears from the curves Figs. 7, 8 and 9, in which the explosion pressures are plotted against time in seconds. Quick combustion is characteristic of a medium mixture, slow combustion of poor and rich mixtures. The highest measured pressure was 6.5 atmosphere, and the highest calculated combustion temperature, 2000 deg. C.

Actual conditions in the depths of a mine are somewhat different from those that prevailed during the experiments, which were made on the ground with the gases under 1 atmosphere pressure. For example, at a depth of 2620 feet, the gases are under a pressure of 1.1 atmospheres, for which the explosion pressure would be 7 instead of 6.5 atmospheres. The designer should keep this point in mind.

In one experiment a casting enclosing the slip-rings of an induction motor was destroyed, although the dimensions were properly calculated to withstand the expected pressure. This led to the conclusion that higher pressures are likely to arise if the conditions are different from those of the original experiments.

As a matter of fact, if the ignition is allowed to pass from one space to another, the explosion pressures become dangerous. This was shown by the following experiment: With reference to Fig. 10, the iron cylinder was divided into the spaces A and B by means of a partition provided with an opening. At a certain distance from this opening the ignition was produced and a pressure of 1.7

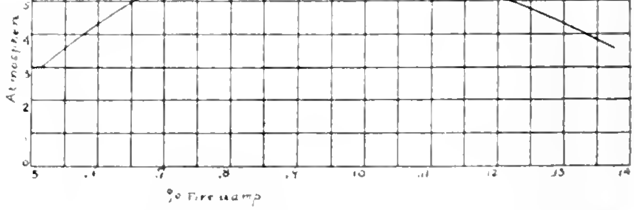
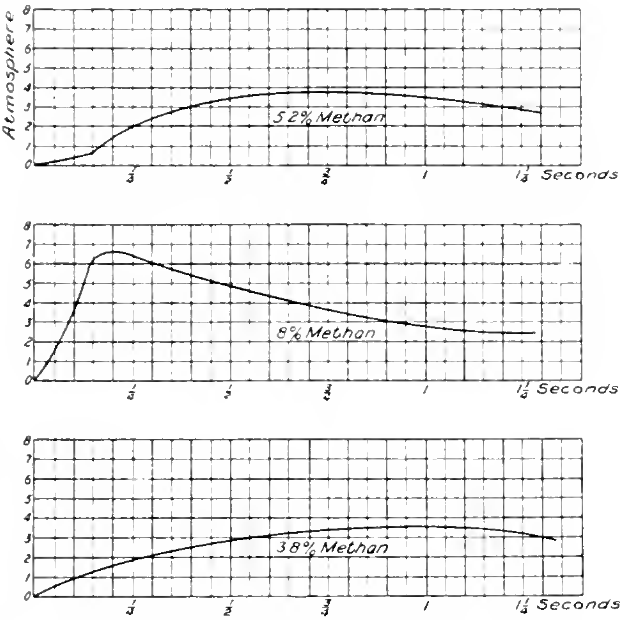


Fig. 6. Curve Obtained from Experiments with Iron Cylinder of Fig. 5

atmosphere was observed at B before the gases had passed from A to B. When the ignition passed over to B, an enormous pressure arose in B and the partition was destroyed. The pressures in A and B then equalized.

A considerable number of motors with enclosed frames failed in the tests on account of insufficient rigidity or because of large openings in the frame. In a 30 h.p. motor, the cast iron cover for the slip-rings was



Figs. 7, 8 and 9. Curves Showing Process of Burning of Different Mixtures of Coal Gas and Air in the Iron Cylinder of Fig. 5

completely destroyed, owing to the fact that the shaft did not fit tightly to the bore of the bearing bracket. The clearance was then reduced to a minimum and a heavier cover and rubber gaskets provided. No puncture occurred this time, but the gaskets were pushed out sideways. Without the gasket puncture occurred, a considerable slit appeared, and the cover became deformed. In this case the gases had a second outlet through the oil chamber of the adjacent bearing.

The doors of a 7.5 h.p., 500 volt induction motor were torn off and puncture occurred, an inspection showing that there was a 1.2 in. opening at the bottom of the frame.

Enclosed controllers and fuse boxes have proven safe. Rough surfaces should be provided with gaskets. The fuses should be so designed that they will not burn with an external flame.

Notwithstanding the fact that the protection by means of solid cases has frequently failed, its application to small apparatus may be recommended; also, slip-rings or collectors may be safely protected by rigid covers. Attention is called to the danger which may arise if machined surfaces are used with gaskets, as these may be blown out by the explosion pressure.

(3) Opening Protection.

While with net protection the ignited fire-damp escapes under small pressures, high pressures arise with "opening protection." The surprising phenomenon that the high pressure fire-stream does not ignite the surrounding gases is explained by the considerable reduction of temperature corresponding to the degree of expansion. Furthermore, the gases assume an enormous velocity, which prevents ignition. This peculiarity is practically identical with that manifested when one passes the hand rapidly through a flame without getting burned.

The application of "opening protection" appears to be very limited, since it depends to a large degree upon the location of the ignition point and the character of the mixture. For instance, if the ignition takes place near the opening, the gases escape under small pressure and cause ignition. The experiments also showed that poor and rich mixtures are more dangerous than medium mixtures. This is due to the fact that poor and rich mixtures burn slower, as was shown in Figs. 7 and 8, and have more time to escape. They assume lower pressures and weaken the effect of expansion. Fig. 11, a and b, shows how, with a rich mixture

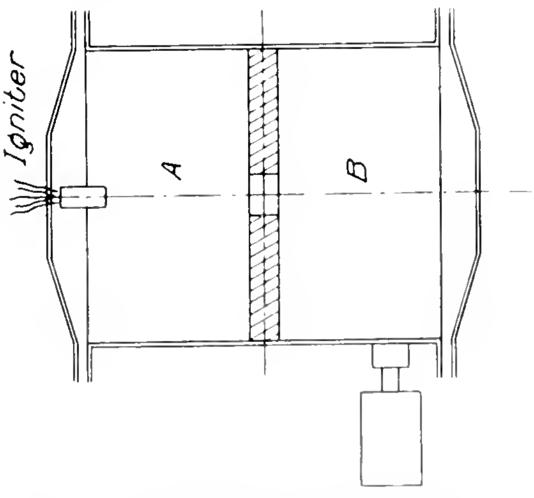


Fig. 10. Iron Cylinder of Fig. 5 Divided into Two Parts by Wooden Disc with Opening in Center

and the same location of the ignition point (in the back part of the cylinder), the pressure increases with decreasing cross-section of the opening. With the same mixture and open-

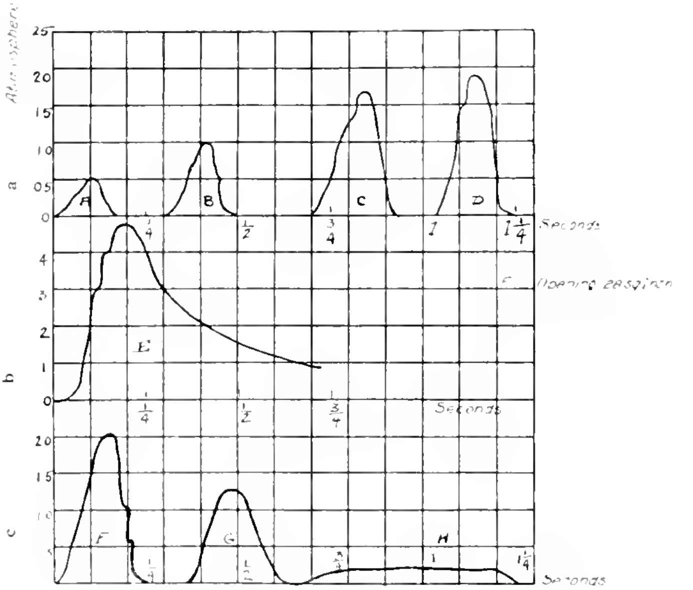


Fig. 11, a and b. Pressure Corresponding to Various Cross Sections of Openings for Rich Mixture and Same Position of the Ignition Point, c, Pressure Corresponding to Distance of Ignition Point from Opening for Same Mixture and Size of Opening

ing, the pressure increases with the distance of the ignition point from the opening, as illustrated by Fig. 11, c.

When the ignition was caused by a glowing platinum spiral instead of an electric spark, the cylinder "inhaled" fresh fire-damp from the outside (the ignition occurred without puncture) and these gases were ignited by the spiral. This process occurred several times until puncture finally resulted.

Fig. 12 shows the pressures for different cross-sections of openings and is of fundamental importance.

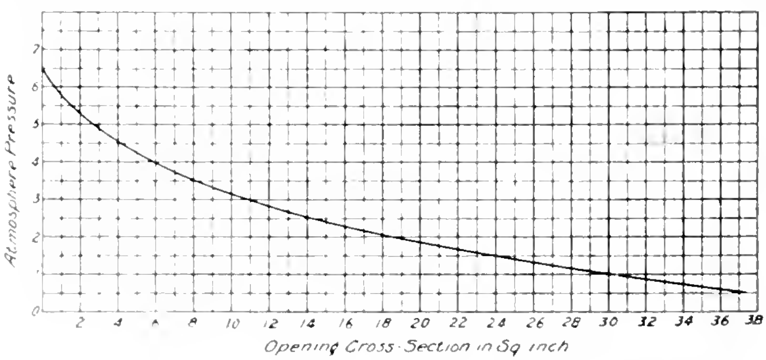


Fig. 12. Pressures Corresponding to Different Cross Sections of Opening

The small profit resulting from the experiments with "opening protection" is compensated for by the fact that they have given us an understanding of very important phenomena. It now appears that cracks, joints, openings, etc., in enclosed frames may not be dangerous in many cases, as the effect of expansion prevents ignition of the surrounding gases. It is important that these openings do not exceed a certain size. Referring back to the net protection, which is based on cooling effect and the breaking up of the escaping gases into fine currents, any opening greater than 0.0197 in. to 0.0295 in. will allow the escaping gas stream to remain hot and cause ignition.

The two important principles of fire-damp protection are based on the cooling and the expansion effect.

(4a) Labyrinth Protection.

In a labyrinth several openings are so arranged as to allow the gases to escape in zigzag. To obtain high pressure it is essential that the fire-damp be ignited in the rear. The labyrinth also offers a cooling effect, but has proven of little practical value.

(4b) Tube Protection.

The idea is obviously to conduct the escaping gases through pipes. Fig. 13 shows an iron cylinder with 12 tubes, each 0.515 in. inside diameter and 20 in. long. No puncture occurred with the ignition point in the center of the cylinder. When the tubes were arranged on both sides of the cylinder, the ignition of the surrounding gases occurred.

Wrought iron tubes of different inside diameters and lengths were filled with fire-damp, closed at one end and ignited at the other. Puncture took place with a tube of 1 in. inside diameter and 73 in. length; no puncture occurring with a 0.51 in. diameter tube of the same length. It seems that good protection would be obtained with tubes of smaller diameters.

(4c) Flange Protection.

The cylinder was provided with a flange in such a manner that a clearance remained between the two bodies. With an opening of 0.094 in. puncture could frequently be prevented. Flange protection is a modification of the "opening protection," with an additional cooling effect. It has not found practical application.

(4d) Plate Protection.

With reference to Fig. 14, thin discs are arranged above each other in such a manner as to allow the escaping gases to pass through parallel ring-slits, in which the fire-damp is broken up into small streams and efficiently cooled. When the distance between plates was 0.0196 in. and the thickness of the plates 0.0196 in. ($\frac{1}{2}$ mm.), the experiments were most gratifying. Tests were made with a large and a small percentage of mixture, the point of ignition being placed near and at a distance from the plates, and in no case did puncture occur.

When the clearance between the plates was enlarged from 0.0196 in. to 0.039 in., puncture occurred in several cases. This would indicate that a clearance of 0.0196 in. should not be exceeded. The rings should be 0.0196 in. thick, and the width of the path of passage 1.96 in.

"Plate protection" with a large number of slits represents a large cross-section and acts in a manner similar to the net protection:

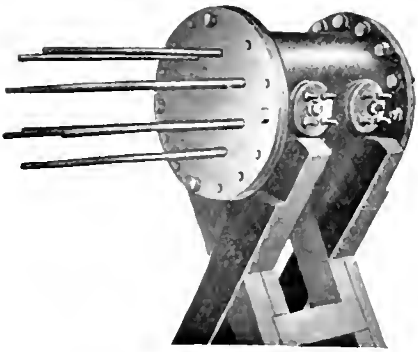


Fig. 13. Iron Cylinder Fitted with Twelve Tubes 0.515 Inside Diameter, 20 Inches Long

i.e., the fire-damp is broken up into small streams and abundant coolin is secured. In this case the degree of protection increases with the number of slits. With a small number of plates, the principle of protection is similar to that of the "opening protection," which is based on the expansion effect. Here the safety of protection increases with a reduction of plates.

The interesting curve of Fig. 15 illustrates

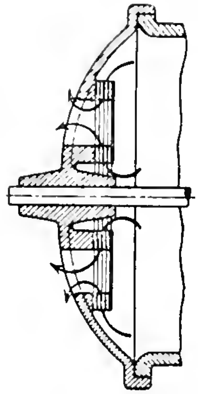


Fig. 14. Protection by Means of Thin Discs or Plates

the "degree of safety," or the distance from the puncture limit depending on the number of slits.

A combination of plate and net protection proved to be absolutely safe. Afterburning was rarely observed and always ceased in a short time.

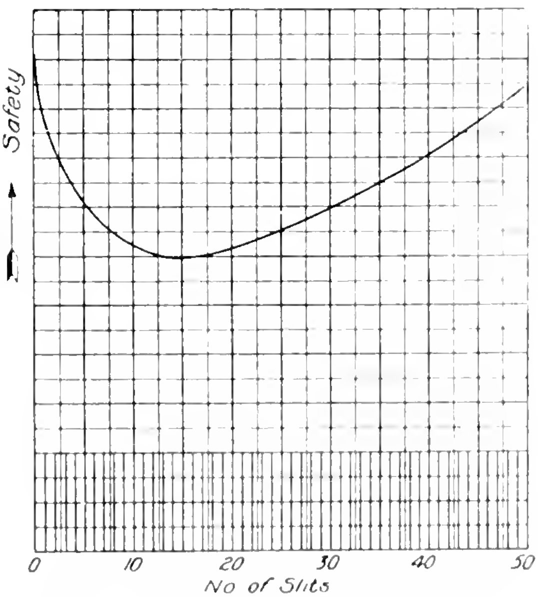


Fig. 15. Degree of Safety Secured by Plate Protection Depending Upon Number of Plates

Fig. 16 shows the design for a 30 h.p., 500 volt enclosed motor with plate protection, the discs of which have an outside diameter of 30 in. and correspond in every respect to those of Fig. 14. The armature has

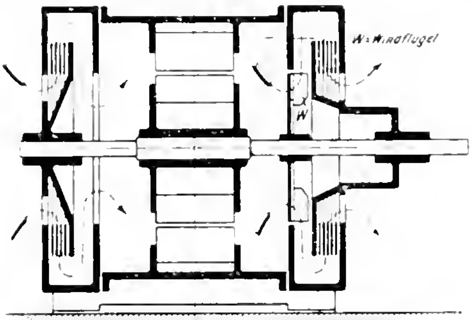


Fig. 16. Design for 30 H.P. 500 Volt Motor with Plate Protection

fans for self ventilation, and as an open motor the frame is good for 35 h.p. The motor was tested with poor, medium and rich mixtures when in operation at normal load, overload, and standstill, both when hot and when cold, and in no case did puncture occur.

Another 30 h.p. motor with plates of proper dimensions gave interesting results. In this case the motor failed. Instead of using distance pieces between the discs, the plates had grooves 0.0196 in. in depth which on the other side appeared as ribs. Where these grooves occurred, the total distance between plates was 0.0392 in.

One of the later designs of plate protection

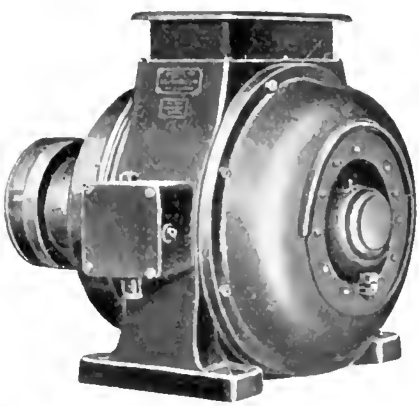


Fig. 17. 15 H.P. Induction Motor with Plate Protection

is shown in Fig. 17. The motor is good for 15 h.p. One part of the plates is arranged in a cast iron frame at the top of the motor, the other plates being located within the two end shields. The motor is provided with fans and the air enters through the end shield slits, strikes along punchings and windings, and is blown out through the top slits, the action corresponding to that of a chimney. By this arrangement the output of the motor is reduced to 75 per cent. of that of an open motor with the same mechanical dimensions. The frames containing the plates can be taken out conveniently and cleaned from coal dust, etc.

A 50 h.p., 1000 volt induction motor with this protection has been successfully tested by Belgium mine authorities.

Plate protection, of course, does not embody the only solution of the problem. Principally, any efficient protection will always be based on the cooling and expansion effect.

(5) Protection by Submerging Sparking Parts in Oil.

Fig. 18 shows a 10 h.p., 500 volt induction motor, the slip-rings of which operate in oil covering the brushes. The motor ran safely

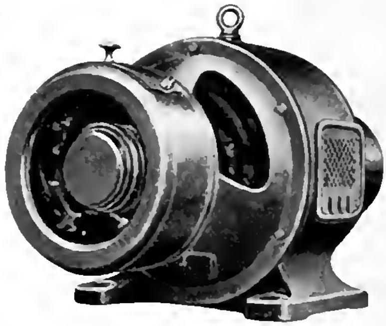


Fig. 18. 10 H.P 500 Volt Slip Ring Induction Motor, the Rings of which Operate in Oil

with long overloads, frequent starting, and reduced number of brushes. Artificial sparks were produced without giving any trouble. Whether the motor operated satisfactorily under actual working conditions is not known. The General Electric Company has built an induction motor with slip-rings under oil and, as far as is known to the writer, it has given no trouble. Attention is called to the danger which may arise if the brushes are not covered by the oil; in several experiments this was the cause of explosion, as the oil could not suppress the sparks.

Oil switches may be considered fire-damp proof if the oil completely covers the contacts. Resistance grids are often protected by a double net.

(6) Artificial Ventilation.

Where fresh air is available in mines, the installation of even the largest types of totally enclosed motors does not offer difficulties. The frame must be provided with gas-tight openings for the pipes which supply the fresh air in such quantities as to keep the motor cool. This artificial ventilation has the advantage of reducing the weight of the frame to a minimum, practically allowing the same dimensions which would be required for an open frame.

In concluding this article the writer wishes to emphasize the statement that it is not possible to say with certainty that plate protection is the best safeguard that it is possible to devise; it is, however, the best at present known. The intention of the article is to show the direction along which the design of fire-damp proof apparatus should be taken up.

Incidentally, it may be mentioned that the experimenters and designers have not taken out patents covering the various schemes.

The available literature has been freely used, especially the *Elektrotechnische Leitzschrift* and the *Zeitschrift des Vereins Deutscher Ingenieure*.

COMMERCIAL ELECTRICAL TESTING

PART XI

BY E. F. COLLINS

TRANSFORMERS

Special Tests

The following order of tests on transformers has been found to be most convenient:—Cold resistance; polarity; ratio and checking of taps; impedance; core loss and exciting current; parallel run; insulation tests; double potential for one minute; one and one-half potential for five minutes; and high potential test.

Transformers built for potentials above 50,000 volts should have the double potential test taken after the high potential test.

Since many of the tests on the different types are almost identical, a complete discussion on the air blast type will first be given, and then shorter discussions on the others.

Single-Phase Air Blast, Type AB Transformers

The transformer should be properly placed over the pit and the supporting boards must be sufficiently strong, otherwise the transformer may fall into the pit and injure anyone who may be stationed under it. No opening should be left through which air can escape and influence the reading of the thermometer on the transformer iron. When the transformer is in place, a careful inspection should be made, making note of any defect, no matter how slight, and if found, it should be repaired immediately.

The order of tests may be varied if found necessary; *i.e.*, if a resistance measuring set is not available, then ratio and taps may be taken; or, if the core loss alternator is in use, some other test should be made to prevent loss of time. Usually two or more transformers of the same rating are tested at once. In the following discussion, two or three transformers are considered.

Cold Resistance

As the temperature guarantee of the windings specifies that the increase-in-resistance method be used, considerable care must be taken in measuring resistances. This measurement is usually made as follows: Place a thermometer on the coils of each transformer and send from 10 to 15 per cent. full load current through the transformer coils; this being generally the proper amount for two or four transformers. The ammeter should not read below the center of the scale, nor should the current be sufficient to appreciably heat the windings while taking resistance. For very low voltage secondary windings, use about 40 amperes, as this current usually gives sufficient drop to be read on the voltmeter. The drop lines must not include the resistance of any temporary connections. Adjust the resistance in the box until the reading comes to about the middle of the scale of the voltmeter. Considerable time will be saved by short circuiting the secondary while the primary is being measured, and by short circuiting the primary while the secondary is being measured. In measuring secondary resistances, especially when low, the contacts for the voltmeter leads should be carefully cleaned with sandpaper.

Take three readings on each coil, holding about the same current. It is far better to allow the ammeter to vary slightly, than to try to hold exactly the same reading, as the observer is likely to be prejudiced. In entering readings, always record the constants of the meters, the voltmeter resistance, the resistance of the drop lines, the resistance in the box and the temperatures of the coils. If the transformers have more than one primary and one secondary coil, a clear sketch should be made and the coils so marked as to prevent confusion. In recording results, the value of the unit deflection should be noted and readings pointed off accordingly. Readings should be taken as rapidly as is consistent with accuracy. The method of calculating rise in temperature by increase of resistance is explained under heat runs.

Polarity

The polarity test is taken, since it affords the only means of readily determining the connections required for transformers in banks; for instance, several transformers in parallel. When transformers are connected for measurement of resistance the polarity test can readily be made with a special voltmeter. Select one transformer as a standard; when several are in test at once, one near the middle of the group should be chosen as it will be safer and more convenient when the transformers are run in parallel. With direct current flowing through one winding of the transformer, connect the special voltmeter across the terminals so as to get a positive deflection; then transfer the drop lines to the corresponding terminals of the other winding and break the current in the first winding. If the polarity is correct, a positive kick will be obtained. When making this test, have sufficient resistance in series with the voltmeter to protect it from damage.

It is not necessary to take polarity on more than one transformer of a group, as the parallel run will show whether or not they all have the same polarity. In taking polarity on special transformers, a clear sketch should be made showing the polarity. For tap polarity, see headings "ratio" and "checking taps."

Ratio

The ratio of a transformer is the ratio of primary voltage to secondary voltage, and should be equal to the ratio of primary turns to secondary turns. The usual method of determining this value is to apply about one hundred volts to the secondary winding and read the primary voltage, stepping it down with a suitable potential transformer. The ratio of the potential transformer should be as nearly that of the transformer in test as possible. The potential transformer must be operated at normal frequency and voltage, otherwise the ratio will be unsatisfactory. In very small transformers, the voltage should be applied to the primary windings.

When the ratio of the potential transformer is very nearly that of the transformer in test, the voltmeters should be interchanged after five readings have been taken. When this is done it is not necessary to correct voltmeter readings from curves, as the meter errors will appear in both columns and be eliminated. In determining any ratio at least five readings should be taken, and the result carefully calculated. If the ratio by test varies more than *one* per cent. from the rated ratio of voltage, check the ratio of turns; if the ratios of voltage and turns agree, repeat the ratio with the same meters; and if still out, repeat with an entirely different set of meters and potential transformer. If the ratio is still out, the transformer is wrong. Try the ratio of another transformer. If, however, the ratio should be correct when the second set of meters is used, a third set should be used and the ratio checked again. If the second and third sets of meters give a correct ratio, record both sets of readings.

In taking ratio on transformers with taps or dial switch, note whether or not full windings are used. If the transformer has more than one primary or secondary coil, note whether the coils are in series or multiple. The ratio must check within one per cent. of the ratio of turns. It is not necessary to take ratio on more than one transformer of a group, as the parallel run will determine whether they all have the same ratio.

Checking Taps

Nearly all transformers are provided with taps in one or both windings, so that a slight change in ratio or a low voltage for starting may be obtained. Before checking taps, procure the proper winding specification and sketch. Taps are easily checked by applying a certain voltage per turn to the low tension winding and reading the voltage between the terminals of the winding and the first tap; then between successive taps on the same coil. In some cases it is equally satisfactory to apply full potential to one winding and read the voltage between adjacent taps. This is done on dial switch transformers.

The method can best be explained by an example. Take an AB-25-100-6300/6195/6048 5985 5835 5600-170. The primary winding has six coils connected in series, of 43 turns each, with inside and outside ends.

This is called a single section coil. The secondary winding consists of six coils connected in multiple of 7 turns each. Taps are brought out of the primary coils P-1 and P-6 at the ending of the 29th, 34th, 38th and 41st turns from the inside end. This gives tap turns of $43-41=2$, $41-38=3$, $38-37=1$, $37-34=3$, $34-29=5$ turns. Since the secondary winding has four coil terminal blocks, these coils can be connected in series, giving 14 turns. Applying 5 volts per turn $=70$ volts to the secondary (Fig. 44), we read volts across terminals $(1-2)=10$, $(2-3)=15$, $(3-4)=5$, $(4-5)=15$, $(5-6)=25$. The same readings will be obtained on the other end of the primary winding. These readings must be checked with the voltages required by the sketch. The volts per turn at normal potential $=\frac{170}{7}=24.2$ volts. In changing from (1-7) to (2-8), four turns are cut out of the primary winding, and the primary voltage is decreased by $6300-6195=105$ volts. Multiplying 24.2 by 4, 96.8 is obtained, which is as near 105 as possible, unless a tap be brought out at a half turn, which is seldom done.

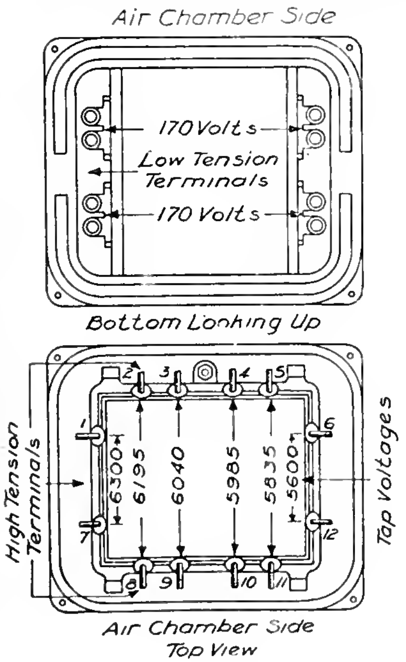


Fig. 44. Taps

Changing to (3-9), six turns are cut out and the primary voltage is decreased by $6195-6040=155$ volts. Now $6\times24.2=149.2$, which is near enough to 155. The remainder of the taps should be checked in the same manner.

Great care should be taken in handling the voltmeter connected to the taps, for while the voltmeter reading is low, the circuit to which it is connected may be several thousand volts above ground. If the opposite end of the circuit be grounded, a severe shock may be obtained from the meter.

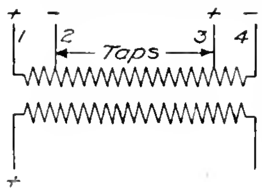


Fig. 45. Taps

In checking 50 per cent. taps, one meter should be used as a check and another to read the voltage across each half of the winding, the readings being taken first on one side and then on the other, holding the same reading on the check meter. A neat sketch showing the position of the taps should always be made. On transformers with only one tap on each end, it is often necessary to check its location by polarity. (See Fig. 45.) This is done as follows: with direct current flowing through the secondary, take polarity of (1-4), (1-2) and (3-4); if all the deflections are in the same direction, the taps are properly brought out; if some are reversed, the tap and line lead are interchanged.

Impedance

The expression $C=\frac{E}{R}$ for continuous current circuits is replaced in alternating current circuits by the equivalent expression $C=\frac{E}{\sqrt{R^2+(2\pi fL)^2}}$, where C is the current, E the impressed e.m.f., f the frequency, L the coefficient of self-induction, and R the ohmic resistance. The expression $\sqrt{R^2+(2\pi fL)^2}$ is known as the impedance of the circuit and is defined as the apparent resistance of a circuit containing ohmic resistance and self-induction. The term $2\pi fL$ is called the reactance of the circuit.

The impedance of a transformer is measured by short circuiting one of the windings and impressing an alternating e.m.f. on the other winding, taking simultaneous readings of amperes, volts, watts and frequency. The impedance of transformers should be carefully measured for the following reasons: Transformers operating in multiple divide the load inversely as their impedance voltage; *i.e.*, the transformer having the higher impedance will take the smaller part of the load and *vice versa*. When transformers of different types are operated in multiple, the impedance of one transformer must sometimes be increased by putting a reactive coil in the secondary circuit and adjusting until the desired impedance is obtained.

Impedance tests show whether a given arrangement of coils is satisfactory or not.

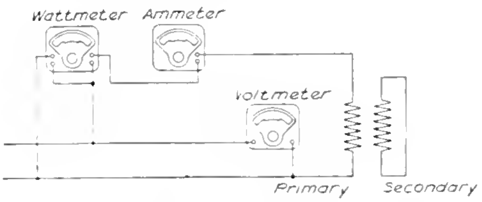


Fig. 46. Connections for Impedance Test

If the arrangement is not satisfactory, excessive magnetic leakage will take place and a high impedance voltage result. The impedance watts will also be high, due to excessive eddy currents in the copper. Since regulation depends upon impedance to a great extent, a low impedance is very necessary for close regulation.

The impedance voltage of transformers usually varies from 1 to 4 per cent., although it may be as high as 6 to 7 per cent. The impedance watts usually do not exceed 1 to 1½ per cent. of the total capacity of the transformer and will be more than the calculated C^2R on account of eddy current losses in the copper. In transformers wound with large conductors the impedance watts will differ from the calculated C^2R of a transformer wound with small wire.

The following method should be followed in making an impedance test: Place a thermometer on the coils to obtain the temperatures; make a good short circuit on one winding, using as short a cable as possible and one of ample cross section so that no appreciable losses will occur. Calculate the full load current by dividing the watts capacity by the maximum voltage of the winding in which the meters are placed, unless the engineering notices call for tests under different conditions. Select suitable meters and make connections as shown in Fig. 46, wiring to the alternator through a suitable transformer. The alternator must be operated at as near normal voltage as possible when the normal impedance reading is taken.

Take ten readings, starting at 50 per cent. and raising to 125 per cent. full load. Hold the speed constant and take simultaneous readings of amperes, volts and watts. It is essential that the speed be exactly right, since the reactance varies directly with the frequency. This curve should be plotted after the readings are taken (not as they are taken) to see if the curve is smooth; if the curve is not smooth, check it at once. Plot volts as ordinates and watts and amperes as abscissæ. The volt-ampere curve should be a straight line; the volt-watt curve should be a parabola. (Fig. 47). In taking the readings, results will be more satisfactory if meters are selected so that no change in them is necessary throughout the curve. On the record sheet, note the temperature of transformer coils and constants of all meters used. If a potential transformer is used, record its number and ratio. Also, state plainly the hour at which the test is taken.

The connections shown in Fig. 46 are used in preference to those in which the losses of the voltmeter and of the potential coil of the wattmeter are included in the reading of the wattmeter. In Fig. 46 the only extra loss is that in the current coils of the ammeter and wattmeter, and this is negligible.

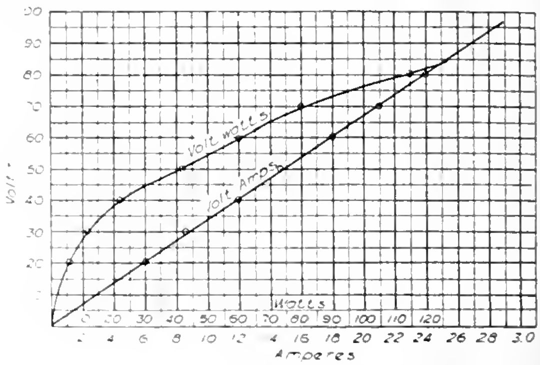


Fig. 47. Impedance Curve

A potential transformer or multiplier should be use with a wattmeter when the voltage exceeds 150 volts. It will be noted that the lower binding posts on Thomson wattmeters must be connected together when neither a potential nor a current transformer is used; and when the voltage of the circuit is above 2000 volts, they should be connected by a small fuse wire. The secondary of the potential transformer should not be grounded, however, unless a current transformer is used. The adjacent ends of the current and potential coils are connected to these binding posts and, unless they are connected to the same side of the line, there is danger of breaking down the insulation between the coils and burning out the wattmeter. Above 2000 volts the fuse wire is used to avoid electrostatic effects.

(To be Continued)

APPLIANCES FOR ELECTRICAL MEASUREMENTS

PART II

By C. D. Haskins
Manager Lighting Department, General Electric Company

Portable Instruments

It seems superfluous to deal at any considerable length with portable instruments. They involve all of the primary characteristics of the switchboard instrument, combined in such physical form as to permit of portability without damage.

For direct current purposes the preferred instruments today are of the permanent magnet type, and are generally constructed on the D'Arsonval principle, with spring restraining forces and Foucault current damping. They are commonly non-astatic, and for this reason care must be exercised in their use to insure freedom from stray fields. Where any doubt exists as to this it is well to take reverse readings, by moving the instrument through 180 degrees and repeating the observation; if there is a difference between the two observations the mean is used as the true value.

The manufacturer usually strives to provide a somewhat higher degree of precision in the better class of portable instruments than in switchboard instruments.

To insure long continued good service it is essential that portable instruments be so constructed as to have a very light moving element and thus obviate the likelihood of damage to the bearings or pivots in transportation and use.

The voltmeter and the ammeter are the only two direct current portable instruments commonly used. Ohmmeters are manufactured and used to some extent, but are far less common than the portable Wheatstone bridge, within which, in fact, the former instrument is embodied, and can be cut in or out by a key button. It is not unusual to find voltmeters which are also so constructed as to permit of cutting out the resistance for the purpose of using the instrument for the measurement of very small current values, in which case the instrument becomes a milli-amperemeter.

Portable ammeters in capacities up to about 30 amperes generally have a self contained shunt; above this size they are generally accompanied by separate portable shunts, several shunts frequently being provided for use with a single instrument.

In the alternating current field portable instruments closely parallel the more important switchboard instruments, and their mechanisms are essentially the same, modified only as the conditions of use demand.

In most modern structures the portable alternating current voltmeter or ammeter or indicating wattmeter may be used also upon direct current, but subject to certain errors.

Many of the portable ammeters and voltmeters are provided with a moving iron vane armature, which, when the instrument is used on direct current, becomes polarized, and consequently introduces hysterisis errors, due to residual magnetism, so that the instrument when used on direct current will not give the same values at the points going up across and coming down the scale, a phenomena which disappears when these structures are used on alternating current. (This statement is not literally, though practically, correct, there being certain trifling variations at different frequencies.)

Moving coil instruments of the portable alternating current class may also be utilized on occasion for purposes of direct current measurement. Being so constructed as to be devoid of a dense magnetic field, they are more susceptible to deviation due to stray field or earth's field than instruments of the direct current D'Arsonval type.

Portable alternating current voltmeters are often and portable indicating wattmeters substantially always of the moving coil type, and practically all portable indicating wattmeters as commonly used in the art are primarily and essentially of the type preferred for alternating current; they are sensitive to stray fields, and are to be safeguarded in observation accordingly when used, as they often must be, on direct current.

Portable instruments have been particularly subject to specialization of construction for various purposes.

No better example of such specialization is to be found than that of the recently introduced watt indicator for lamp consumption measurements, an instrument which is so constructed as to screw into a lamp socket at one end whilst the lamp itself is screwed into a socket in the instrument, thus making it possible to get quick lamp values.

For the purpose of those who desire to make a further study of the physical principles which have been resorted to in devising indicating instruments, an appendix has been added to this lecture, classifying the structures into physical groups and summarizing their essential characteristics. For our immediate purpose we may run over these principles in the briefest possible way at this point.

Recording Instruments and Integrating Meters

It is well to say at this point that early practice seems to have been definitely formative in determining the nomenclature of the art in connection with the various classes of mechanisms used in applied electricity.

The terms which are current, and so well established that perhaps they must always remain permanent, are not always techinically correct; but they are established, and it is probably well to recognize them and use them.

Measuring devices which have a needle moving over a scale giving a fixed indication at a fixed value are classed broadly as "instruments." Structures which draw a line upon moving paper, showing the fluctuations in values of magnitude and of time, are known as "graphic recording meters" or "curve drawing instruments;" whilst those devices to which I have referred up to this point as "integrating meters," and which give electrical units × time are known broadly as "meters," or "recording meters," this latter being a misnomer now established and to be recognized by reason of usage.

Graphic recording instruments are useful in many connections since they provide a fixed physical record over a considerable period of all the fluctuations upon the system to which they are attached.

A paper ribbon or disk is moved at a fixed rate of speed, bringing a certain portion of the accurately divided paper under the needle at each hour of the day.

The needle in such instruments is armed with a pen or with other means for permanently marking the paper, and the result is a crooked line which may be read against the scale marked upon the paper itself; thus the "load" at any hour of the day or night is a matter of record.

Coming almost within the class of graphic recording instruments is the oscillograph, an instrument by which current fluctuations of minute value and of excessively brief period, are recorded on a rapidly moving sensitized ribbon, sheet or plate by means of refracted light

In the modern oscillograph records of current fluctuations in a telephone circuit are easily obtained, and movement periods as low as one-twentieth of a second are readily recordable in large amplitude.

Thus an oscillograph excited in a telephone circuit makes upon the moving film a linear record of a word, dependent upon the volume of vibration and consequent current fluctuation in the circuit, which is readily recognizable. It seems entirely feasible, and indeed probable, that at some early day actual language can thus be reduced to a linear equivalent which the trained eye may be capable of reading. I have myself in a very brief time become able to read numerous words thus inscribed by the current fluctuation incident to the brief vibration with little or no difficulty. In short, the eye may thus be trained to read the sound wave, and, whilst radically different voices may speak the same word and transmit it with varying vibrations through the same circuit, the characteristic form of vibration remains. The amplitude may vary with the tone and the wave period may vary with the rapidity of enunciation, but the characteristic shape remains readily recognizable.

It will be seen that where it is advisable to have a record day by day, or month by month, of the voltage of the system at a given point, recording instruments are almost invaluable; they are, for example, frequently used to determine the voltage fluctuations at the ends of feeders, etc.

Graphic recording ammeters are useful in determining the load characteristics at given points. It may be important, for example, to determine whether at some time during the day the energy delivered at a given portion of the circuit is extremely high in relation to the average, and if so at what time this occurs.

When alternating current service is involved a wattmeter of the curve drawing type is even more valuable and important.

For purposes of general rough measurement, structures involving the use of the paper disk for record are common and generally satisfactory; but where greater precision is required, and especially when it may at times be desirable to integrate the result of a day's performance by means of the planometer, the unidirectional paper ribbon is to be preferred since obviously the use of the planometer is not possible on a paper disk on which the lower values of the scale are moving at a lower rate of speed than the highest values.

It seems necessary to devote but few words to the consideration of integrating meters, or, as they are known in the art, "recording meters." The purpose of the recording meter is naturally to record the power-time units delivered to a given point of consumption, generally to determine the charge basis, as in the case of the gas meter. Such structures are of course used for other purposes also, notably upon switchboards for the determination of the gross output from generators or over feeders. In the latter connection the record of such meters is frequently used for checking the efficiency of the generators against pounds of coal consumed, or the losses of the distribution system by checking against the sum of the consumers' meters.

In the early days of the art substantially all recording meters were ampere hour meters, and they were constructed in almost numberless physical forms.

During the days of the ampere hour meter (they are still in use in some parts of Europe), electrolytic meters of various types were exceedingly common, as, for example, the so-called Edison meter, which depended for its record of ampere hours used upon the electro-deposition of metal from one plate to another, the increase in the weight of one plate, or the decrease in the weight of the other being the measure of the number of ampere hours passed.

Clocks were used whose speed was varied by the amount of current passing, a differential gearing giving the record.

In alternating current primitive split-phase induction motors were resorted to, utilizing such a form of construction as to result in speed varying directly with the current, the propelling mechanism being retarded by an air vane load.

Such hundreds of mechanisms might be described thus briefly as having been in some measure current in some period in the art during the past twenty-five years.

The ampere hour as the unit of measurement could not endure and will probably never be introduced for general purposes, because the true measurement of output—that is, the value that measures the input into the plant—is power, horse powers or fractions of horse powers, and obviously, the ampere hour was not a measure of this, except when delivered at a fixed voltage. Even in direct current the voltage is literally never constant, and when alternating current became, as it has become, practically universal, the question of power factor rendered resort to the "watthour" as the value unit quite unavoidable.

The established recording meters of 1910 are substantially without exception, recording watthour meters, and are, as the result of economic evolution, practically all constructed on the electro-dynamic principle. It is probable that there are in use in the United States today not less than two and a half million recording electricity meters of the electro-dynamic type, commonly referred to as "motor meters."

For direct current such meters generally have a wound field and a wound armature, the armature being in series with a high resistance and responding to fluctuations of potential, the fields being fixed and generally in direct series with the load and consequently responding to fluctuations of current.

The torque of such a meter is obviously dependent upon the product of the concurrent volts and amperes, or the true watts on the system.

The torque of such a mechanism is directly proportional to the watts imposed upon it, and therefore the restraining force must constitute a load increasing directly with the speed.

Good modern practice has demonstrated, by a process of engineering elimination, that in such structures, i.e., motor type meters for use on direct current, the speed through the range within which accuracy is to be expected should not be less than one and one-half or more than thirty revolutions per minute.

It is good practice to prescribe that recording meters for general use shall have no error in excess of five per cent. at any load between five per cent. and one hundred and twenty-five per cent. of the meters normal rating. The full load torque of such meters should be guaranteed to be not less than one hundred and fifty grammes, millimeters.

Since the moving elements of such structures rotate upon step bearings, and since the weight of these moving elements ranges from one hundred to three hundred grammes, it is obvious that the nature of the fixed bearings and the material from which these are made, plays an important part in the permanent good behavior of these devices.

At the present time but two good materials are known for this purpose, and it is usual to specify that the bearing jewel shall be either of sapphire or diamond.

It is interesting to note at this point and in this connection, that the contact area of the rotor of such motor meters is so inconsiderable that the actual pressure upon the step bearing is about two hundred tons per square inch. A noteworthy fact in view of the delicate nature of the mac ine.

Meters of this type may be readily calibrated by moving the damping magnets radially in relation to the damping disk, and calibration through a range of 10 per cent. can generally be thus accomplished.

In testing it is usual to connect a load to the meter in series with an ammeter, and place a voltmeter in multiple upon the system.

The volts multiplied by the amperes then give the true watts; by using the simple formula:

$$S = \frac{watts}{3600 \times constant}$$

the speed at which the disk should revolve in revolutions per second is obtained. The speed of the disk should now be obtained with a stop watch, and such corrections made as may be required.

It will be noted that a constant is introduced in this formula; it is so introduced because a very large number of the meters in common use utilize a dial constant. The constant is used for the purpose of keeping the speed range of the structure within the theoretical limits indicated by good mechanical practice. In some cases the constant is eliminated at the dial, this elimination being dependent upon the gear ratio. In other cases it is not so eliminated, and in such cases it is necessary to multiply the reading of the dial by the constant. In all cases the constant of the meter will be found marked upon some portion of the structure.

Alternate current meters differ radically in mechanical features from the direct current meters, but in essentially no electrical details.

The motor mechanism consists essentially of a split phase motor, having current and potential coils, both fixed, however. The actual rotor or armature consisting of a disk in which Foucault currents are induced, dependent upon the inductive coercion of the coils, responding to true watts.

The restraining mechanism, as in direct current watt hour meters, is a Foucault current disk or cup, and for mechanical convenience the motor armature and restraining armature are usually one, thus securing a lighter moving mechanism.

The weight of the moving element in alternating current meters being materially less than in direct current meters, it is unnecessary to provide so considerable a torque, and it is considered good modern practice to specify full load torque of 75 grammes milli-meters for single-phase, and 150 grammes milli-meters for polyphase inductive type alternating current meters.

The method of testing alternating current meters is essentially the same as for direct current meters, save that it is customary to use a portable indicating wattmeter instead of the voltmeter and ammeter; or in connection with either direct current or alternating current meters, a portable calibrated load, with a voltmeter, may frequently be resorted to as a convenient expedient.

It seems scarcely necessary to say that both direct and alternating current meters are used today in a very great number of modified forms, according to their application.

In the case of switchboard meters, especially where very large values have to be measured, alternating current meters are usually used with current coils in the secondary of current transformers, and potential coils in the secondary of potential transformers; frequently the transformers are the same as those used in exciting the switchboard instruments.

Direct current meters for the measurement of large values are almost without exception designed to be connected directly in series with the circuit to be measured; this fact, by reason of the large masses of copper involved, seriously modifies the physical design of the structure, but in no case is the inherent principle involved affected.

Sustained, rather than initial accuracy differentiates the good from the bad recording meter, and it is therefore peculiarly necessary in connection with recording meters to prescribe accurately the qualities which the meter shall embody, since no initial test can be relied upon to determine what the behavior of the structure will be at a relatively early subsequent time.

No other branch of the electrical art seems to have developed along two parallel lines more clearly divided than the instruments and meter art.

In all of this group of machines the moving forces are at best very small, the work done minute, and therefore friction, (a constant variable,) is the real enemy of accuracy. This is true of indicating instruments, but most noticeably true of recording meters.

One school of engineering has developed along the line of the creation of structures of the greatest refinement, in relation to the minimizing of friction and the reduction of weight of the moving parts. This school obviously drifted towards continually greater structural refinements of finish, and speedily brought itself into the field of mechanisms involving the jeweler's and the mathematical instrument maker's skill.

The other school, and the essentially American school, whilst it gave due importance to the minimizing of weight and initial friction, gave paramount importance to the securing of high torque, and *high load*. Its purpose can best be stated by a physical example. If the coercive mechanism of the meter be constructed to do, at a given point of its load, one thousand units of work, and if the restraining mechanism or load be accordingly made to dissipate (consistent with the same law) nine hundred and ninety units, the remaining ten units of work being expended in overcoming friction in the initial condition, then a doubling of the friction affects the total load but one per cent., and introduces but that error into the instrument.

Such a structure is therefore obviously better than one in which the work at the same load as above is one hundred units, (limited by the effort to secure light moving weight) the work done being distributed in the ratio of ninety-five units in the restraining element (load) and five units for initial friction. In such a structure the initial friction is but half that of the more rugged mechanism, but the doubling of this friction in service results in the introduction of a five per cent. increase in the load and a corresponding deviation from accuracy.

These two examples may be said to exemplify the character of the two schools under which development has taken place in the electrical measuring device industry, and it is unnecessary to say that the school which provides the robust, well constructed, high energy machine has prevailed over that which demands ultra-refinement of construction and of care.

Appendix.

1. Modifications of the marir r's compass, on simple galvanometers, consisting of a polarized movable element under the influence of a coil or coils, carrying the current to be measured. This is the earliest group.

2. Solenoids.—Dependent upon the pull of a coil or coils on an iron plug or armature acting against gravity, a spring or other restraining force.

3. Magnetic repulsion instruments having iron, consisting of a movable and a fixed piece of soft iron, both situated in the same field, consisting of a coil or coils carrying the current to be measured. Both pieces of iron being polarized in the same direction tend to repel each other, this force acting, as in all of the instruments of the mechanical group, against some restraining force.

4. Magnetic vane instruments.—Consisting of a vane or armature of soft iron, constituting the moving element, and placed within the influence of a coil or coils carrying the current to be measured. The normal position of the magnetic vane at no load is across the magnetic path created by the current in the coil or coils, the tendency being for the vane to place itself parallel with or in some cases to surround the field created by the passage of current through the coil.

5. A fixed and a movable coil or coils, sometimes with, but generally without iron—a development of the Siemens dynamometer. The movable coil tends to place itself either at right angles to, or in the same plane with the fixed coil, depending upon the relative direction of current in the two coils. This principle may obviously be modified to provide for one fixed coil repelling and another fixed coil attracting a movable coil.

6. A movable coil or conductor, with or without iron, situated in the field of a magnet, the movable coil tending to take a position at right angles to or parallel with the flux of the permanent magnet, depending upon the direction of current in the moving coil—a development of the D'Arsonval galvanometer.

7. A movable coil or conductor, commonly with a small number of turns and frequently consisting of a disk or sector instead of a coil, constituting a short circuited secondary in the field of a coil or coils carrying the current to be measured. This device is operative on alternating current only. The movable short circuited coil or sector tends to move in relation to the fixed coil or field, exerting force in opposition to the restraining force of a spring or gravity.

These classes, Groups 1 to 7, inclusive, constitute what might be termed the dynamic group.

It will be noted that of these four groups, 1 to 4, consist of instruments having a moving element carrying no current, and are therefore free from conductors. Groups 5, 6 and 7 have moving wire carrying current, necessitating the introduction of flexible conductors or collectors.

We now come to a series of somewhat indefinite groups, which may be broadly classed as temperature instruments, in which the position of the needle or indicator is governed by a change in temperature; in short, thermometers applied to electrical measurement by resorting to structures, the temperature of governing parts of which will vary with the current to be measured. There are in this general class the following groups, which unfortunately are less well defined than the genera of the dynamic group.

8. A thermometer surrounded by a conductor whose temperature varies with the current, the scale of the thermometer being graduated to indicate the current causing any given temperature. Such instruments, in common with most of this class, are dependent upon a fixed room temperature, unless a correcting constant or means for mechanical correction be provided.

9. Instruments in which the position of the needle is dependent upon the expansion or contraction of a conductor due to changes of temperature in that conductor, caused by the current passing through it. A well known type of this group is the Cardew voltmeter.

10. Thermostats provided with an indicating needle, and in which either the moving element consists of a metallic and a non-metallic substance with differential co-efficients of expansion, the metallic elements carrying the current, or the moving element consists of two metals of different co-efficients of expansion connected in series, and carrying the current. A third form consists of a simple thermostat heated by radiation from a fixed coil, the moving element carrying no current.

There is one principle which has been used in electrical instruments which is more commonly seen in pure thermostats. It falls within the next group.

11. This principle is the development of pressure within a confined space, due either to the expansion of gas or fluids under temperature increases, or to the volatilization of a fluid having a low boiling point. The generated pressure may either expand a diaphragm forming a portion of the walls of the receptacle retaining the gas or fluid, or may cause the straightening of a bent tube containing a volatile fluid or gas, as in a common form of thermostat. In the first form motion is communicated to the needle as in a steam gauge or an enaroid barometer, in the second form by the direct attachment of the needle to the bent tube.

There are other instruments falling within the thermal class which hardly come within the scope of the definitions I have cited. They are unimportant and are intentionally omitted.

12. Electrostatic instruments.—These comprise a single family and genus. They consist of practical applications of the electrometer and several practical forms. Two or more plates are symmetrically arranged in two, or in some cases three, groups. One group is attached to one pole of the system under measurement, and the second to the other pole. The moving element consists of a light metallic vane having capacity large in relation to its mass. The tendency of the moving vane is to place itself with its greatest length parallel to the shortest path between the plus and minus fixed plates. Another form has one or more fixed plates attached to one pole of the system to be measured, and a movable vane attached to the other pole. The tendency in such a structure is for the movable vane to place itself parallel with the shortest path between the fixed plate or plates and the point of attachment of the movable plate or plates.

Instruments of this class are largely used for the measurement of very high potentials where the conducting of current through a coil, moving or otherwise, would be attended either with grave practical difficulties, or with material physical danger to the structure or human life, or with an unnecessary expenditure of energy.

We now come to a class of instruments in which the actuating force of the needle is derived from an independent source, and its application to the moving element is only governed, either in volume or in period, by the current to be measured. We have in this class two general groups:

13. The first being a source of air or fluid pressure, controlled in intensity by a valve; for example, a reducing valve electrically controlled, a source of air or fluid pressure and a pressure gauge.

14. The second group comprises a clock or its equivalent, directly connected to a

needle. In such a structure the clock is started by the current and drives the needle forward over the scale until the torque of a spring connected to the hand balances the coercive force of the measuring coil, at which point the relay contact is broken, causing the clock to stop with its needle upon the value reached. This device is a modification of the balance, and is practically a weighing machine. Unless still further modified the needle remains upon the highest reading reached during use.

We now come to a class of instruments rarely used as working instruments of position, but very generally used for secondary or bench standards. These are balances, structures incapable of indicating the desired measurement without manual manipulation. They are in two general classes:

15. Instruments in which a definite torque is produced by resorting to any of the structures heretofore described (but generally to a fixed and movable coil or coils). This torque is manually balanced by the winding up of a spring, as in the Siemens dynamometer, or by the manual adjustment of a counterweight, as in the Kelvin balance the position of the needle attached to the spring manualy wound, or the position of the weight manually adjusted, being read. Such readings may be direct, but for convenience are more commonly arbitrary, and are multiplied by a known constant.

16. Finally we have instruments designed to be brought to zero, used in conjunction with a Wheatstone bridge.

A NEW METHOD OF COLOR TESTING

By R. B. Hussey

In connection with the general investigation of candle-power distribution and the efficiency of different luminous sources, the writer has been trying for some time to find a method of determining and expressing the color of any light. The result sought was not so much the physical composition of the light as it was the everyday effect or common usefulness of the given light.

As a physical problem, the color of a light source may in general be determined by the use of a spectrophotometer, where the spectrum of the light under test is compared section by section with the spectrum of any desired standard. This process, however, is long and tedious and requires somewhat elaborate and special apparatus; and the results, while of considerable interest as a physical determination, are of less value when the apparent and commercial values of lamps are sought. For practical purposes the value of a light source is determined not so much by the particular wave lengths present as by the apparent effect of the light on ordinary goods; not on white goods alone, since it is possible to have a lamp, for instance, such as the mercury vapor lamp, which will give good results where nothing but black and white is viewed, but which will badly distort nearly every separate color. As it seems to the writer, the practical criterion must be the effect on white and on colored material and in order to get some definite comparative figures, the following method has been tried and found to give good results.

In this method an ordinary Lummer Brodhun comparison photometer head is employed, and in place of the usual white screen a series of colored screens are used, each consisting of an opaque slide covered on both sides with colored paper. A set of sixteen colored papers was selected, of as near pure colors as it was possible to obtain, and extending through the range of the spectrum from the red to the violet. Particular care was taken to have both sides of each slide covered with paper of the same hue.

If the two lights under comparison are of the same color, the reading obtained will be the same whatever color of screen is employed, provided, of course, that the screen is of the same color on both sides; but if the lights are of different colors, a reading will be obtained which will represent the relative effect of the two lights on the particular color used. It is, of course, impossible to obtain colored paper or any colored material with pure spectral colors, and in the papers used in this test it is quite evident that the violet contains a considerable amount of red. But since this lack of purity is a general and, it may almost be said, an unavoidable condition, effort should not be made to entirely eliminate its effect, inasmuch as the end sought is, as noted above, the apparent effect produced on colors in common use.

After having obtained readings of the intensity of each of the colors of a luminous source as compared with that of a convenient working standard, it becomes an easy matter

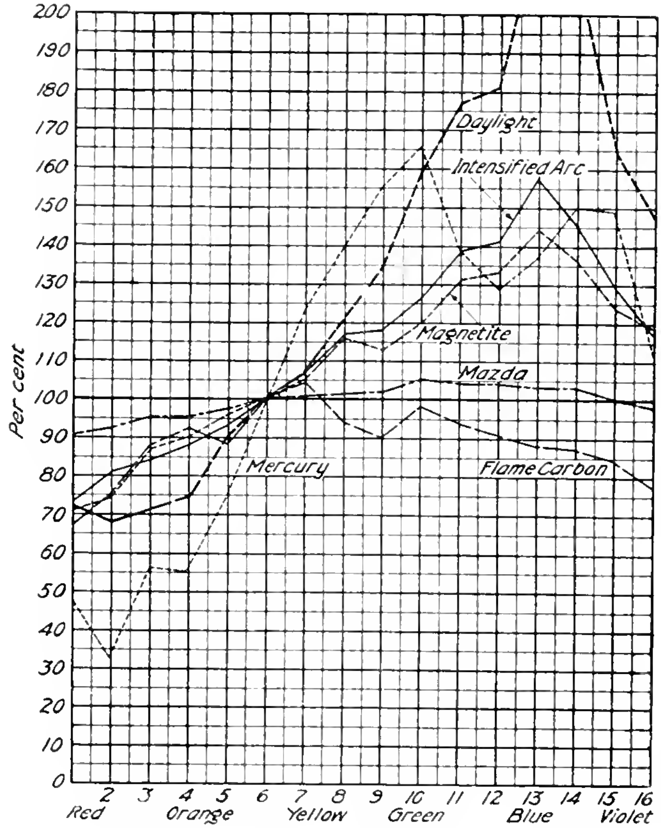


Fig. 1. Analysis of the Light Produced by Various Illuminants

to reduce these to terms of percentage values of the standard, taking any desired point as a basis (100 per cent.). In order to make the results more nearly comparative with ordinary spectrophotometric curves, the color (No. 6) that seemed to be nearest the color of the sodium flame (D line) was chosen as the basis and all the curves brought to 100 per cent. at this point. After a number of different lamps have been tested, any one may, of course, be chosen as the standard, and the others figured to that as a basis of reference.

The diagram of Fig. 1 shows the results obtained from tests on several common forms of lamps, as compared with a carbon incandescent lamp running at 4 watts per horizontal candle.

In the case of arc lamps, the test was repeated several times with different observers in order to get an average result that would be somewhat independent of the variations in the arc, and also to eliminate largely the differences in the eyes of different persons. It may be said, however, that among those who have taken these readings there have been only comparatively small differences. All the observers were men who had done considerable photometric work and were familiar with the apparatus. In order to reduce the chances of an error creeping in from the so-called "Purkinje effect," the intensity on the screen was kept at a reasonably high figure and not far from the same value for all lamps. The range of intensity was from 1 to 3 foot candles.

In addition to tests on a number of different commercial lamps, tests were also made to determine the comparative color value of daylight. The variation of intensity and color in ordinary daylight is so marked that it was necessary to take a large number of readings under as many conditions of sky and weather as possible. The curve for daylight as given represents an average of readings taken in summer and winter from clear and cloudy sky, with and without direct sunlight. From these daylight value the curves taken on commercial lamps have been reduced to the daylight basis, so that each represents the color value of the particular

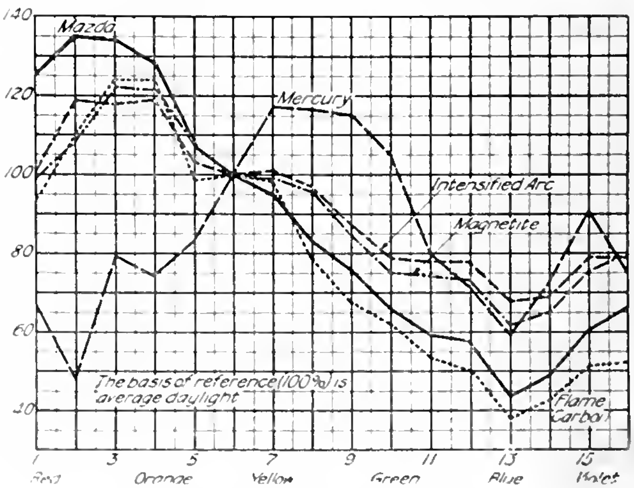


Fig. 2 Analysis of the Light Produced by Various Illuminants, as Compared with that of Daylight

luminous source as compared with daylight, which is the normal standard.

MOTOR DRIVE IN A BOOK BINDERY

By F. J. Chisolm

The Williams Book Binding Company, of 40 Rose St., New York City, was organized in 1889 by George T. and W. J. Williams. At that time two machines were used to assist in the hand work and power for the plant was obtained from a vertical shaft driven by a Corliss engine located in the basement. This shaft passed through the various floors and to it was belted the horizontal shafting. The ceilings were obstructed with shafts and belts which became an increasing annoyance owing to loss of production from damage by oil and dirt. The breaking of belts and consequent delays, and the lack of flexibility in obtaining variable speeds resulted in the adoption, in 1898, of the electric drive.

At present a 40 kw., 250 volt, 650 r.p.m. generator supplies current to the various motors and to the lighting system of the plant. This generator, which is mounted on the ceiling as shown in Fig. 1, is belted to a horizontal shaft provided with a friction clutch, this shaft in turn being belted to the vertical shaft mentioned above. By means of the friction clutch the generator may be started or stopped from the floor below.

Fig. 2. General View of Fourth Floor

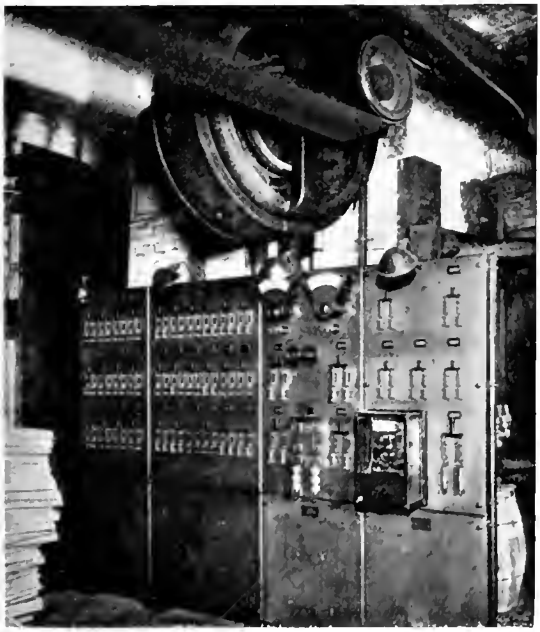


Fig. 1. 40 Kw. Generator and Main Switchboard

Fig. 1 also shows the main switchboard, which is located directly beneath the generator. The generator panel (second panel from right hand end as shown) is provided with a main line switch, a 300 scale voltmeter, a 200 scale ammeter, a field rheostat controlling handle, and several smaller switches for the 230 volt lighting circuit. The panel to the extreme right is a feeder panel for the 230 volt lighting circuit and also feeds the fourth floor distribution board (Fig. 2). A Thomson astatic totaling wattmeter is mounted on this panel and has been found to be a source of valuable information as regards the power requirements of the plant. The two remaining panels serve as distribution boards for the lights and motors of the fifth, or generating floor.

A battery of six Dexter folders with mechanical feeders is shown in Fig. 3. The motors for these folders are started and stopped by means of two-button push buttons, six of which are located at different points about each machine, so that the attendant may stop or start the machine from any position. These push buttons control an automatic starter for the motor. A field rheostat is also installed, and by setting this the foreman in charge can arrange for any given speed, so that the attendant need only operate the controlling buttons. The automatic starter, field rheostat, main line switch and fuses are mounted on a slate panel set up within the framework of the folder, but not visible in the cut.

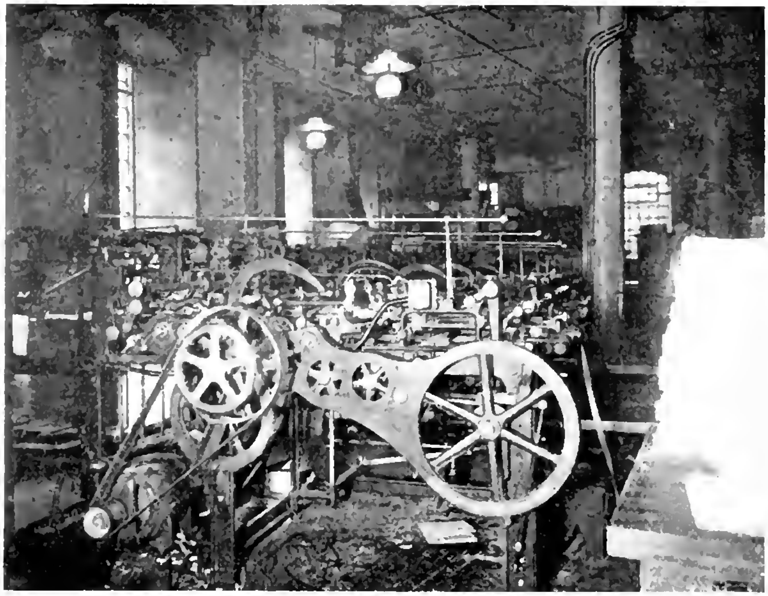


Fig. 3. A Group of Six Dexter Folders Fitted With Mechanical Feeders

Fig. 4 shows a cutter, the attendant of which is working busily. The motor for this machine is started and stopped about once in every ten minutes. The apparatus is self-explanatory.

The makers of the pasting machine shown in Fig. 5 did not believe that this piece of apparatus could be operated by a motor because of the fact that it had to be stopped quickly and would require an unusually strong man on the brake. A motor, an automatic starter, and a dynamic brake made this machine manageable by a girl attendant, who needs only to push the control button.

A rounder and backer is a slow moving machine used for rounding the back of a book. As ordinarily equipped, the electrical application consists of a hand operated rheostat, a motor, and a foot switch to open the holding coil of the rheostat when the brake is worked. When it is desired to reverse the machine, the flywheel is pulled back by hand. Fig. 6 shows an arrangement by means of which considerable time is saved both in the frequent use of the hand starting rheostat and in the cumbersome method of pulling back the flywheel by hand. The reversing switch, when moved from the vertical, will cause the automatic starters to operate, thereby energizing the motor. The foot brake is made in the form of a lever and is so connected to a contactor that when the lever is pressed down, the circuit will open at the time that attendant's weight comes on the flywheel; the operation being the same when the machine is reversed. The attendant

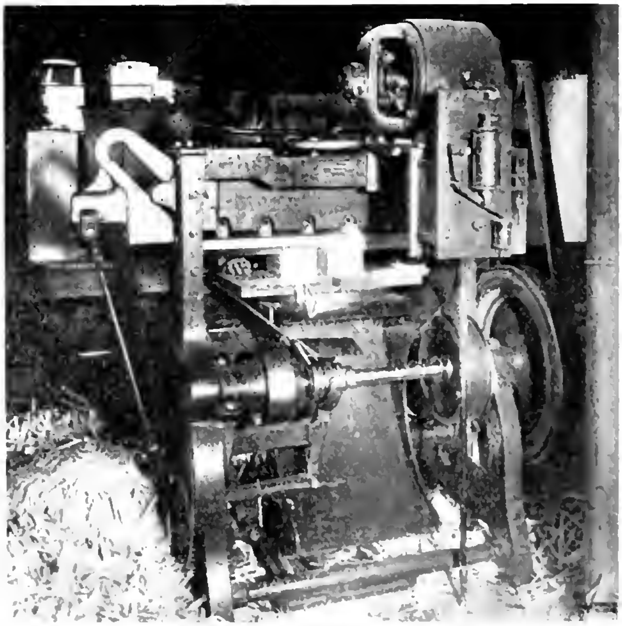


Fig. 4. Paper Cutter

keeps his foot on the brake most of the time. A field rheostat enables the foreman to set the speed for the output desired; this may vary from 30 to 90 books an hour according to size, shape and weight of material.

A very interesting machine is that which, from its function, is known as the gatherer. A book is usually made up of sections which will ordinarily vary in number from 25 to 60. It is the purpose of this machine to gather these sections in proper order so that when delivered the pages read consecutively. The starter for this gatherer is mounted on the far wall, as shown in Fig. 7, the operating buttons being located on the machine at the receiving end. The motor is mounted on pipe supports, out of the way, as shown.

About 35 motors varying in size from 1/4 h.p. to 5 h.p. are now installed in this plant. Small motors of one horse-power or less, operating machines which require practically no starting torque, are compounded and thrown across the line. These motors are started by 3-way snap switches which give full field before the armature is switched onto the line; this arrangement obviating considerable trouble from the blowing of fuses.

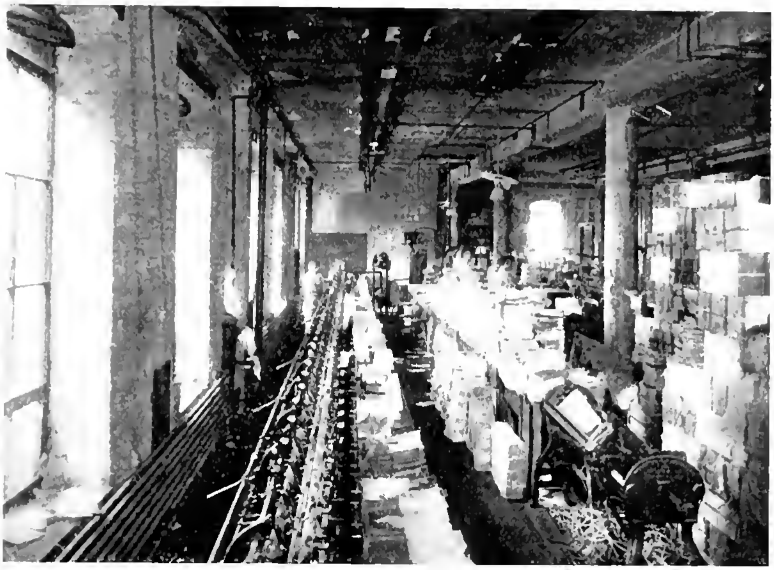


Fig. 7. Gatherer

Nearly all motors larger than one horse-power are provided with automatic starting devices, the result of which is an increase of 15 per cent. in the output for a given number of men and machines. This increase in production has not been due alone to the speeding up of various machines, but to the time saved through not having the employees concerned with starting the motors.

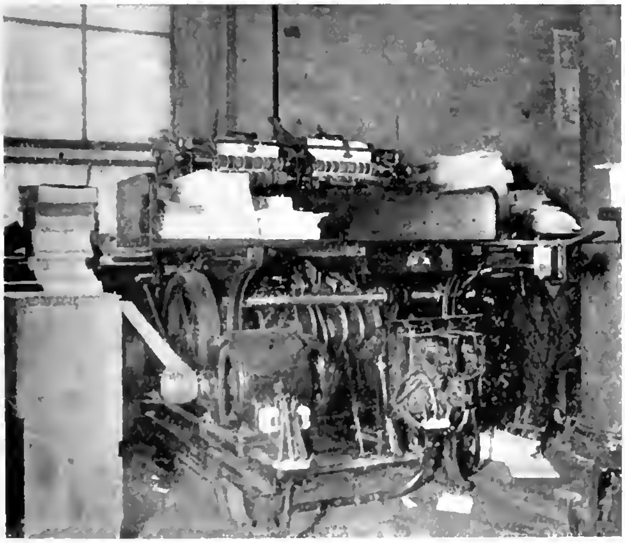


Fig. 5. Pasting Machine

At first, when hand operated rheostats were used, the girl attendants would pull away from a rheostat handle when a spark occurred; several attempts usually being made before the lever was finally set on the holding coil. The male attendants, on the other hand, would hold the handle on a point until smoke came from the rheostat, when they would let the handle go and wait for the rheostat to cool. It was to eliminate these losses that the company installed automatic starting devices and the results have more than justified the expenditure.

Before the addition to the switchboard equipment of the totaling wattmeter mentioned previously, it had been the custom of the company and the owners of the building to arrive at an agreement as to the probable power requirements and to draw up a contract accordingly. The wattmeter showed a 25 per cent. smaller average load than that agreed upon and a corresponding reduction was made in the price for power.

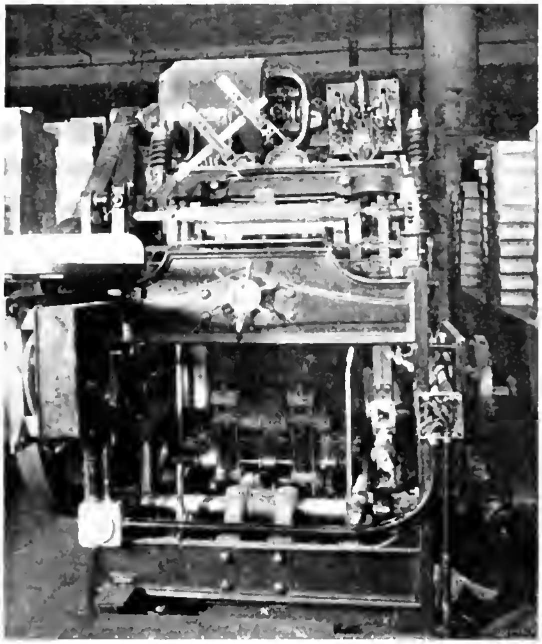


Fig. 6. Rounder and Backer

For service of this kind, motors of at least 25 per cent. greater capacity than ordinarily required for driving the machines must be used, in order to provide a reserve when starting on weak field. The variation of field strength in this installation was between normal and 60 per cent. As stated before, many of these motors were compounded to obviate the bad effects of starting on weak field, and with this precaution no trouble has been experienced in operating the motors.

The electrical equipment of this plant is of General Electric manufacture throughout.

THE VOLTAGE CONTROL OF GENERATORS AND FEEDER SYSTEMS*

By F. W. Shackelford

In our consideration of this subject, we will discuss only alternating current system, as this system is the one most commonly in use.

The study of central station conditions may be classified under three heads:

1st.—The source of energy.

2nd.—Its generation.

3rd.—Its distribution.

The first of these has no part in this paper, but in the construction of a station it bears a most important relation to the second. The selection of the kind of energy; that is, whether coal, gas or water power, will, of course, depend upon the existing conditions; but I wish to point out that this selection is made only after a most careful consideration as to economical operation. The generation of electrical energy comes most vitally into our consideration, and to a large extent the form of generating units will be dependent upon the system decided upon in the first case.

Assuming that the speed and regulation characteristics of the generating units have been most carefully selected, we are still confronted by the fact that the station may be required to deliver current not only for lighting but also for power and electric railways. The power and railway loads can, in general, be readily handled during the day hours, but will always conflict with the lighting peak, and during the winter months considerably overlap it. Many plants are required to furnish lighting during the entire day and are consequently more difficult to handle. Without some form of automatic voltage regulator it is impossible to take care of the heavy swings in voltage caused by fluctuating power and railway loads. Even in the case of purely lighting loads it is an exceedingly hard matter to take care of the voltage properly by hand regulation, and especially so at peak load. It is essential, therefore, for good service and economical operation of the generators to automatically control their voltage.

Accurate generator voltage regulation means that the exciters and generators shall deliver energy in exact proportion to the demands made upon them. A slight increase in voltage of a large station means increased

*Paper read before the National Electric Light Association, St. Louis, Mo.

losses in transformer cores; likewise a decrease in voltage at maximum station load means actual losses in revenue.

Many forms of generator voltage regulators have been developed, but on account of the many variable elements entering into the problem, few have met with any great success.

Regulators have been designed which operate directly on the alternating current generator field rheostat by varying the resistance. Such a scheme may be made to give fairly good results where only one generator is concerned, but at best it is sluggish and not anti-hunting. With any such scheme it is impracticable to operate two or more such devices in parallel where more than one generator is operated on the same 'bus, on account of hunting and cross currents.

It is always best from the standpoint of regulation to operate both the generators and the exciters in parallel, or groups in parallel, by which arrangement it is possible to regulate all of the machines from a single regulator.

The most successful and best known devices for this purpose are the General Electric Type TA generator voltage regulators.*

These regulators are now designed with from one to twenty-four relays, and I believe it would be safe to say that with a properly designed station equipment the largest regulator would take care of an output of from 50,000 to 60,000 kilowatts.

Before leaving this subject it might be well to mention that, by installing one regulator on each side of the system, this type of regulator has been adapted to the control of direct current stations and has also proven most successful in the control of three-wire direct current systems where the neutral is derived by using two 125 volt generators.

These regulators have also been adapted to the control of power factor and have been used successfully on long transmission lines in connection with synchronous condensers for boosting the power factor and the voltage.

We now come to the third consideration, namely, that of the feeder systems of distribution.

It would seem as though in some instances, after the power and generating plant had been constructed and the lowest cost per kilowatt obtained at the switchboard, the feeder systems had been laid out indiscriminately. It should, however, be borne in mind that a station may lose in the feeding system that which has been saved by carefully designing and selecting the prime movers and generators. It is in the feeding system and the distributing network that we suffer the greatest losses, having to consider both transformer losses and the loss in the lines. Without regulators it becomes a question of

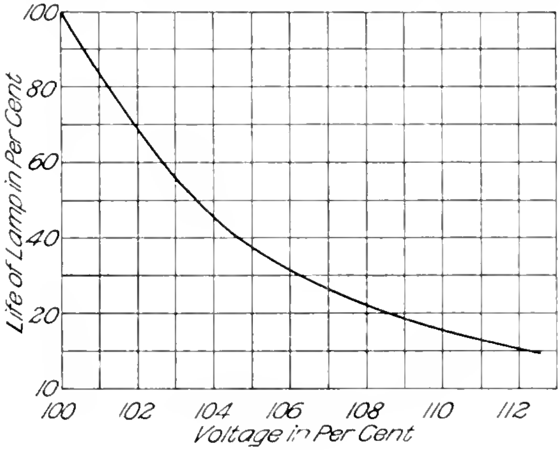


Fig. 1

putting up not the most economical copper but copper of such section as will take care of the drop within at least 2 per cent.

Such a large section of copper could in a great number of cases be avoided by the use of regulators, and it is therefore a question of the cost of copper required to keep the drop within limits, as against the cost of the most economical copper plus the cost of regulators.

Considering that a station has designed its feeders for a 2 per cent. drop to the centres of distribution, we also find it necessary to deal with the fluctuations on each individual feeder, which cannot be compensated for even by increasing the copper.

In any city of average size, we have three distinct groups of lighting consumers:

1st.—Business.
2nd.—Manufacturing.
3rd.—Residence.

It is practically impossible to regulate the voltage of the generators at the station so that the voltages at the centres of distribution in each of these three divisions are approximately normal. The lighting of the business section in nearly every case demands first attention, and as its load is generally at peak in advance of that of the others, its voltage could be maintained fairly well, while that of the other sections would, with few exceptions, be above normal.

The curves will serve to give you a clear idea of the performance of incandescent lamps.

*A description of these regulators will be found in the REVIEW for June, 1909.

Fig. 1 shows the life of the lamp in percentage, the normal life being taken at 100 per cent., at 100 per cent voltage. Fig. 2 shows the power consumed by a lamp in percentage, corresponding to the voltage in percentage. Fig. 3 shows the candle-power of a lamp corresponding to the percentage of voltage applied to its terminals.

It will be noted that the life of a lamp is affected most seriously by increases of voltage. This becomes a source of much expense to a station giving free lamp renewals and much trouble to those that do not supply lamps free, as it then becomes a burden on the consumer, which in turn reacts on the station.

The useful life of a lamp at 4 per cent. excess voltage is only 45 per cent. of the life at normal voltage.

On the assumption that the average lamp is operated at 4 per cent. excess voltage for one-half the time, and at normal voltage the remaining time, this condition would decrease the life of the lamp by one-third. On the further supposition that each connected lamp is used two hours per day, 300 days per year, and that the average useful life of a lamp is 800 hours, the excess cost of lamp renewals is shown in the following tabulation:

Total Number of Lamps Connected	Total Lamp Renewals at Normal Voltage (800 Hours)	Total Lamp Renewals Under Conditions Given (532 Hours)	Cost of Excess Renewals Taking Cost at 10 cents per Lamp
10,000	7,500	11,200	$370
20,000	15,000	22,400	740
30,000	22,500	33,600	1,110
40,000	30,000	44,800	1,480
50,000	37,500	56,000	1,850
100,000	75,000	112,000	3,700
500,000	375,000	560,000	18,500
1,000,000	750,000	1,120,000	37,000

By reference to Fig. 2, it will be noted that the decrease in power consumed by a lamp at reduced voltage is in the ratio of 2 to 1, that is, a 2 per cent. drop from normal voltage results in a 4 per cent. loss in power.

This fact may be insignificant when considering a single unit, but its importance will be appreciated by the tabulation given below, which shows a direct loss to a station without beneficial or compensating features.

Assuming, as in the previous case, that each lamp is used two hours per day, 300 days per year, and that the voltage is maintained at normal one-half the time and 4 per cent. below normal the remainder (which latter condition would necessarily occur at peak load), the average loss in power for the total time

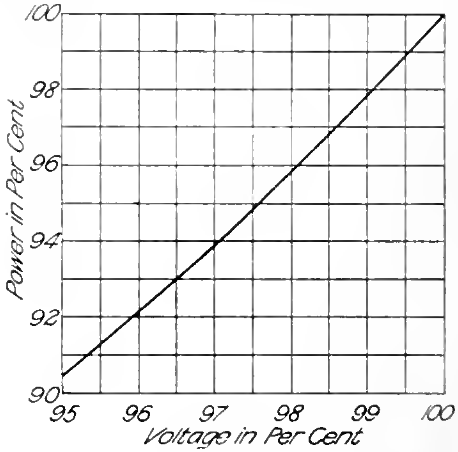


Fig. 2

is 4 per cent. On the basis of using 56 watt lamps, and taking the average selling price

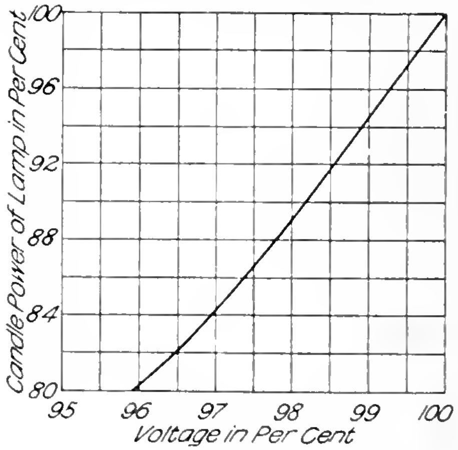


Fig. 3

per kilowatt hour at nine cents, the loss per year is as follows:

Total Number of Lamps Connected	Anticipated Revenue per Year	Lost in Revenue per Year Resulting from Above Condition
10,000	$30,240	$1,209
20,000	60,480	2,418
30,000	90,720	3,627
40,000	120,960	4,836
50,000	151,200	6,045
100,000	302,400	12,090
500,000	1,512,000	60,450
1,000,000	3,024,000	120,900

The candle-power of a lamp is affected most seriously by a decrease in voltage, and because of the poor and variable illumination is often the cause of righteous indignation on the part of the consumer. The watchword of any station should be "good service," whereby is gained satisfied customers and increased business.

Feeder circuits, like individuals, have their own characteristics, and when the load on a feeder becomes of importance it is necessary to regulate it individually.

It is apparent from the foregoing that the need of regulation would develop many schemes for correcting voltage troubles. Some of the schemes proposed embody the use of a permanent boosting transformer to take care of peak conditions, or the use of two transformers, one with saturated and the other with unsaturated cores, the primaries opposing and the secondaries in series, thus boosting the voltage as the load increases. Each of these schemes present several objections, which I believe are so well understood that it is unnecessary for me to take up your time in explanation of them.

Of all the methods tried, that of a variable ratio transformer is the only one which has given satisfaction. This may be a standard transformer with primary in shunt and secondary in series with the circuit to be controlled, the secondary being provided with a number of taps which are connected to a dial switch or controller, so that the line voltage may be raised or lowered as required. The induction type of regulator is essentially a variable ratio transformer but, instead of the voltage being raised or lowered in a few steps, the voltage is adjusted by almost infinite steps.

Such devices may be hand, motor, or automatically operated. The hand and motor operated regulators, however, are necessarily dependent upon the station operator for service, while the automatic regulator, when once adjusted for line conditions, is always on the job.*

Now, as to the method of applying such regulators to different systems, it will be necessary to discuss briefly the following systems of distribution.

1st.—Single-phase.

2nd.—Two-phase, three-wire and four-wire.

3rd.—Three-phase, three-wire and four-wire.

* Descriptions of these regulators will be found in the issues of the REVIEW for July, 1908 and June, 1909.

Single-Phase System of Distribution

The single-phase system of distribution is very simple and has been widely used in the past for lighting circuits. In such a system it is only necessary to supply one single-phase regulator to each feeder.

Two-Phase System of Distribution

The two-phase system of distribution may be divided into two classes; *i.e.*, two-phase three-wire, and two-phase four-wire. The two-phase three-wire system possesses an advantage over the single-phase in that it can take care of a power load as well as a lighting load. In applying regulators to such a system it is necessary to use two single-phase regulators, since under certain conditions the load on one phase tends to unbalance the voltage of the other phase.

The two-phase four-wire system, which is established by inter-connecting the phases at the middle point or by maintaining the phases entirely separate, is an improvement over the two-phase three-wire system. It is preferable to operate the phases entirely separated, and the application of regulators is made by installing a single-phase regulator on each phase in cases where the phases are not balanced, and by using a quarter-phase regulator where the phases are practically in balance. In some stations it is advantageous to use both methods of regulating, though this is an exception to general practice.

Three-Phase System of Distribution

The three-phase system of distribution can be either three-wire or four-wire. In applying regulators to a three-phase three-wire system it becomes necessary, in case the three phases are unbalanced, to employ three single-phase regulators, one in each phase. Wherever practicable, however, it is advisable to use only one phase of a three-phase feeder to handle the lighting load, installing a regulator in this phase and letting the other two phases shift for themselves. Where a three-phase power load is regulated it is desirable to distribute the load so as to maintain as nearly as possible a balanced system, and therefore to use a three-phase regulator for controlling it.

Where the three-phase four-wire system is used, it is generally necessary to employ single-phase regulators, one in each leg, operating between this leg and the neutral wire. However, by properly balancing, it is possible to employ a single three-phase regulator on each feeder.

THE ELECTRIC LIGHT PLANT AT MUKDEN, MANCHURIA*

In 1908, the Manchurian Government was largely controlled by a coterie of foreign educated, progressive and competent officials, of which H. E. Tang Shaoiji, Governor of the province, was the leader. Many improvements were inaugurated during their brief tenure of office, not the least of which was the appropriation of funds for the installation of an electric light system for the capital, it being proposed to furnish light principally for the many Government Yamens, and streets.

The first plans, therefore, called for a rather limited plant, as commercial lighting seemed rather hopeless at first, owing to the cost, and the fact that all shops close at sundown and the inhabitants as a rule retire very early.

Data of Present Plant

Normal capacity of present plant	5000 lights—16 c.p.
Lights in operation	5000 " carbon.
Street lights 60 c.p.	300 series tungsten.
Miles of streets lighted	10
Miles of pole line constructed	23
Miles of wire on poles	70
Capacity of line wires	20000 lights.
Transformers installed	62
Capacity of transformers	8000 lights.

Due to the number of poorly constructed telephone lines and the inflammable interior walls and ceilings of houses, special attention and extra precautions have been taken to protect all circuits with enclosed safety fuses. Double the number of fuses that are used in American or European practice have been placed in the circuits. Wires of ample size have been used and special efforts have been made to securely fasten wires to insulators. The poles are set deep and are well guyed, and strong cross-arms with iron insulator-pins support insulators designed for a much higher voltage than that in use.

The entire work of installation was completed with remarkable celerity. The engineer of the General Electric Company, who had the matter in charge, arrived in Mukden the first of July, 1909, and began the organization of several gangs of workmen and drew plans for power station and pole line arrangements. House wiring was started in the Government Yamens about August 1st, and the erecting of power-station machinery August 15th. The plant was given a twelve hours test run on September 30th, and put in operation with about one thousand lights, October 3rd. The lighting service has been supplied for seven months to date without accident or interruption, except for one period of twenty nimutes, due to a misunderstanding of orders. The G.E. series tungsten street lighting system which was put in operation in November, shortly after the arrival of the final shipment of equipment, has been generally approved by the officials and public, and is giving every satisfaction, as it is peculiarly adapted for the streets of a Chinese city.

Contrary to expectations, since the date of starting the plant, orders for the installation of lights have been received more rapidly than they can be filled. Practically all of the new buildings, public and private, have been equipped with ample illumination. Yamens, schools, shops, theatres, hotels and residences have electric lights, and the people evince rapidly increasing knowledge of their advantages and a desire for sufficient lights of the latest type. A good market for heating and cooking apparatus, as well as small power motors, is being developed.

Plant Extension

Shortly after putting the plant in operation the management was convinced that the plant would be loaded to its capacity before the following spring, and arrangements were made for its extension. Owing to the high cost of fuel, the most efficient machinery would be most economical and it was decided to install a 600 h.p. Curtis steam turbine driving General Electric dynamos of 400 kilowatts capacity. To add to the reliability of the plant, a separate small turbine-driven dynamo of 20 kilowatts capacity will be installed. The steam from the turbines will be condensed in Wheeler surface condensers and a high vacuum held with electric motor-driven pumps. The condensed steam will be pumped direct to the boilers and used continuously. Babcock & Wilcox boilers of the latest design will be installed and equipped with automatic mechanical stokers. A super-heater will be integral with the boilers to eliminate the danger of water in the steam. The boiler capacity will be sufficient for the two turbines.

The General Electric Company has received orders for transformers, wire, meters, lamps and wiring supplies of the most approved design, which will be delivered this

* Abstracted from the *Far Eastern Review* for May, 1910

spring. The quantities will be sufficient to bring the system to twelve thousand lights. The equipment for four hundred more G.E. series street lights of the same type as adopted by the Shanghai municipal council, will also be delivered this spring, with a number of flame arc-lights and miniature lights for advertising signs.

Although power for lighting is sold by meter cheaper than in other cities in China, the receipts for lighting service have considerably exceeded expenses from the start, and with the plant completed as now designed, the receipts will cover operating expenses and cost of extensions, and leave a reasonable profit on the invested capital.

By next summer all of the mint machinery will be driven with 25 h.p. and 50 h.p. General Electric three-phase induction motors, supplied from the lighting dynamos. This will make it profitable to run the electric plant all day and supply motors installed in any part of Mukden, as well as fans and other electrical conveniences.

The credit for the success of this plant must be given to Taotai T. Y. Key through whose foresight, ability to appreciate new conditions, and knowledge of engineering problems, it was made possible to complete the installation of the plant in a space of time hitherto considered impossible in China. All the installation work (except some trivial pole setting done previous to the arrival of the General Electric Company's engineer from New York and which it was necessary to do over again) was done between the dates of July 2nd, and September 30th, when lights were turned on—a period slightly under three months. The Chinese and foreign inhabitants of Mukden have repeatedly given testimony to the extreme quickness with which the engineer in charge successfully completed the work, after a proper beginning was made on his arrival.

LIFE OF DIAMOND JEWELS

By F. G. Vaughen

What is the life of a cupped diamond jewel? This question is often asked by prospective users who are weighing the first cost of the diamond against that of the sapphire. To answer is impossible, for some of the cupped diamond jewels first manufactured are still in service; and although in some cases they show signs of wear, have an unbroken, perfectly polished bearing surface and are apparently good for millions of revolutions to come. During the past six years one of the larger lighting companies has purchased for use in direct current meters, a total of 17,000 diamond jewels, of which 13,000 were placed in service in 1906 7 or earlier, and have been in continuous use ever since. Three of these jewels have been lost by fire or have been crushed, and 57 have been worn to a point where it seemed desirable to reject them. This means that in three years' continuous service, less than one-half of one per cent. have had to be replaced for any cause.

The following tabulation, taken at random from this company's records, shows the remarkable life of cupped diamond jewels. It will be noted from column 2 that a majority of these jewels have been installed *prior* to a certain date, thus showing that the actual number of revolutions is more than the tabulation gives—how much more it is impossible to say, as no record of installation date was made. All of these jewels are still in service, so the tabulation gives no indication of what the ultimate life may be.

Ampere capacity of meter	Jewel installed prior to	Jewel installed	Life up to present date in millions of revolutions
75	8-06		17.8
7 1/2	7-06		5.5
25	3-07		6.3
15		11-2-06	9.
25	9-06		8.7
200	9-06		14.7
50		1-29-07	25.
50	12-06		6.2
7 1/2	7-06		12.8
150	7-06		11.3
150	8-06		12.8
50	7-06		11.3
150	8-06		16.
150		1-16-07	25.6
50		10-15-07	11.5
150	4-07		15.6
100		10-16-07	19.5
100	8-06		10.1
50		1-15-07	15.9

THE VERTICAL CARBON FLAME ARC LAMP

By G. N. Chamberlin

Engineer Arc Lamp Department, General Electric Co.

The 6.6 ampere luminous lamp is acknowledged to be the most modern and efficient means for general street illumination. This fact has become so well recognized that,

Fig. 1. Vertical Carbon Flame Arc Lamp

after thorough investigation of other illuminants, particularly other forms of arc lamps, its conspicuous merits have led to its being adopted for the lighting of many of the large cities, among others Boston, St. Louis, Pittsburg and Minneapolis.

In many cases, however, there are certain squares, parks or sections of streets where lamps of greater power are desired. In any city using the 6.6 ampere luminous lamp (or even the enclosed 6.6 ampere direct current system) for its general lighting, these areas can be illuminated to advantage by the General Electric vertical carbon flame lamp, on account of its high candle-power, exceptional efficiency, attractive appearance and the character of its light, which through its penetrating quality furnishes excellent illumination even in foggy weather. The lamps are so designed that, without other change in lamps or system, they may be used to replace lamps of either of the above systems by simply being connected in their stead.

Fig. 3 shows the light distribution from the 6.6 d.c. enclosed; the 6.6 d.c. luminous, and the 6.6 d.c. flame lamps, the latter lamp being equipped with a 26 in. diffuser and a light opal globe.

Figs. 1 and 2 show respectively the external and the internal appearance of the vertical carbon flame lamp. It has been designed along the lines of modern commercial arc lamp practice; it consists essentially of a simple focusing frame operated by a design of magnets, armatures, clutches, cutouts, etc., that has been tried out for years in the

Fig. 2. Mechanism of Vertical Carbon Flame Arc Lamp

standard General Electric direct constant current enclosed lamp.

Lamp casing is of heavy copper and is made in two sections so arranged that they may be telescoped on each other, thus rendering any section of the mechanism easily accessible.

The upper electrode consists of an ordinary ½ in. by 12 in. cored enclosed arc carbon, while the lower electrode is a carbon tube $\frac{11}{16}$ in. by 11 in. having a specially prepared core, manufactured and sold only by the General Electric Company. A pair of carbons will burn about 20 hours. It is interesting to note that lamps must be connected so that the lower carbon will be positive. To insure perfect alignment, the lower carbon holder has a ball and socket joint.

Aside from smaller installations, about 50 of these lamps have been in continuous operation in the streets of Boston for over a year.

Fig. 4 shows one of these lamps with pole as used in Copley Square, Boston; the lamps are hung so that the arcs are 50 feet from the curb.

Multiple Flame Lamps

By removing the cutout contacts and replacing the starting resistance with a series resistance, the lamp is suitable for constant potential 110 volts, d.c. operation, giving practically the same light distribution and carbon life as is obtained with the series lamp.

For multiple work the lamp is adjusted for 6.5 amperes, 70 to 75 volts at the arc. The advantage of operating lamps singly on 110 volt circuits instead of two in series at the higher current is obvious.

For multiple series operation, two lamps are used in series on 220 volts, or 5 in series on 500 volts, this being one-half the number of lamps that are required in the case of either potential if the higher current, converging carbon types of lamps are used.

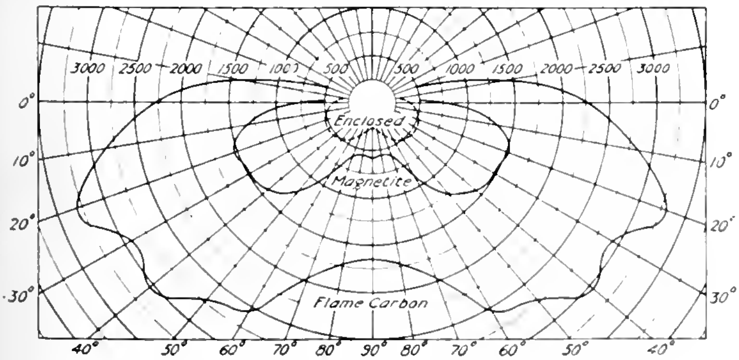


Fig. 3. Distribution of Light from Enclosed, Magnetite and Vertical Carbon Arc Lamps

For multiple series connection the series lamp with the magnetic cutout removed or disconnected, is used. This gives to each lamp a self-contained cutout and cutout resistance, insuring the operation of the remaining lamps in circuit in case one arc for any reason becomes extinguished. An external series of steadying resistance is used with each set of lamps in series.

Fig. 4. Vertical Carbon Flame Arc Lamp, Copley Square, Boston

For the present the lamp is available for d.c. circuits only.

Summarizing, the lamp has the following advantages over all types of converging carbon flame lamps:

Simple mechanical construction.

Higher efficiency.

Efficiency obtained at low current (6.6 amperes) making lamp available for existing series circuits.

Lamps may be connected singly on 110 volt circuits and thus operate with less complication in line wiring and lamp design.

Longer carbon life.

NOTES

During the month of June the following student engineers entered the Testing Department of the General Electric Company.

Georgia School of Technology

Fosterling, C. W.

Iowa State College

Corlette, L. H.
Mercer, J. M.
Noble, J. A.

Lehigh University

Foust, C. A.
Swope, R. B.

Leland Stanford University

Binns, C. A.
Cramer, H. P.
Parker, F. T.
Wall, R.

North Dakota Agricultural College

Moore, D. H.

Ohio State University

Taylor, B. W.

Pennsylvania State College

Beebe, L. H.
Bower, G. W.
Graeff, W. K.

Purdue University

Dull, A. W.
Harrison, E. M.
Knapp, L. H.
Proctor, W. R.
Sage, W. C.
Snyder, T. I.
Thomas, E. E.
Whicker, M. N.

Rose Polytechnic Institute

Henry, H. W.
Madison, H. J.
Poindexter, P. W.

Stevens Institute of Technology

Whyte, A. C.

Tuffts College

Taylow, C. W.

Tulane University

Wolf, A. F.

Union College

Becker, W. J.
Charest, J. G.
Dennis, A. R.
Dillinger, G. A.
Grover, H. H.
Kelley, S. D.
Kriegsman, A. E.
Paul, W. E.
Sears, R. P.
Sherman, A. H.
Slutter, N. W.
Whitmore, P. J.

University of California

Cumming, G. B.

University of Colorado

Allen, H. E.

University of Illinois

Bailey, E. H.
Pierce, L. G.
Wheatlake, B. C. J.

University of Kansas

Card, B. A.
Farber, E.
Morris, G. S.
Ponsler, R. L.

University of Kentucky

Bennett, C. S.
Mills, G. P.
Shanklin, S.
Shelby, J. B.

University of Maine

Chadbourne, V. R.
Hall, C. A.

University of Nebraska

Hepperlen, J. A.
Huston, C. B.
Smith, D. F.
Thornberg, C. E.

University of Wisconsin

Stilwell, E. D.

Virginia Polytechnic Institute

Paine, R. A.

It is expected that the present G.E. Investment Club will be gradually liquidated after the August assessment is paid. There seems to be a general desire among the present members that a new club should be formed along substantially the same lines, but not requiring compulsory liquidation at any specific time. It is proposed to start a new club early in September, 1910, and preparations are already under way to that end.

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OCTOBER, 1910

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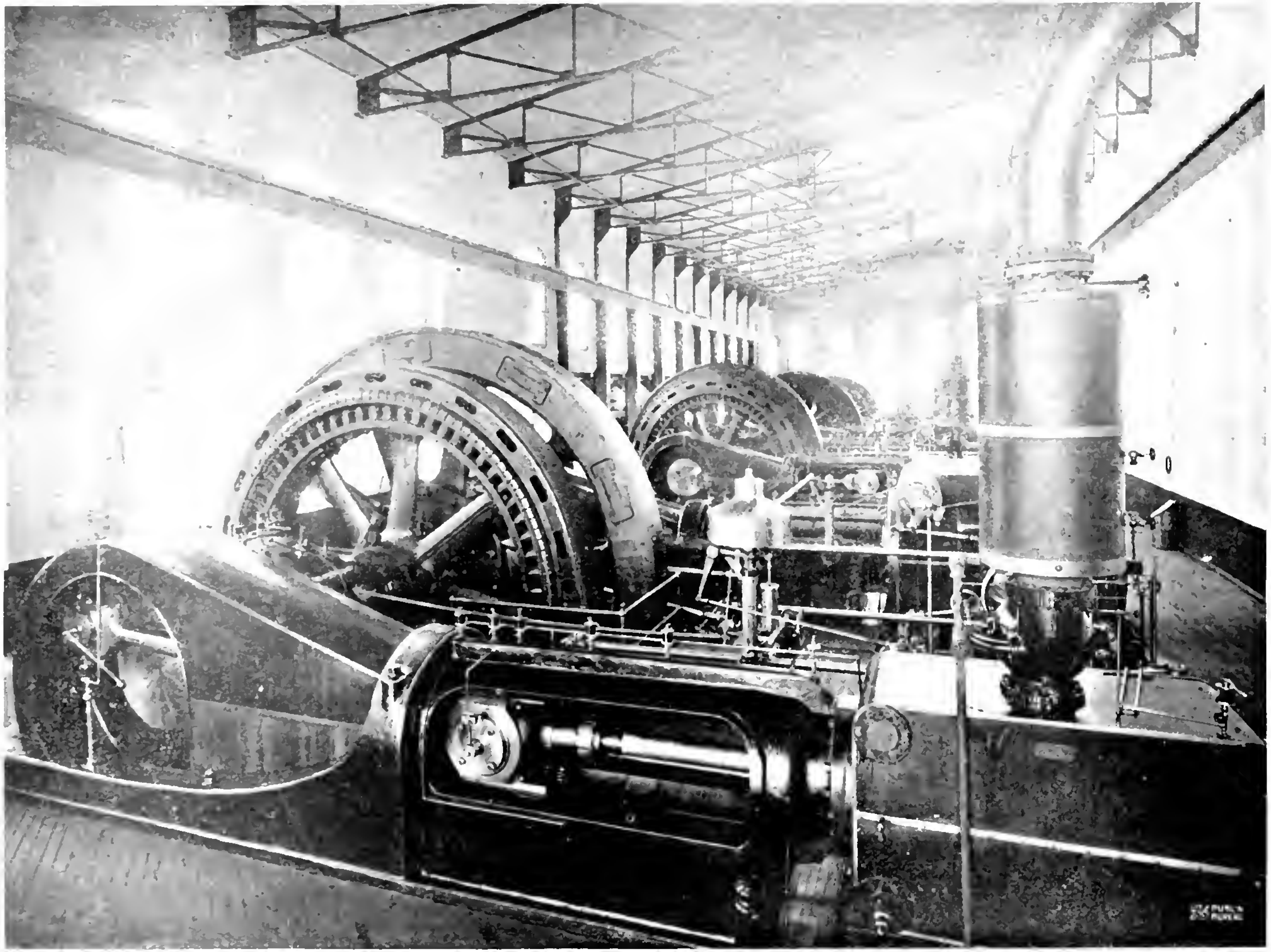


Power House of The Proximity Manufacturing Company, Greensboro, N. C.

(See page 472)

GENERAL ELECTRIC REVIEW

CURVES OF REACTIVE POWER

The advantages in transmission possessed by the alternating current and the simplicity and durability of the induction motor have led to the adootion of these motors in ever-increasing numbers for all kinds of power purposes that do not require great variations in speed. For this reason, the various features of their installation and operation are of much importance.

One of the characteristics of these motors that requires consideration is their action in lowering the power factor of the circuits on which they operate, through taking a magnetizing current that is practically wattless. While this wattless or magnetizing current can be generated with little expenditure of power on the part of the prime mover (only enough to account for the I^2R loss), it is by no means negligible, as it adds to the heating, and thus increases the generator capacity required for a given load as well as the size of the distributing conductors, and in addition affects the regulation by increasing the IR drop.

An effective remedy for this condition of low power factor is found in the synchronous motor, which, when operated with over excited fields, supplies a leading component that, by properly selecting the synchronous machine, can be made to raise the power factor of the system as much as is desired.

A simple explanation of the use of these so-called "rotary condensers" was given by Mr. A. L. Jones in the March, 1909, issue of the Review, from which we quote the following:

"It should be remembered that the power factor of the generator is determined by the wattless magnetizing current required by the inductive load, and further, that a power factor of less than unity value has the effect or rendering unavailable part of the generator capacity. If all the magnetizing current can be supplied from some source external to the generator, the latter will operate at unity power factor and its whole output will be available for power.

"Synchronous motors * * * can be used to supply magnetizing current to induction motors, thereby removing this burden from the generators. Such a motor, of course, has to be separately excited from some direct current source. There is, however, a critical value of field current at which the current taken by the synchronous motor is at unity power factor. If excitation below this value is supplied, the current taken from the line becomes lagging, and the effect on the generator supplying the motor is the same as if the motor were of the induction type; that is, the generator must make up the deficiency in excitation. If on the other hand the field current is in excess of the proper value, the motor draws leading current, and the effect is as if it had more excitation than it needed; this excess being delivered to the system, where it serves to excite or magnetize induction motors and relieve the generators. It follows that if enough leading current is supplied by over-excited synchronous motors to furnish magnetizing current to all the induction motors of the system, the generators will operate at 100 per cent power factor.

"A synchronous motor without mechanical load, and having its field over-excited to deliver leading current for exciting induction motors in other parts of the system, is called a rotary condenser. Such a machine may be located near the induction motors and used to supply the excitation needed by them, thus avoiding the flow of this wattless current through the transmission system and the burdening of generators therewith. In cases where a considerable number of induction motors are concentrated at some distance from the generating station and the conductors necessarily become of considerable size, by supplying the magnetizing current practically at the motors the line current will be reduced and a considerable saving in copper effected. What is more important, however, the generator is not burdened with this wattless current, and its full capacity is available for power. Locating the condenser at the generating station relieves the generator, but the wattless current still has to be transmitted over the conductor net work."

The article by Prof. Karapetoff, in the present issue, furnishes a simple means of determining the size of synchronous motor that is necessary to meet the requirements of any given case, in which the load and existing power factor being given, it is desired to raise the latter to any predetermined value.

SOME NOTES ON THE BEHAVIOR OF D.C. MACHINES

On page 456 of this issue we reprint an interesting article from ELECTRICAL ENGINEERING of London, on the behavior of d.c. machines. Little has been published on this subject, and the article contains suggestions regarding the starting of commutating pole motors that should prove of value to those operating these machines.

It should be particularly noted, however, that a number of the troubles discussed in this article are apparently due to the very small air gap or the narrow interpolar spaces (or both), that are present in the case of many of the foreign-built machines.

The General Electric motors are liberally proportioned in respect to both of these features, and a tendency for the speed to rise on load (as noted on page 459) does not exist in these machines, nor is there any evidence of surging; in consequence, the brushes are run in the neutral position, or as nearly so as that point can be determined. For this same reason, the second remedy is unnecessary, the placing of accumulative series windings on General Electric commutating pole motors not being required, except when the nature of the service demands a markedly drooping speed characteristic.

Again, it would appear from the article that only variable speed motors are furnished with commutating poles, in American practice, however, constant speed machines are quite generally so supplied.

NOTES ON ELECTRIC LIGHTING

In the present issue we print the first of a series of articles on Electric Lighting by Mr. Caryl D. Haskins, Manager of the Lighting Department of the General Electric Company. The articles are taken from a course of four lectures delivered to the students of civil and electrical engineering at the Rensselaer Polytechnic Institute, Troy, N. Y.

In covering a subject of such scope within the limits of four lectures, it was manifestly impossible to enter into a discussion of engineering details, and in these "talks" as the author prefers to call them, the effort was made to avoid technicalities, in so far as possible, and to treat the general subject of public service lighting in a purely practical way; to present to the students a bird's eye view of the field into which they were about to enter.

The first lecture was devoted to an analysis of the political and economic relations of the electric industry to the community; it has been omitted from the present series, which is confined to the engineering aspects of electric lighting, commencing with the second lecture.

It is assumed that a plant is to be installed capable of generating from 300 to 1000 kw. to supply a town of 10,000 to 20,000 inhabitants. With this as a starting point, the author takes up the subject of the power plant under the heads of water power, internal combustion engines, and steam, and discusses the criteria that lead to the selection of each form of motive power. Thus, under water power, the general conditions that make for success or failure in such installations are described; while under steam, the relative advantages of the reciprocating engine and the turbine for different cases are clearly presented.

Following the selection of the type of prime mover and the number of units to be installed, the conditions governing the choice of the direct current or the alternating current system are discussed, together with the determination of the frequency to be employed.

In the lecture following, distribution and translation are considered, both underground and overhead construction being discussed. The Edison "ring" and three-wire systems are described and the phenomena of electrolysis and interference with telephone lines are briefly touched upon, as are also the subjects of lightning arresters and line insulators.

The final lecture has to do with the utilization of the electric current for illuminating purposes. The author first considers the development of the incandescent lamp and its culmination in the tungsten lamp, following this account with a description of the improvements in arc lamps, from the Jablochkoff candle to the high power flame arc of today.

The lecture closes with a brief reference to some of the important features of the modern meters.

ELECTRIC DRIVE IN PULP AND PAPER MILLS

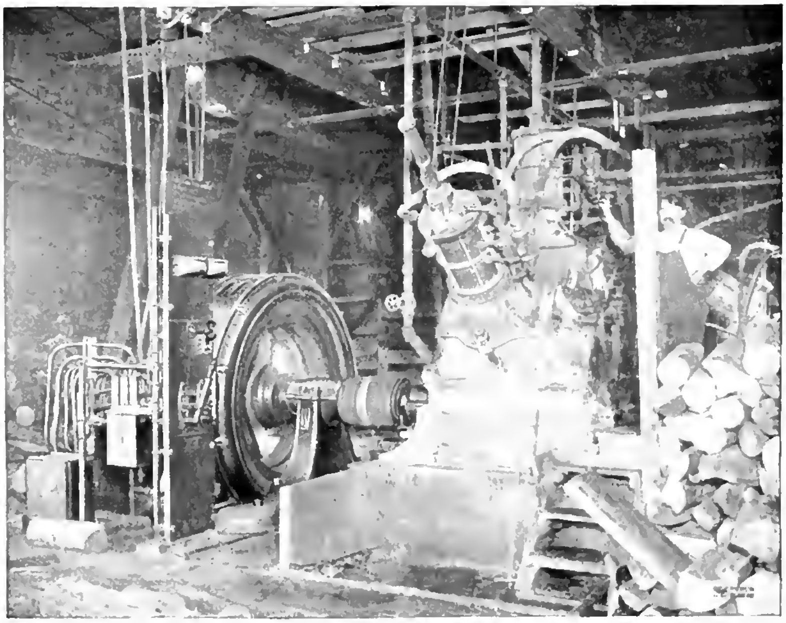
By John Liston

The ideal of modern production is the attainment of a maximum output for a given investment in plant and power. Owing to the relatively large amount of power required in pulp and paper mills, it is essential in order to secure the most economical operation, to carefully scrutinize all factors which enter into the power costs of production and to determine in every instance the relative values of the different methods of power application. The extensive adoption of electric drive in this industry is due to the growing appreciation of the inherent reliability, economy and high efficiency of motor drive as compared with the mechanical application of power for this class of service.

In considering the adoption of electric drive in a new plant, or the replacement of mechanical drive in an old one, the practical operator must be assured that he will thereby obtain uninterrupted service and a definite saving in the cost of production; either by a low installation expense, by lessening the power losses (thus securing for useful work a greater percentage of the initial power developed) or by a reduction in operating expenses. It has been demonstrated in numerous installations, some of which are illustrated herewith, that electrical drive combines all the advantages outlined above, and the following statement outlines briefly its points of superiority when compared with mechanical drive for the operation of pulp machinery.

With electricity the location of the power plant, whether steam or water driven, may be selected to obtain the greatest economy in the generation of power, without regard to the arrangement or location of the manufacturing buildings. These in turn may be erected at the point most advantageous to production and the shipment of finished material without reference to the location of the power plant.

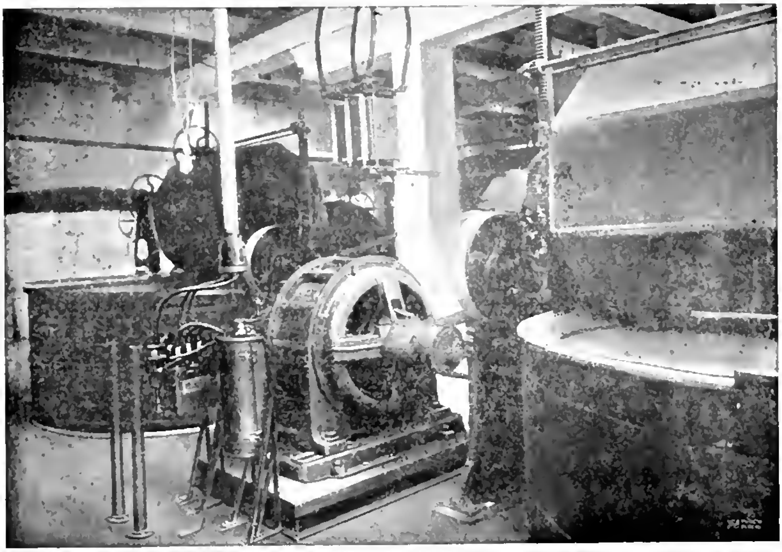
In a new mill, the adoption of electric drive will considerably reduce the building construction cost, due to the elimination or reduction of the heavy shafting and belting inseparable from mechanical drive. The structural work can therefore be of a much lighter character, and in the average mill the saving effected in this way will amount to about five per cent of the total cost of the building.



300 H.P. Motor Direct Connected to Grinder and Provided with Individual Switch and Control Panel. Carolina Fibre Co., Hartsville, S. C.

The machinery can be located with a view to the elimination of all unnecessary handling of the product, as each machine or group of machines can be supplied with its own motor and operated as an independent unit. The average motor used for driving paper mill machinery does not require special foundations, and as the adoption of motor drive eliminates a large percentage of the long shafts and heavy hangers and belting that are required for mechanical drive, their original cost and maintenance should be considered when comparing the initial expenditure required by the two systems.

Subdividing the power application, where numerous motors are used, permits the starting or stopping of any machine, or group, without interfering with the operation of the remaining machinery.



100 H.P. Induction Motor Driving Two 1000 lb. Beaters Through Belts
Elkhart Paper Mills, Elkhart, Ind.

Great economy in power can be obtained where individual motor drive is adopted, by the elimination or reduction of the friction loss involved in the operation of shafting, belts, gears, idlers and other consumers of energy. The power consumed by the different sections or different machines can be readily measured by connecting a recording instrument in the motor circuit; the graphic record will show at once whether the power consumed is normal, and this will frequently serve as an indication of the condition of the machinery and will insure a prompt detection of any defects. As the power can be conveniently measured, all machinery may be operated at such speeds as will produce the best results without unnecessary consumption of power.

The use of recording instruments will permit motors of various capacities, temporarily installed, to be tested in operation, so that the exact size motor required for the most efficient operation of any machine, or group, can be accurately predetermined. This will enable any errors of installation to be corrected and will eliminate haphazard methods of ascertaining the power necessary for driving the machinery required for additions to the plant.

Electric drive has great flexibility, in that additions to an existing plant may be made without interfering with the operation of the original equipment.

The generating plant may be economically divided into two or more units, thus insuring against a complete shut down in case of accident and permitting economical operation with individual sections of the plant. If there are a number of small water powers in the vicinity which can not be profitably utilized for mechanical drive, small generating plants may be established at these places and the power transmitted and applied at the mill.

In supplementing water power with steam power, the engine and generator may be located at a distance from the water power, so as to facilitate the receiving and handling of fuel; and, without other connections than the wires between the generators, can be arranged to automatically supply any deficiency in the power of water-driven plants. This method is especially valuable during periods of low water.

In a plant already equipped with reciprocating steam engines, a low pressure steam turbine can be installed which will utilize the exhaust steam of the reciprocating engine to good advantage. So efficient is this turbine that in many cases its adoption has practically doubled the power output of the reciprocating engine plant without increasing the boiler capacity.

Where a properly equipped central station exists within a feasible transmission distance of the mill, it will be found in many cases more economical to purchase electric current than to generate it. The steady demand of the paper mill renders it an attractive proposition for the central station and as a rule low rates can be obtained. By using central station power in a new mill, the investment expense for power house equipment and the cost of maintenance are avoided, while the possibility of interrupted service due to the breakdown of a machine in an isolated plant is overcome, as the modern central station is, as a rule, amply equipped with reserve machinery.

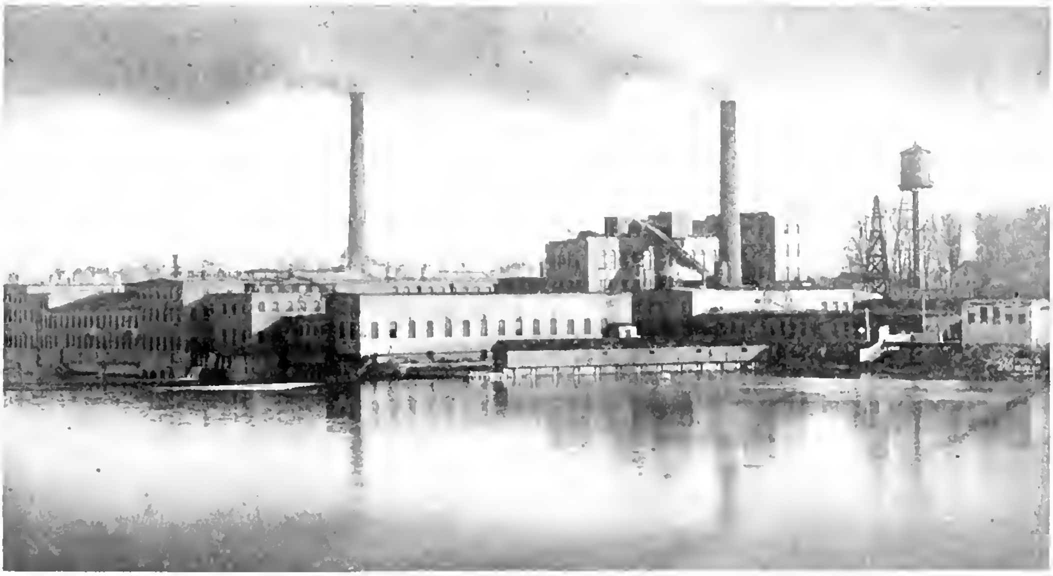
Even in an old mill already equipped with a steam plant, it may be true economy to discontinue the use of the steam plant, and disregard the investment already made that it represents, as in some instances this results in a reduction in the cost of power. When utilizing central station power the cost of operation of any machine or group is incurred only during the time the machinery is in service and the cost of running the machine is directly proportional to the amount of production.

Motor-Driven Grinders

The average pulp mill is operated by water power and as this power can not always be depended upon, the grinder room is usually equipped with a larger number of machines than would be required if constant operation were assured. In some mills it has been found advisable to operate the grinders as shown in the illustration on page 437; that is, by direct connecting the motor to the grinder shaft, each motor operating one, two or four grinders. Where the supply of water power is intermittent it has been found economical to utilize the water power while available and to supplement this with motor drive during periods of low water, either connecting the motor to the grinder shafts by means of removable couplings, or through belts.

The fact that wood pulp can be stored for future use, brings up the question as to whether or not motors can be profitably employed for auxiliary power. If a waterwheel mill is located near other sources of water power, generators can be installed at these points and the power transmitted to the mill as described above; so that the capacity of the mill may be largely increased with little or no additional building construction. In some instances this has been done so successfully that the utilization in this way of what would otherwise be waste power has obviated the necessity of building other mills to increase production.

Many central stations, especially those that are dependent upon a variable water supply, will grant low rates for current during the flood seasons; at other times low night rates may be obtained, as the use of power at that time will enable the central station to bring up its load factor. By taking intelligent advantage of these conditions, which will vary somewhat in different localities, the average water-driven wood pulp mill can largely increase its productive capacity with a minimum of additional investment.



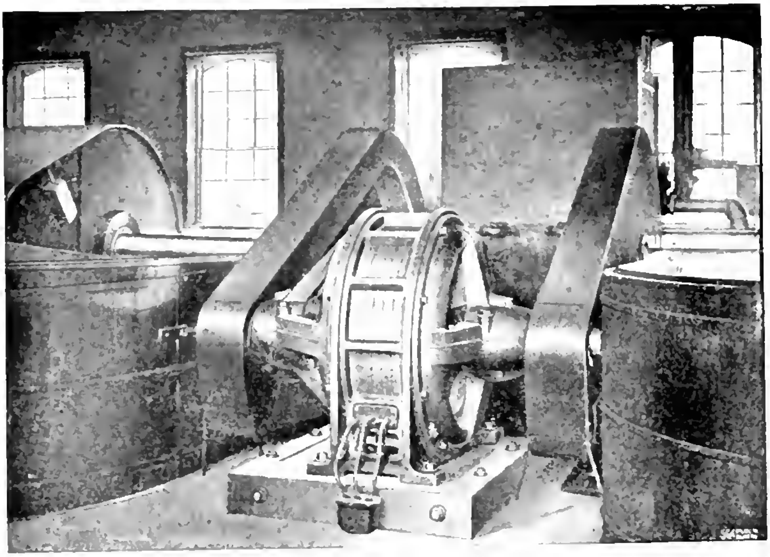
Kimberly-Clark Paper Mill at Kimberly, Wis.

Motor-Driven Jordans

For the operation of Jordan engines by induction motors a highly efficient and compact equipment has been designed, an installation of which is illustrated on the first page of the cover. This consists of a regular wound rotor induction motor with self-contained starting resistance, mounted on a sliding base and direct coupled to the Jordan shaft. In order to permit the adjustment of the Jordan without affecting the efficiency of the motor, a shaft is run under the Jordan and connected at one end to the motor base, the other end being geared to the adjusting hand wheel; thus any change in the adjustment of the Jordan may at once be compensated for by the movement of the motor on the sliding base. In this way there is no displacement of the rotor with respect to the field, as in some methods of motor-driven Jordans, and the motor will therefore operate under normal conditions at all adjustments of the Jordan.

As a heavy starting torque is sometimes required the type of motor chosen for this service will give approximately 150 per cent of full load torque at starting.

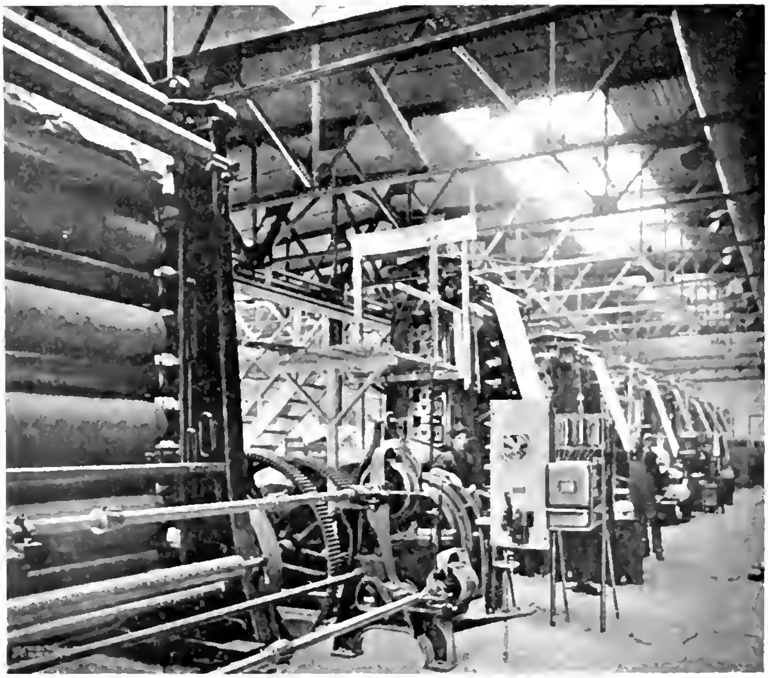
So efficient is this method of operating Jordans that it has practically superseded all belt-driven motor equipments.



150 H P Induction Motor Driving Two Beaters Through Chain Belts
Kimberly Clark Co., Kimberly, Wis.

Alternating versus Direct Current

In choosing between alternating and direct current motors for pulp and paper mills service, the requirements of the individual machines should be considered. A large percentage of the machinery operates at constant speed and for this work the alternating current induction motor can be used to advantage. Where a wide variation in speed is required, as in the operation of the finishing end of a paper machine, a direct current motor will insure a ready control and a prompt variation of the speed. As a rule, direct current



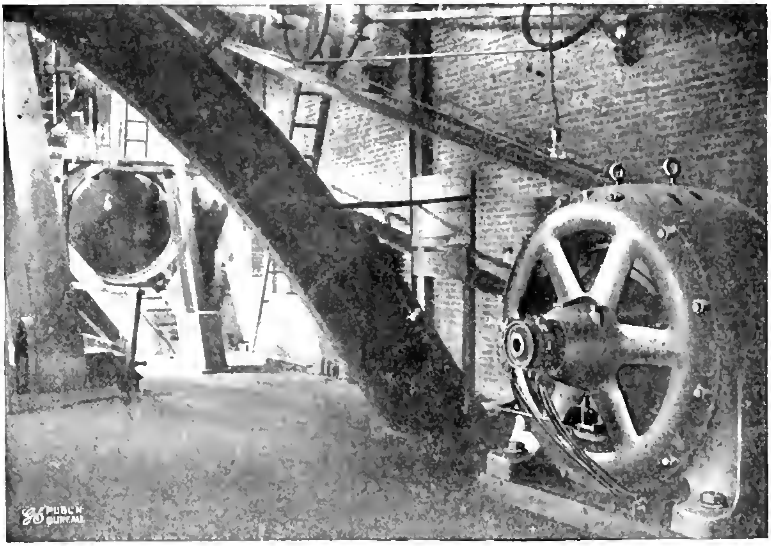
10 Super Calendars Driven by Back Geared Induction Motors, Provided with Individual Compensators and Control Panels
Kimberly-Clark Co., Kimberly, Wis.

motors should not be used for the remainder of the machinery. In order to supply direct current for the operation of the variable speed machinery, a motor generator set may be employed and operated from the alternating current power circuit.

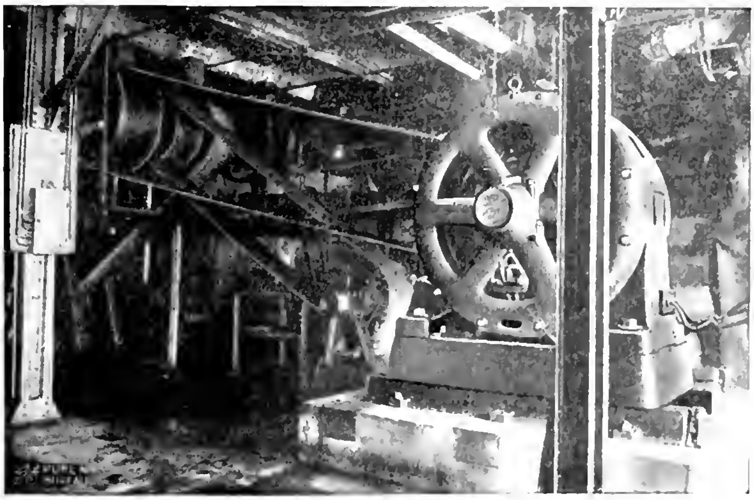
After many years practical experience in the equipment of pulp and paper mills, the General Electric Company decided to adopt the polyphase induction motor as a standard for this service where constant speed is required. This motor is built to withstand hard usage and to operate continuously in exposed locations and under disadvantageous conditions. The parts are few in number and have been carefully designed, so that a minimum of attention is required when the motor is in operation, and the cost of maintenance and repairs is practically negligible. The electrical design is such that high efficiency is obtained over a wide load range, and the motor is capable of withstanding heavy overloads for considerable periods without serious overheating.

The induction motor having no commutator the danger of sparks from this source is avoided, a feature that is especially valuable when motors have to operate rag cutters, dusters and thrashers or are used in any location exposed to inflammable dust.

This motor is easily controlled and will start readily under full load. Its rigid construction and light weight enables the user to mount it wherever desired, and in many cases where floor space is valuable and a machine is belt connected to a motor, space economy can be effected by suspending the motor from the ceiling or wall. For special applications these motors can also be arranged to operate on vertical shafts with the same high efficiency as that obtained with the horizontal shaft type.



300 H P Induction Motor Driving Chipper Room Machinery
Berlin Mills Co., Berlin, N. H.

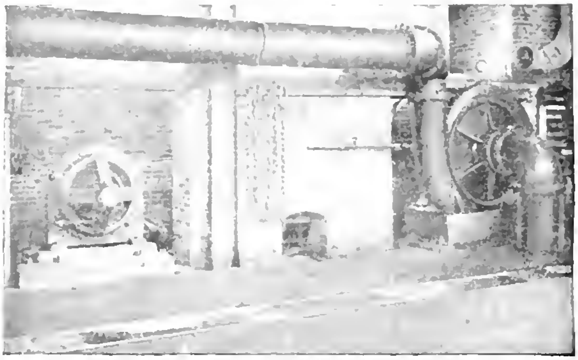


250 H.P. Induction Motor Driving Stock and Water Pumps for Ground Wood Screen. Berlin Mills Co Berlin, N H.

Group versus Individual Drive

In the application of electric drive, two general systems are now in vogue, namely, the operation of each individual machine by a single motor, commonly termed "individual drive," and the operation of machinery in groups by means of line shafting, which in turn is driven by a motor, this plan being generally designated as "group drive."

While there are many successful examples of economical group drive, it is now the concensus of competent opinion that in a large majority of cases the highest efficiency, both for the machinery to be driven and for the electrical equipment, can be best obtained by



60 H.P. Induction Motor Driving No. 15 Morris Centrifugal Pump in Grinder Room. Great Northern Paper Co., East Millinocket, Me

the application of separate motors to each unit. This is especially true where the operation of the machines is intermittent, as in this case the cost of current, if obtained from an outside source, is incurred only during the actual operation of the machine.

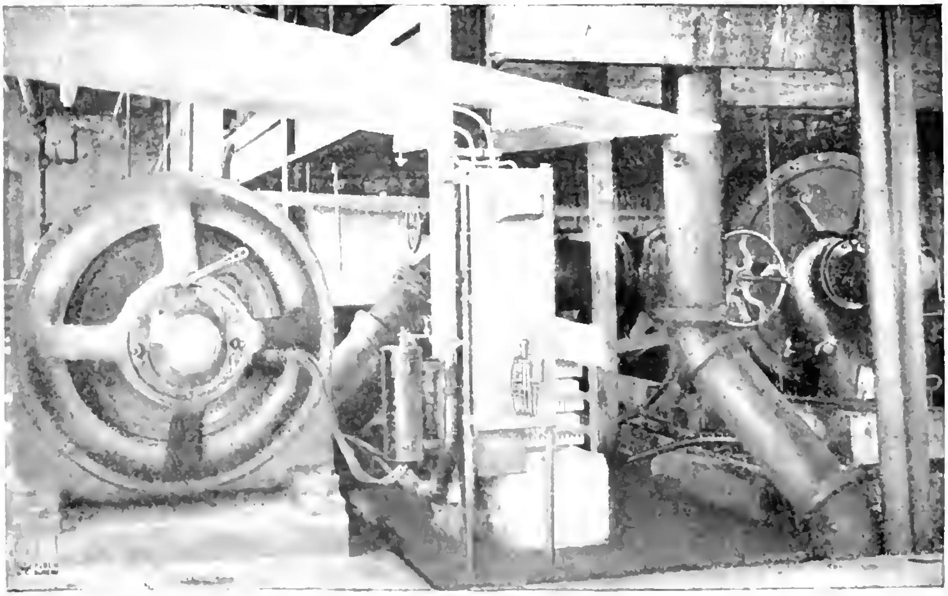
If, on the other hand, the plant generates its own current, the size of the prime mover and generator, as well as the power factor in the case of alternating current plants, will be appreciably affected by the choice of group or individual drive; as in the latter case, each machine can be equipped with the motor that most nearly meets the exact requirements in regard to speed and power.

Where the operation of the various units is intermittent, the individual drive system will, in practically every case, permit of a much smaller generating outfit than group drive, even if there is considerable variation in the length of time that the units are in service; for, in the latter case, power is wasted through the unavoidable operation of shafting and belting which, during varying periods, performs no useful work.

The motor operated plants illustrated herein are typical of the large number of pulp and paper mills which are similarly equipped, the entire success with which they have utilized motor drive constituting a potent argument for its general adoption throughout the industry.

KIMBERLY-CLARK PAPER COMPANY KIMBERLY, WIS.

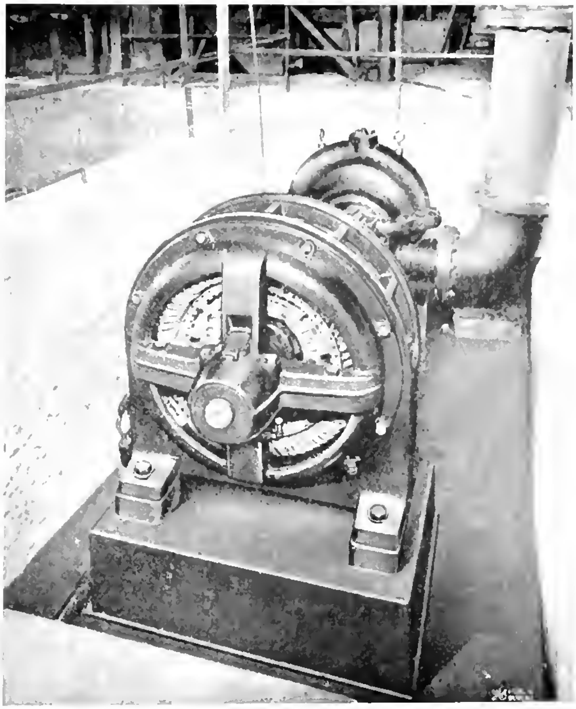
The Kimberly Mill of the Kimberly-Clark Paper Company is located on the Fox River



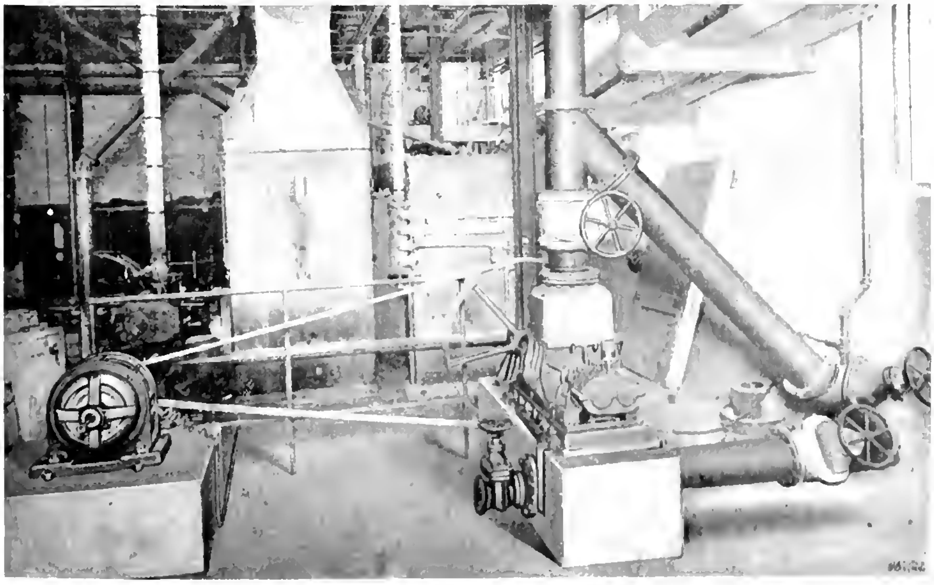
300 H.P. Induction Motor with Controller and Individual Panel, Driving Two Centrifugal Pumps for Filters. Great Northern Paper Co., East Millinocket, Me.

and manufactures book paper by the sulphite process, the capacity of the mill being 75 tons per 24 hours.

The mill machinery is operated electrically, and water power, steam and oil engines are utilized for the generating of electric current. Two power stations supply current to the mill, both being located on Fox River, one in the mill itself and the other at Appleton, five miles up stream. The available head at Appleton is 16 feet and current from a 750 kw., 3-phase, 25 cycle, 6600 volt generator is transmitted to a substation at the mill, where it is stepped down by means of three 300 kw. transformers to 170 volts. At the mill a 700 foot crib dam has been constructed across the river and a head of 9 feet is available. The water wheel equipment here consists of nine vertical shaft reaction turbines. Five of these are geared to a common horizontal shaft, to which a 300 kw. generator is coupled. The remaining four turbines are connected in the same way to a second 350 kw. generator, but in addition to the water-wheel drive, this generator is also arranged for oil engine drive, the generator being located between the turbine-driven shaft and an oil engine and equipped with removable couplings on both ends of the shaft. In this way the oil engine can be readily used to operate the generator during periods of low water. In addition to these there is one 350 kw. generator mounted between two oil engines and direct driven by them, and one 175 kw., also oil engine-driven. The exciters



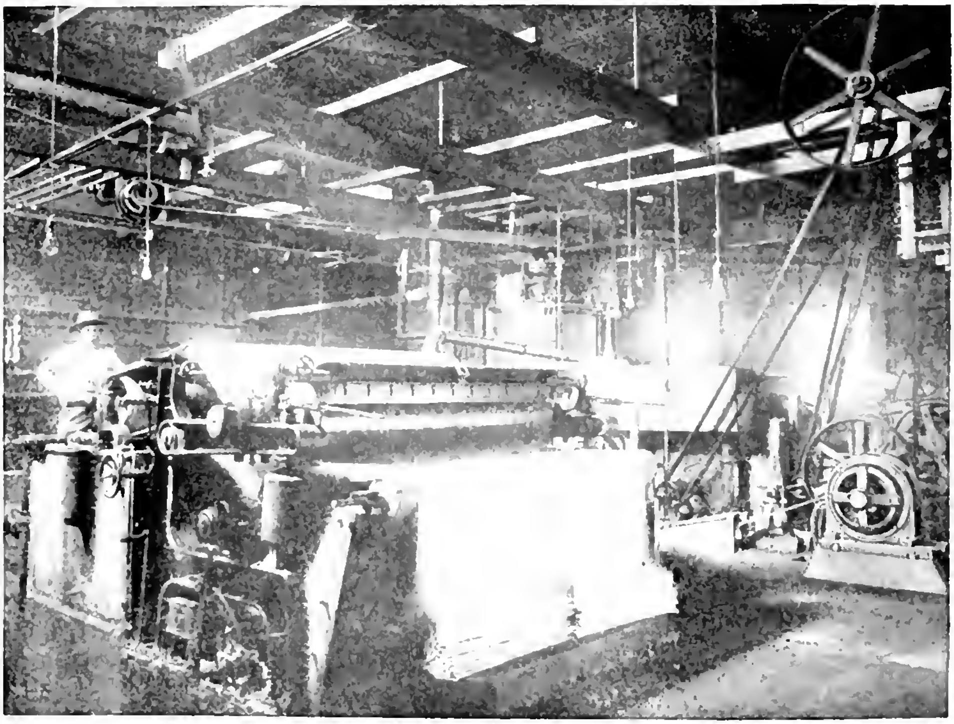
100 H.P., 1200 R.P.M. Induction Motor, Direct Connected to a 10 Inch, 2750 Gal. Centrifugal Pump
Finch, Pruyn & Company, Glens Falls, N. Y.



Double Impeller Stock Pump Driven by a 22 H.P., 1200 R.P.M. Motor. Finch, Pruyn & Company, Glens Falls, N. Y.

are belt-connected and arranged for parallel operation. A steam engine is included in the equipment and is employed to drive a 360 kw. generator and exciter. It will be seen from this description that through the subdivision of the generating equipment, and the various prime movers available any possibility of interruption to the electric service is reduced to a minimum.

The first application of motor drive in this mill was made about six years ago and at the present time the motors in actual operation total fifty-five: provision has already been made, however, for additional installations. The application of motors to paper mill machinery in this plant exemplifies both the group and individual systems, as well as different methods of connecting the motors to the machinery, there being examples of direct connection, belt, and chain drive, and motors direct geared to the driving shafts.



20 H.P. Induction Motor Driving Sulphite Machine and Flat Screen, and 15 H.P. Motor Mounted on Ceiling, Driving a Centrifugal Screen Through a Quarter-Turn Belt
Carolina Fibre Co., Hartsville, S. C.

In the bleach room eight agitators are driven in a group by one 60 h.p. motor.

In the beater room there are three Jordans driven by three 150 h.p. motors, as shown on first page of cover. These motors are equipped with the General Electric adjusting device which permits the motor to move on a sliding base with each change in the adjustment of the Jordan. The control panels for these motors are mounted in a small gallery so that the operator who manipulates them has an unobstructed view of the motors, while at the same time the panels occupy no useful floor space and are protected from accidental injury. There are three other Jordans in this room, which constitute an older equipment; they are driven from a countershaft, which is belted to a 300 h.p. motor mounted on the floor below, the controller being installed on the floor beside the Jordans. There are three other motor-driven Jordans, two of them being operated by a 250 h.p. motor while the third is provided with a 150 h.p. motor. These three machines are belt-driven and are not ordinarily used in production, being held as an emergency equipment in the event of injury to the other Jordans.

In the beater room a pair of beaters is driven by means of a 150 h.p. motor with the shaft extending on both ends and connected to the driving shafts of the beaters by chain belts, forming in this way a compact and highly efficient unit, as shown on page 440.

Four other beaters are driven in a group by a 250 h.p. motor, belt connected.

In the washer room chain drive is used for one 40 h.p. and two 75 h.p. motors, operating three washers. There are also four screens and four deckers belt-driven in a group by means of a 75 h.p. motor.

In the size room the mixing outfit is driven by a 50 h.p. motor. Four paper dusters are driven by a 25 h.p. motor and a waste paper baler by a 2 h.p. motor, both motors driving through belts.

The pump equipment of the mill is practically all motor-driven. It comprises a hydraulic pump driven by a 50 h.p. motor, a pump for agitators and stock tanks by a 30 h.p. motor; two stock pumps and chests by a 15 h.p. and a 20 h.p. motor; the boiler house pump by a 15 h.p. motor, and boiler feed pump by a 30 h.p. motor, and two water pumps, one driven by a 35 h.p. and the other by a 75 h.p. motor. There is also an equipment utilizing a 15 h.p. motor to drive a water pump and air compressor, the latter supplying pressure for blowing out the water filters. All of these pumping sets employ belt drive. In addition to these there are three save-all pumps, to each of which a 10 h.p. motor is direct connected.

The constant speed ends of the three paper machines used in this mill are driven through chain belts by three 75 h.p. motors; the paper winder by a 20 h.p. motor, belt-connected, and the rewinder by a $7\frac{1}{2}$ h.p. motor.

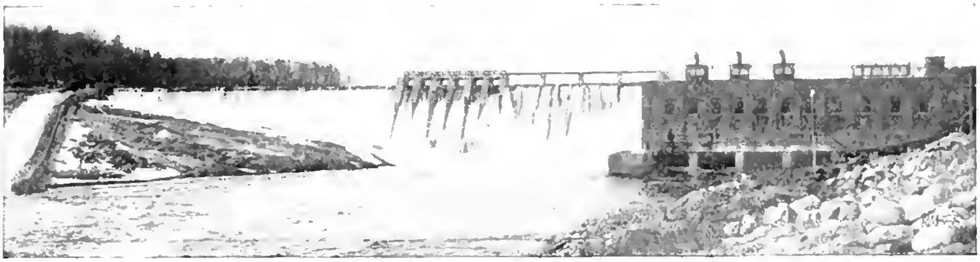
In the finishing room, ten motor-driven super-calendars are used, the ten motors being back geared to the super-calendar driving shaft. Four of these motors are of 75 h.p. capacity, five 50 h.p. and one 100 h.p. The threading-in rolls are individually driven by ten 15 h.p. motors, back geared to the driving shaft; and ten paper cutters and one trimmer are driven in a group, through belting, by a 30 h.p. motor.

The machine shop is equipped with a 15 h.p. motor driving the machinery through countershafting.

All the above motors are of the alternating current induction type and operate on 25 cycles, three-phase circuits.

In addition to the induction motor equipment, the finishing room is supplied with an overhead motor-driven traveling crane, for handling paper rolls of any weight up to two tons. This crane is operated by a direct current motor, and current is provided for it by means of a motor-generator set consisting of an induction motor direct coupled to a 220 volt d.c. generator.

Three systems of lighting are used in the mill, alternating current being used for incandescent lamps, while the motor-generator set referred to above supplies direct current for arc and mercury vapor lamps.



Dam, Power House and Grinder Station on the Penobscct River. Great Northern Paper Co., Dolby, Me.

Motor Distribution	No.	H.P.	Drive
8 Agitators	1	60	belt
3 Jordans	3	150	direct
2 Jordans	1	250	belt
3 Jordans	1	300	belt
1 Jordan	1	150	belt
2 beaters	1	150	chain
4 beaters	1	250	belt
2 washers	2	75	chain
1 washer	1	40	chain
4 screens and 4 deckers	1	75	belt
Size mixing outfit	1	50	belt
4 paper dusters	1	25	belt
Waste paper baler	1	2	belt
Hydraulic elevator pump	1	50	belt
Pump for agitators and stock tanks	1	30	belt
Stock pump and chest	1	15	belt
Stock pump and chest	1	20	belt
Boiler house pump	1	15	belt
Boiler feed pump	1	30	belt
Water pump	1	30	belt
Water pump	1	75	belt
3 paper machines constant speed end	3	75	chain
3 save-all pumps	3	10	direct
Water pump and air compressor	1	15	belt
Paper winder	1	20	belt
Paper winder	1	7.5	belt
4 super-calendars	4	75	geared
5 super-calenders	5	50	geared
1 super-calender	1	100	geared
Threading-in rolls	10	15	geared
10 paper cutters and 1 trimmer	1	30	belt
Machine shop	1	15	belt

THE THREE-VOLTAGE RATING OF INCANDESCENT ELECTRIC LAMPS.

By F. W. Willcox

The three-voltage method of rating incandescent lamps, which was first adopted for the metallized filament, or Gem lamps, has now been applied to all types of regular incandescent lamps made in the standard commercial voltages of 100 to 125 volts. The Mazda, tungsten, tantalum, carbon and Gem lamps are now all rated on this basis.

A proper rating for incandescent lamps should provide for rating the lamps in total watts instead of by candle-power. The reasons for this are as follows:

First. The conventional candle-power rating, as employed for illuminants, has been a much abused and misused method of rating. As there are many different candle-power values (such as the horizontal, spherical, hemispherical, candle-power at different angles, etc.), candle-power, unless specifically defined, tends to become a misleading and meaningless basis for rating. Lamps are a current-consuming device and the logical rating for such devices is a total watt rating, since lighting and power are measured and sold almost entirely on a wattage basis. Candle-power values need not be abandoned, but can be used, when required, in a more definite way, properly defined and accurately stated for any given wattage of lamp.

Second. A desirable condition for the rating of an incandescent lamp is that the lamp should have its most exact measure

TABLE I—Life and Efficiency Ratings of Mazda Lamps at the Three Labeled Voltages.

Size of Lamp in Watts	TOP VOLTAGE		MIDDLE VOLTAGE		BOTTOM VOLTAGE	
	W.P.C.	Life in Hrs.	W.P.C.	Life in Hrs.	W.P.C	Life in Hrs.
25	1.33	1000	1.39	1300	1.45	1700
Small bulb 40	1.25	1000	1.30	1300	1.35	1700
Large bulb 40	1.25	1000	1.30	1300	1.35	1700
60	1.20	1000	1.25	1300	1.30	1700
100	1.20	1000	1.25	1300	1.30	1700
150	1.20	1000	1.25	1300	1.30	1700
250	1.15	1000	1.20	1300	1.25	1700
400	1.15	1000	1.20	1300	1.25	1700
500	1.15	1000	1.20	1300	1.25	1700

TABLE II—Life and Efficiency Ratings of G. E. Tantalum, 100-125 Volts Lamps at the Three Voltages.

Size of Lamp in Watts	TOP VOLTAGE			MIDDLE VOLTAGE			BOTTOM VOLTAGE		
	Nominal W.P.C.	Actual W.P.C.	Life Hrs.	Nominal W.P.C.	Actual W.P.C.	Life Hrs.	Nominal W.P.C.	Actual W.P.C.	Life Hrs.
25	2.0	1.97	1000	2.1	2.06	1300	2.2	2.14	1700
40	1.8	1.79	800	1.9	1.87	1100	2.0	1.95	1500
50	1.8	1.79	800	1.9	1.87	1100	2.0	1.95	1500
80	1.8	1.79	600	1.9	1.87	800	2.0	1.95	1050

NOTE.—The above [illegible]. On alternating current of 60 cycles and below, the lives are conservatively rated as 500 hours for the 25 watt [illegible] 600 [illegible] 40, 50 and 80 watt lamps.

TABLE III—Life and Efficiency Ratings of GEM Lamps at Three Voltage.

Size of Lamp in Watts	[illegible] VOLTAGE		MIDDLE VOLTAGE		BOTTOM VOLTAGE	
	W.P.C.	Life in Hours	W.P.C.	Life in Hours	W.P.C.	Life in Hours
40	2.56	700	2.71	1000	2.89	1500
50	2.50	700	2.65	1000	2.83	1500
80	2.46	700	2.60	1000	2.78	1500
100	2.46	650	2.60	950	2.78	1400

TABLE IV—Ratings of Carbon Lamps, Single-Voltage and Three-Voltage Basis. 100 to 130 Volts. Standard Lighting Lamps. Regular Types.

Basis of Rating	Nominal Watts	Voltage	Actual Watts	Actual W.P.C.	Actual C.P. *	Spherical C.P.	Total Lumens	Lumens per Watt	Hours Total Life	Style Bulb
Single Voltage	10	Single	10.	5.	2.	1.7	21.3	2.13	2000	SS11
	20	Single	20.	4.15	4.8	4.0	50.3	2.52	2000	SS14
	20	Single	20.	4.15	4.8	4.0	50.3	2.52	2000	SS17
Three Voltage	25	Top	25	3.1	8.1	6.7	83.6	3.34	500	SS17
		Middle	24.1	3.31	7.3	6.0	75.4	3.14	725	SS17
		Bottom	23.2	3.52	6.6	5.4	68.3	2.94	1050	SS17
	30	Top	30	3.23	9.3	7.7	96.4	3.21	1050	SS17
		Middle	28.9	3.46	8.4	6.9	87.0	3.00	1500	SS17
		Bottom	27.8	3.69	7.5	6.2	77.7	2.81	2100	SS17
	50	Top	50.0	2.97	16.8	13.9	174.0	3.49	700	SS19
		Middle	48.2	3.18	5.2	12.5	158.0	3.26	1000	SS19
		Bottom	46.4	3.39	13.7	11.3	142.0	3.06	1500	SS19
	60	Top	60	2.97	20.0	16.5	208.0	3.49	700	SS19
		Middle	57.9	3.18	18.3	15.1	190.0	3.26	1000	SS19
		Bottom	55.7	3.39	16.4	13.5	170.0	3.06	1500	SS19
	100	Top	100	2.97	33.6	27.7	349.0	3.49	600	SS24
		Middle	96.4	3.18	30.5	25.2	316.0	3.26	850	SS24
		Bottom	92.9	3.39	27.4	22.6	284.0	3.06	1350	SS24
	120	Top	120.0	2.97	40.4	33.3	419.0	3.49	600	SS24
		Middle	115.8	3.18	36.6	30.2	379.0	3.26	850	SS24
		Bottom	111.4	3.39	32.8	27.1	340.0	3.06	1350	SS24
200 to 260 Volts										
Single Voltage	35	Single	35	4.40	8.0	6.9	84.0	2.40	1000	PS19
	60	Single	60	3.69	16.3	13.6	171.0	2.84	750	PS21
	120	Single	120	3.69	32.5	27.3	341.0	2.81	750	SS24

* New International Candle-Power, by which a former 16 c.p. lamp now gives 16.26 c.p.

neither candle-power nor total watts, but watts per candle, which determines the temperature strain of the filament. The reason for this is that the watts per candle determines the degree of incandescence or temperature strain on the filament, and exact rating in this value will insure the most uniform service from the lamps.

All standard lighting lamps operating in multiple must be rated at an exact voltage (such as 110, 115 volts, etc.). It is a practical impossibility to manufacture all lamps, particularly those with metal filaments (such as the Mazda, tungsten, etc.) to either an exact total wattage or candle-power for any fixed voltage. It is possible, however, to so select the lamps, by allowing variations from the average value of total watts and candle-power, as to bring the lamp, at its rated voltage, to an exact watts per candle efficiency. This insures that each lamp is burned at a uniform degree of incandescence and, although the actual candle-power may vary somewhat, nevertheless the lamps will appear to the eye to be of uniform brilliancy and the variation in initial candle-power will not be as noticeable as under the old method of rating by candle-power with a varying efficiency. The filaments are also subjected to a uniform temperature strain, and this method of rating therefore insures a uniform lighting effect and a maximum of well maintained candle-power and life.

The total watts assigned to any lamp will represent the average value, but the variation necessary to give an exact watts per candle rating will not amount to enough to disturb conditions.

Third. A proper rating for incandescent lamps should further provide a flexible method which would permit of using the lamps at several different efficiencies in order to adapt them to varying conditions of voltage regulation and power costs.

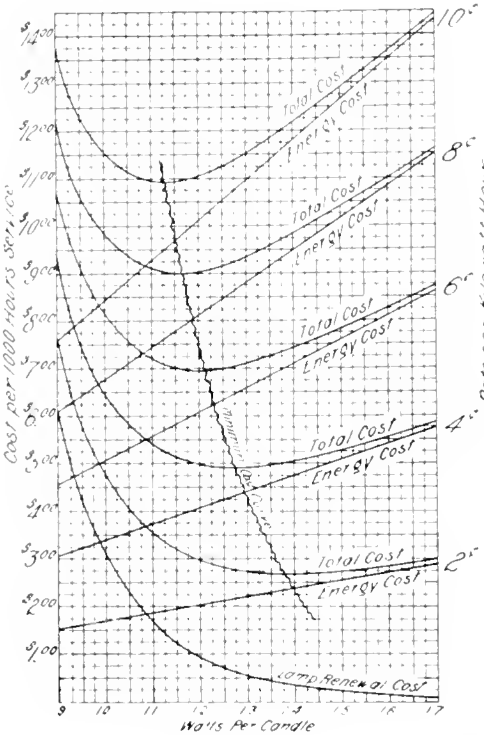


Fig. 1 Cost of Lighting with 100 Watt Mazda Lamp Showing the Efficiency Which Gives the Lowest Lighting Cost at Different Current Rates. Price of Lamp, Based on Cost to Customers Using 10,000 Lamps Yearly

Since the cost of lighting is made up of the combined cost of the electric energy used and the renewal cost of the lamps, it is evident that it is important that the efficiency be selected in every case which is adapted to the special cost conditions to be met. If the cost of power is high, high efficiences and relatively shorter life is justified; while if the cost of power is low, lower efficiencies and correspondingly longer lamp life is desirable. Moreover, an efficiency which will give satisfactory life on a circuit when the voltage is uniform and does not rise more than two or three volts above normal, would not give satisfactory life when the voltage rises four or five volts above normal. It is therefore desirable that lamps be available in different efficiencies to meet different service conditions. This means that either a large line of lamps be provided at different efficiencies or that each lamp be so rated that it can be used at several different efficiencies.

The former method is objectionable in that it makes it necessary for manufacturers, dealers, central stations and others to carry a large and complicated stock of lamps if they are to meet all service conditions so as to obtain the most economical lighting. Thus, in the past, the same lamp in a number of sizes appears under several different ratings. For example, a carbon lamp which at given voltage is a 24 candle-power, 3.1 watts per candle lamp, becomes at 4 volts lower a 20 candle-power, 3.5 watts per candle lamp, and at 4 volts lower still a 16 candle-power 4 watts per candle lamp. For each rating there was a different label with a different voltage marked on it. Evidently, it would be much simpler to mark these three voltages on one label and use this same label on each of the lamps so that any one of them could be used at any of the three efficiencies. This is the plan followed under the three-voltage method of rating.

120 Volt
Top Voltage

120 Volt
Middle Voltage

120 Volt
Bottom Voltage

Three-Voltage Rating

Under the three-voltage plan each lamp has a label bearing three voltages, for example,

120, 122 or 124
118, 120 or 122
116, 118 or 120

as shown by the sample labels illustrated herewith. In all cases these voltages vary by steps of 2 volts. They are known as the "top," "middle" and "bottom," or "first (V 1)," "second (V 2)" and "third (V 3)." In the first of the sample labels shown, 120 volts is "top" voltage, in the second, 120 volts is "middle" voltage and in the third, 120 volts is "bottom" voltage.

The three-voltage rating permits any lamp to be operated at any one of three different efficiencies and enables the consumer to select lamps of the particular efficiency that will give him the lowest total cost including energy consumed and lamp renewals combined. If for example the regulation of the circuit is originally such as to require that the lamps be operated at an efficiency corresponding to that obtained at "bottom" voltage, and is later improved by the installation of more copper or regulating devices, the customer can readily improve his efficiency by ordering the same lamps at "middle" voltage or "top" voltage, depending upon the extent of the improvement in regulation. In the same way any change in power cost could be met with a similar change in lamp efficiency, which would enable the consumer to keep his total lighting cost, including power and renewals, to the lowest possible figures.

Determination of the Proper Efficiency at which a Lamp Should be Used

The proper efficiency at which a lamp should be used is determined by the lamp renewal cost, which is fixed by the price and life of the lamp. The minimum practical limits of life are generally considered to be about 400 to 500 hours; above this value the life will be varied to suit the conditions of current and lamp cost. For any given efficiency the life will be affected by the voltage regulation; it is therefore the actual life obtained in service that is the determining factor.

Assuming the voltage to be constant, the lives of the various lamps at the different efficiencies are as given in Tables I, II, III and IV. Under the proper conditions of voltage regulation, the most desirable efficiency is that which will give a life not less than the practical limit before stated, and which will give the consumer the lowest total cost for lighting service, including power cost and lamp renewal cost.

At the ordinary rates for current, the cost of the power consumed by a lamp is equal to many times the cost of the lamp itself. Therefore, if the lamp is burned at too low an efficiency, the cost of energy consumed will increase at a much faster rate than the cost of renewals will decrease. As the cost of lighting is made up of the sum of these two factors (energy cost and lamp renewals), a balance should be struck between efficiency and life which will make the combined cost of energy and renewals a minimum. Where the cost of energy is high, the lamp should be operated at a relatively high efficiency. In this case its life will be shorter and the renewal cost will be increased but the energy consumption for a given amount of light will be decreased. On the other hand, where the cost of energy is low the lamps may be operated at a lower efficiency, thus decreasing the renewal cost and increasing the consumption of energy. It is apparent, therefore,

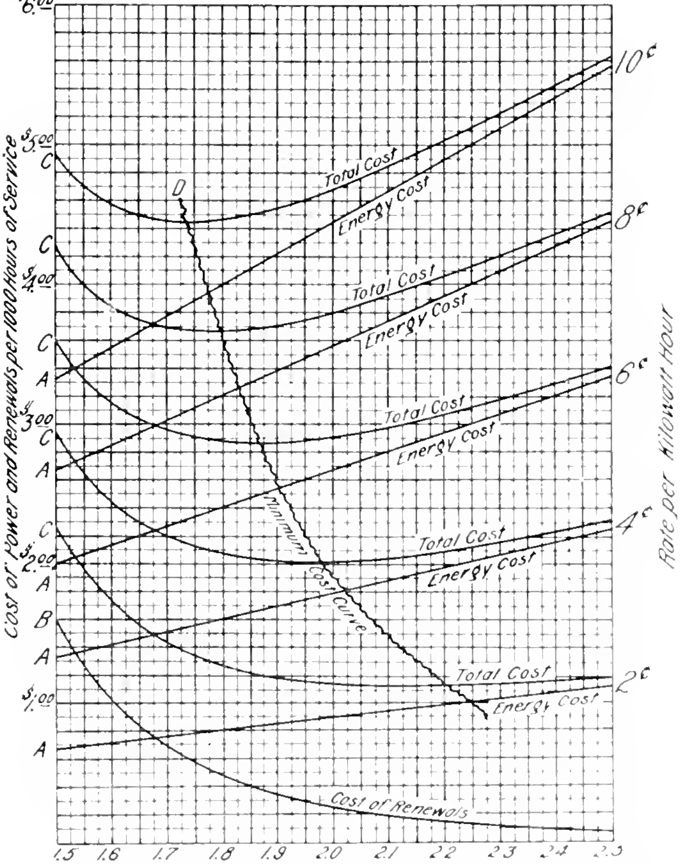


Fig. 2. Cost of Lighting with 40 Watt Tantalum Lamp, Showing the Efficiency Which Gives the Lowest Lighting Costs at Different Current Rates Prices of Lamp, Based on Cost to Customers Using 10,000 Lamps Yearly

that for every energy rate there is a corresponding lamp efficiency which will give the lowest total lighting cost, including energy and renewal cost. In the following pages we will determine this efficiency for one size of each of the various lamps (Mazda, tantalum, Gem and carbon).

Mazda

Table I gives the life and efficiency ratings of Mazda lamps at the three labeled voltages. The top voltage gives the highest efficiency and lowest current cost, and the greatest brilliancy and volume of light, with the excellent life of 1000 hours a year's service for the average consumer. At the lower voltages (middle and bottom), the lamps operate at lower efficiency with longer life, but with reduced brilliancy and volume of light.

The efficiency established for the Mazda lamp at top voltage, as given in the table,

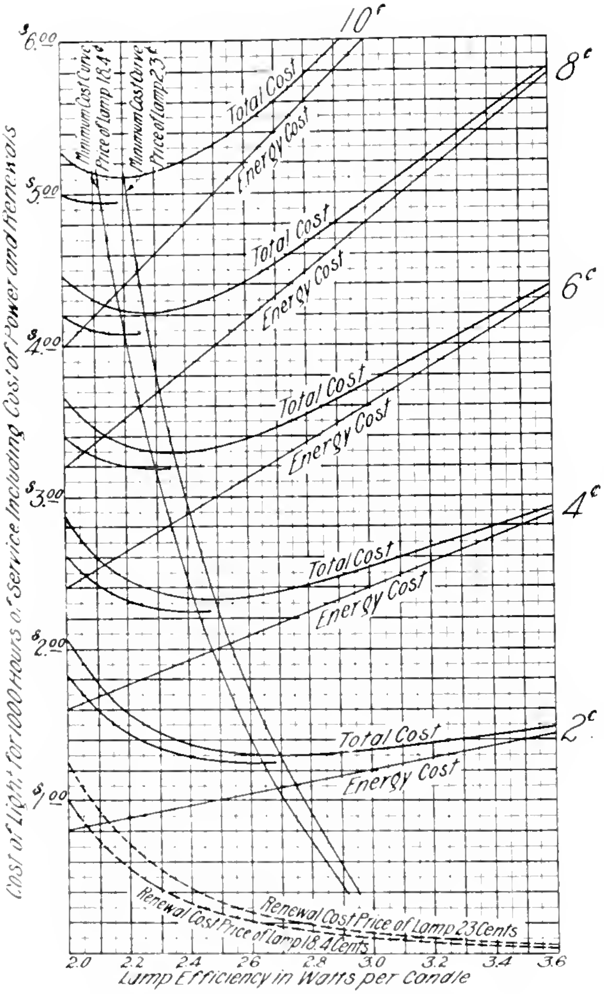


Fig. 3. Cost of Lighting with 50 Watt Gem Lamp, etc. Price of Lamp 18.4 and 23 Cents

has been carefully determined as that efficiency which will give the lowest cost of lighting service, including energy and renewals, to the consumer paying rates of 8 cents per kilowatt-hour and over. The top voltage rating is therefore the one that should be used by the average central station customer.

The diagram of Fig. 4 shows graphically the cost of lighting with the 100 watt Mazda lamp at different power rates and efficiencies.

One curve shows how the cost of lamp renewals varies with the efficiency at which the lamp is operated; another set shows how the energy cost varies with the efficiency of the lamp. Combining the two curves, we get curves which show how the total cost of lighting (energy and renewals) varies with the efficiency of the lamp. These curves are shown in the diagram for energy rates of 2c., 4c., 6c., 8c. and 10c. per kilowatt-hour. The efficiency at the lowest point of the curve is the one at which the lamp should be worked in order to get the lowest total cost of lighting at the rate represented in the curve. The curve connecting the minimum points of all of the total cost curves for the lamp gives the efficiencies to obtain minimum costs, and is known as the minimum cost curve.

From these curves, the efficiencies that will give the lowest lighting cost can be readily determined. For example, suppose the energy cost is 8c. per kilowatt-hour. Referring to the curve, we find that the lowest total cost for light with the 100 watt Mazda lamp is obtained at an efficiency of about 1.17 watts per candle. From Table I it is seen that the nearest efficiency is 1.2 which is obtained at the top voltage rating, with a life of 1000 hours. In like manner, at 4c. per kilowatt-hour we find that the lowest total cost is obtained at an efficiency of 1.27 watts per candle. The table shows that the nearest efficiency to this is 1.25 which is given at the middle voltage rating, with a life of 1300 hours.

The curve shows that at the 8c. rate, the lowest cost of 1000 hours' service is about \$9.00 equivalent to 9c. per kilowatt-hour. Therefore, the cost of lamp renewals is only about 1c. per kilowatt-hour—a very small item compared to the 8c. per kilowatt-hour energy cost. It is therefore shown to be poor economy to operate lamps at low efficiency in order to lengthen their lives, except where the energy cost is very low.

Tantalum

Table II gives the life and efficiency ratings of the tantalum lamps at the three rated voltages. These efficiencies and lives have, like the Mazda lamps, been determined so that the top voltage gives the average consumer the most economical lighting service.

As shown, the efficiencies of the 10 and 50 watt lamps (which are the best and most widely used sizes) have been increased to 1.8 watts per candle at top voltage and the old standard efficiency of 2 watts per candle is given at the bottom voltage, with a life of 1500 hours. The 25 watt lamp gives a life of 1000 hours at top voltage, 2 watts per candle efficiency, and a life of 1700 hours at bottom voltage, 2.2 watts per candle efficiency.

The values taken are those obtained on direct current, the life being somewhat shorter on alternating current. The life for alternating current given in the note is very conservative, as the 40 and 50 watt lamps will considerably exceed 600 hours in the average case. Tests have shown that the average breaking life of the 40 watt tantalum lamp at 2 watts per candle on 60 cycle current, is 1000 hours. In general, however, the bottom voltage rating should be used on alternating circuits of 60 cycles or lower. The top voltage is desirable on direct current service for the consumer paying rates of 8c. per kilowatt-hour and above for current.

This is shown graphically for the 40 watt lamp by the cost curves in Fig. 2, which are similar to those given for the Mazda lamp in Fig. 1.

Gem

The three-voltage method of rating was first adopted for the Gem lamp, and the excellent results obtained from the system with these lamps led to its adoption for the other types.

The life and efficiency ratings of these lamps at the three rated voltages are as given in Table III.

The minimum cost curves for the 50 watt Gem lamp at two different lamp prices, 18.4 and 23 cents, are given in Fig. 3.

Carbon

The Carbon lamps were the latest type to which the three-voltage method of rating was applied, this method having just recently been adopted for these lamps.

This rating is used for those sizes of the regular 100 to 130 volt types which were formerly supplied and used at several different efficiencies. This includes the 25, 30, 50, 60, 100 and 120 watt sizes of the regular types and the 30, 60 and 120 watt sizes of the round bulb and tubular types.

The 200 volt lamps, and lamps below 8 candle-power in the 100 volt types, are still rated at one voltage only, by what is known as the "single-voltage rating," as distinguished from the three-voltage rating. However, these lamps are also now rated for size in watts instead of candle-power.

Table IV gives a list of the standard carbon lamps as now rated, and also the lives and efficiencies at the different ratings (single, or top, middle and bottom).

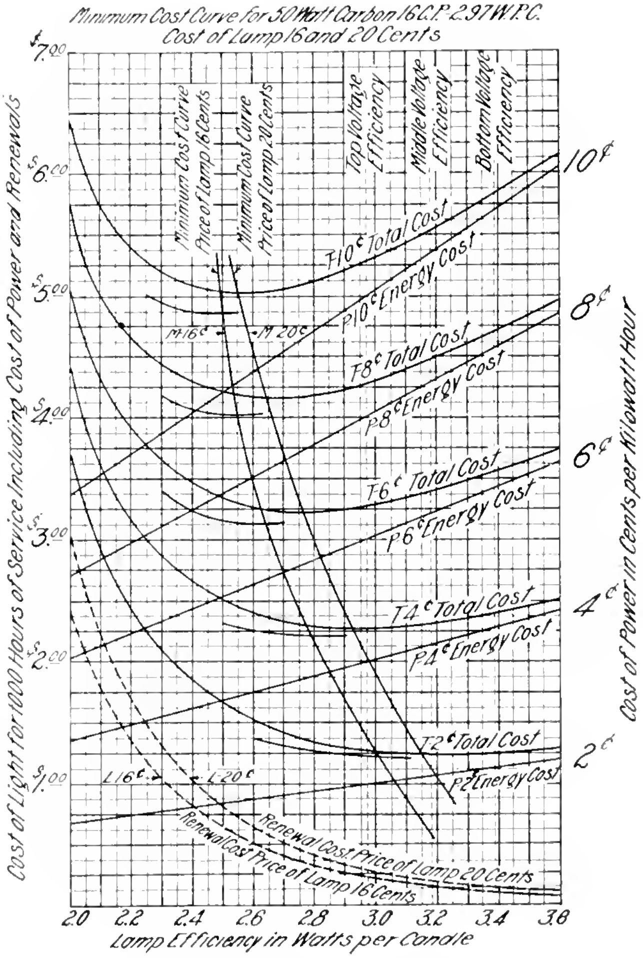


Fig. 4. Cost of Lighting with 50 Watt Carbon Lamp, Showing the Efficiency Which Gives the Lowest Lighting Cost at Different Current Rates. Price of Lamp, 16 and 20 Cents

Fig. 4 shows minimum cost curves for the 50 watt carbon lamp at two prices per lamp, 16 and 20 cents. As shown by the curve, the minimum cost of lighting with the 50 watt lamp at 20 cents, will be obtained by using top voltages for all power rates of 4 cents per kilowatt-hour and over. At rates of 2 cents per kilowatt-hour, the lowest cost is obtained by using middle voltage and it is only when the rates are lower than 2 cents per kilowatt-hour that bottom voltage should be used.

At a lower price the lamp should be operated at a still higher efficiency. This is shown by a comparison of the 20 cents per lamp curve with the 16 cents per lamp curve.

The new method is not a radical departure from the old, and with the exception of a few sizes, any customer can obtain exactly the same lamp he is now using, under the new rating.

NOTES ON ELECTRIC LIGHTING *

PART I

By Caryl D. Haskins

Manager Lighting Department, General Electric Company

Yesterday we gave preliminary consideration to lighting undertakings; the underlying conditions which make them possible, wise or unwise business propositions, their relations to the community, etc., etc. Today we shall go into more specific engineering questions.

The central power station for the generation of electric energy may, of course be anything from a small 50 kw. equipment up to one of those enormous aggregations of many thousands of kilowatts, which characterize Chicago, New York, Boston, and other very large cities; aggregations so large that they stand by themselves as special problems involving serious individual studies.

For the backbone of today's talk, after thinking the matter over rather carefully, I have selected the conditions commonly surrounding plants ranging from a minimum of 300 to a maximum of say, 1000 kw., or from about 100 to 1300 h.p.; an average undertaking, such as one would contemplate for a town of from 10,000 to 20,000 people. I shall occasionally deviate, in connection with special issues, to considerations pertaining to very large concentrations of power; but we shall, except where stated otherwise, regard the subject under discussion as a unit plant of this general capacity.

In dealing with a problem of this kind, the engineer's first decision of course, must relate to the selection of his prime mover and its physical connection to the generating apparatus. In central station practice, we find three general classes of prime movers:

1st. The steam engine

2nd. The internal combustion engine

3rd. Water power.

With water powers the question is largely one of location. Unfortunately, water head and flow can not be found everywhere. Commonly one thinks of water power as without cost *save only the cost of development*. Largely, this is true, but not seldom, when ill considered this cost has proved too much. There have been a very considerable number of unsuccessful water power generating plants in the history of the lighting industry of this country, due to a number of causes. Where such plants have been unsuccessful, however, the cause of failure can generally be traced back largely to poor (too sanguine) initial engineering. Excessive cost of development means bad engineering, and it has not seldom been preceded by a low initial estimate. History tells us also of unwise judgment and over-hopeful estimates as to the probable damage to the works from floods and ice; unwise and carelessly made surveys as to the condition of streams in drought periods, the latter resulting in an inadequacy of water in dry summers and the former in excessive water during flood periods, with the consequent destruction of property, such as dams, tail races and gates.

It is safe to say, that most unsuccessful water power plants have failed because of an

*The article is the first of a series to appear in the REVIEW, comprising the notes of a course of extemporaneous lectures delivered before the engineering students of the Rensselaer Polytechnic Institute, Troy, N. Y. The series begins with the author's second lecture, the first lecture having been devoted to topics not essential to the course from an engineering standpoint.

insufficient water supply. A very high percentage of the early intermediate size, low head, water power undertakings in the eastern states, which started out with brilliant prospects, today have stand-by steam plants as large as their water power development. But bear in mind this does not mean that they are failures by any means.

To civil engineers the development of water power is, of course, of peculiar interest, but it can be no more dealt with generically than can the matter of bridge construction. I shall, therefore, pass it by with the excuse that it is a special study too big and vital to form a part of this lecture. I can not refrain, however, from a few more generalities. Water power developments of low head, such as usually characterize those in the eastern states region, require more careful investigation and involve more unfavorable possibilities and variables, and, in short, constitute a much more indefinite problem than do any plants using steam power. A high proportion of the successful water power plants for lighting and power purposes in this country, are in our western states, where high heads, in rather close proximity to large towns, are far more common.

A high head proposition for electric purposes generally involves a comparatively low cost of development. This must not be misunderstood to mean that low-head propositions are inherently bad, but rather that they are, as a rule, more difficult problems to solve and are more costly.

The price of coal has a very important relation to water power development; often it is the controlling consideration. Every additional dollar per annum for fuel to obtain a given power, obviously justifies an expenditure of from $10.00 to $15.00 for additional development in connection with a water power, providing always that the engineering premises for the development are sound.

I have known few better examples of wise development of small water powers for the generation of electrical energy than that of a certain plant in the Hawaiian Islands. The conditions are unusual. The value of the crops in some portions of the islands exceed one thousand dollars per acre, but the success of these crops is dependent in a very large measure upon irrigation. On the west side of one of the islands which has a mountain backbone, sugar grows very luxuriantly, but a great lack of rainfall prevails upon the other side of the range. It was found that sugar would grow quite as well on the eastern side as upon the other if the land could be properly irrigated. A civil and electrical engineer found that rainfall and springs were plentiful to the very summit of the west side. He drove two shafts into the mountain from the east about four-fifths of the way to the summit, and water was encountered plentifully as soon as the shafts were well into the mountain. A heavy flow was speedily secured at a point giving 800 foot head and the cost was estimated and proved to be low. With this water the engineer drove his electrical generating apparatus, and after doing its work, the water was taken to irrigation ditches and used to wet the crops close in to the east side of the mountains, while the power generated was used to drive a large number of pumps at numerous remote points in the dry belt. This undertaking would probably not have been justified save for the high cost of coal and other fuel equivalents ($10 to $12 per ton).

The internal combustion engine was our second alternative prime mover. For central power station use, the internal combustion engine is comparatively new. No one who has studied the question doubts the enormous promise of this prime mover. It has already been developed to a highly efficient status for relatively small capacities. The preponderance of evidence seems to indicate, however, that the larger units are as yet somewhat unreliable, occupy a large amount of floor area, and are of disproportionally great weight and high cost. They have not yet reached wide use for electric lighting purposes, but they promise much in conjunction with gas producer development. We shall not pursue this subject, because, frankly, I am not well versed in it, and there is not time, anyway, to go into it in greater detail. By the natural process of logical or arbitrary elimination, this leaves us *steam*.

Under the general classification "Steam," we have three alternatives:

(1) The reciprocating engine, belt or rope connected to the generator.

(2) The reciprocating engine, direct connected to the generator flexibly or rigidly.

(3) The turbine, direct connected to the generator, and constituting a unit piece of apparatus with it.

The decision as to which one of these alternatives shall be adopted is the first concrete problem to settle before going forward with the steam generating station.

In considering these things, we have to measure reliability, floor space, weight, efficiency, first cost and maintenance. Efficiency has been placed low in the list, not because it does not belong high, but because it is so largely dependent upon physical conditions. Efficiency and first cost fluctuate in first importance, one up and the other down, as the cost of fuel and labor is high or low and the cost of money is high or low. Efficiency literally and relatively varies with the cost of fuel and water for the boilers, and the availability and temperature of the condensing water.

In reliability, the direct connected engine and the turbine set are probably on a substantially equal basis, with a slight advantage, if any, in favor of the turbine. Either alternative has a material advantage over the belted or rope drive sets as to reliability.

In considering floor space, we must give attention to the cost of the building as well as the land area required, which stated plainly means the cost of real estate. This is of prime importance in large cities where the price of real estate is high. It is not of course, so serious a problem in smaller towns. We must also consider the cost of labor necessary to transport and install the apparatus.

The three alternatives rank thus in regard to floor area:

Belted or rope drive sets . .	100% floor space
Direct connected or reciprocating engines	57.5% floor space
Turbo-generators	20% floor space

In the matter of weight we have to consider freight charges, ease of handling, cost of foundations and the cost of the permanent cranes of the station. The relative weights are about as follows:

Direct connected sets	100% weight
Belted or rope drive sets inclusive of engine and generator	90% weight
Turbo-generators	50% weight

You will note that the belt or rope drive sets occupy a somewhat intermediate position This, however, is exceedingly variable, so much so as to make it quite possible that in some instance they would occupy a higher place as to weight than the direct connected sets.

The speed of the belted generator is, of course, higher in substantially every case than the speed of the direct connected sets.

In the matter of reliability the turbine is the equal of the other alternatives, or better.

In the matter of weight the turbine is materially preferable.

In the matter of floor space the turbine is greatly preferable.

In the matter of first cost, belted sets are generally cheapest, turbo-generator sets intermediate, direct connected sets, except when of very high speed with reduced reliability, most expensive.

These statements and figures are all based on averages and vary materially in individual cases.

Efficiency, as I have already said, is in a considerable measure a question of fuel, condensing water, the temperature of that water, its value, availability, etc. Turbines are at their greatest advantage at very high vacuums. Under all conditions of continued use, the advantage lies with the turbo-generator, but reciprocating engines vary widely. Well built turbines, properly used, give efficiencies better than reciprocating engines under all conditions of sustained service, and these economies increase rapidly as the size of the turbine is increased. Belted sets may be safely eliminated from consideration under the conditions that we are discussing; they should be considered only in connection with very small projects. Let us remember, however, that nearly one-half of the central stations in this country are belted, a condition which must change sooner or later—three thousand problems for the engineer of tomorrow.

How many units should an average central station contain? Under average conditions up to 1000 kw. total, three units of equal rating are preferable. The "valley" to normal load will be taken care of by one unit, the normal to "average peak" load by two units, and all abnormal peaks (as during the night before Christmas), by three units. This installation, in the average plant, permits of the reservation of one unit as a "standby," for use only when abnormal peaks exist, or when repairs to other units become necessary. Under these conditions it is possible to avoid running the generators at low efficiency, that is, at a low proportion of the full load.

The decision as to whether alternating current or direct current shall be generated in a station must now be reached. The conditions governing this decision are dependent upon the amount of energy to be distributed, the relative reliability of the apparatus (a.c. or d.c.), the relative cost of operating, and the first cost of installation. Where power is to be distributed over large areas, this becomes a question of potential rather than direct current versus alternating current; but it is after all reduced to a question of the character of current, because only very low potentials are feasible in direct current multiple distribution. This is due to two reasons: First, incandescent lamps are only made in low voltages (220 volts maximum); and, second, because commutation becomes difficult at high voltages. We may safely assume that where the area over which we are to distribute exceeds, say, 2000 feet maximum radius, it is practically necessary to resort to voltages in excess of those that are feasible for the direct current service of incandescent lamps.

The first cost of a complete system depends very largely upon the cost of feeder copper, and as this varies inversely as the square of the voltage at which power is transmitted, the higher potentials (which means alternating current) are generally imposed upon the central station as an unavoidable condition. We must remember that there is always one factor in favor of the direct current service; i.e., copper depreciates less rapidly than apparatus, and the investment in copper, while initially high, is more permanent than the investment in apparatus under most conditions.

In the matter of reliability of operation, both as to generating and subsidiary apparatus, alternating current has some advantage, largely because of freedom from commutation and its difficulties. The great recommendation for alternating current, aside from the economical distribution of power, is its flexibility, enabling us to do a large number of things at all sorts of voltages. Let us then, decide to use alternating current in our plant.

The next question is one of frequency. We have three common frequencies in the United States and several others which are not uncommon, as for example, 40 cycles, the frequency in use here in Troy. Nevertheless, 40 cycles is not a common frequency throughout the United States. Our common frequencies are 25, 60 and 125 cycles. The latter is the commonest frequency of early apparatus. It is made for light weight transformers and light apparatus. In the early days of the art, when high frequencies were not at a disadvantage, this frequency was widely used—today, a system having a frequency of 125 cycles is generally considered obsolete, for reasons presently to be explained.

Sixty cycles is now the common frequency for lighting undertakings. It is low enough to make synchronizing easy, and is highly satisfactory for induction and synchronous motors. It is not too high to prevent the use of rotary converters and is amply high to give good light through incandescent filaments without noticeable flicker.

Twenty-five cycles is the preferred frequency for long distance transmission systems as well as for railway generating systems. It is peculiarly well adapted to the operation of rotary converters. Twenty-five cycles may well be considered the power distribution frequency and 60 cycles the lighting frequency. For lighting purposes, it has been contended by some authorities that with 25 cycles there is a certain flicker, which, while not observable, is alleged to be fatiguing to the eye. From a practical standpoint perhaps the most important consideration in connection with this question, *is the frequency of electric plants in nearby towns*. An engineer who is building a new plant in the United States today is undoubtedly building it within striking distance of some other plant or plants, generally within reach of a half-dozen other plants. The value of his property is destined to be materially greater if his frequency is the same as his neighbor's. Sooner or later central stations will be tied together for mutual support; the smaller ones will disappear as generating units and the larger ones will assume the load. When this occurs, the wisdom of the adoption of a standard frequency will be apparent; the smaller concern can then buy its power from the larger without changing its subsidiary apparatus. The plant with a special frequency is obviously at a greater disadvantage when it becomes an economic measure for it to purchase current from a neighbor.

Let us assume, that our plant will be a 60 cycle one, and that our voltage will be 2300. This is the commonest standard voltage for lighting projects and is sufficiently high for reasonably economical distribution over areas not exceeding two to five miles radius. The determining of the operating voltage is a purely physical question, dependent upon data as to area, density, and distribution of load.

(To be continued)

SOME NOTES ON THE BEHAVIOR OF D. C. MACHINES*

(With Special Reference to Interpole Machines)

BY P. Q. R.

Shunt Field Faults

In the case of a generator which is required to be self-exciting there is only one correct connection of shunt field terminals to the armature busbars. If the machine be run with correct rotation and does not build up, then probably the shunt field is wrongly connected, and should be reversed. Cases often occur, however, where the field is correctly connected (especially when the machine is being run up for the first time), and some half an hour will elapse before the machine commences to build up; or a machine may build up with the wrong polarity to be put on the station busbars. The remedy then is not in reversing the field connections (if this were done the machine would no longer build up), but in reversing the residual magnetism in the pole pieces by separately exciting the field from some external source for a short time. With a motor there can not be an incorrect shunt field connection, because it is always excited direct from the line. The actual connection determines the direction of rotation.

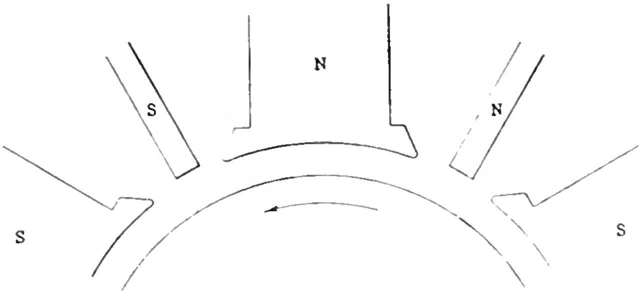


Fig 1 Polarity of Interpoles in the Case of a Generator

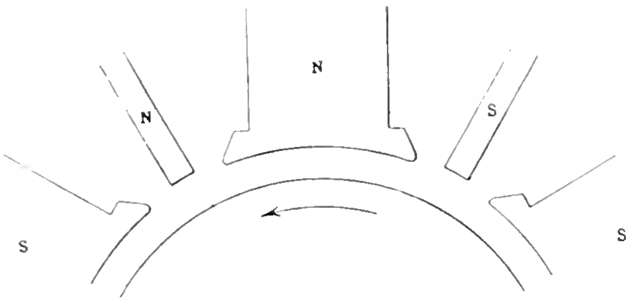


Fig. 2. Polarity of Interpoles in the Case of a Motor

Series Field of Compound-Wound Machines

A generator running at constant speed will have its volts increased as load increases when the series field is correctly connected, and to obtain any degree of compounding it is usual to insert a low resistance or diverter in parallel with it, which can be adjusted for any value of voltage desired. In this way drop in engine speed can be compensated for between no load and full load as well as compounding, and there is no drawback to the use of a diverter, as is the case with interpoles.

With a motor a diverter in the series field is rarely, if ever, used; the drop in speed due to the series turns can be foretold accurately enough, and there is always an allowance of 5 per cent above or below rated speed with any direct current machine. It is of the greatest importance, however, to be certain that the series field is right way when starting up for the first time, especially in a variable speed interpole machine. It would be safe in either case to run the machine light first of all. Load should then be put on very gradually, and if the speed tends to rise appreciably, it is almost certain that the series field is reversed and bucks the shunt field; and in that case the machine should be at once shut down. The shunt field of a variable speed interpole machine is extremely weak when on top speed, and the series field, if reversed, is sufficient to wipe it out altogether, with the result that the machine would either race to destruction or arc over between the brush studs, thus blowing its own circuit breaker and possibly shutting off the supply.

It is a common error also to suppose that the series field of a motor is wound to buck the shunt field, thus slightly weakening the shunt field on full load and keeping the speed constant at all loads. These differentially wound machines are rarely, if ever, to be found; the variation of 3 or 4 per cent in speed between no load and full load of a good shunt motor is quite near enough a constant for all commercial purposes, and, moreover, it appears to be forgotten that any machine must necessarily be some 3 or 4 per cent higher in speed when hot than when cold, due

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to increase of shunt field resistance and consequent weakening of field current.

Interpoles

The object of commutating poles or interpoles is to neutralize the armature reaction at all loads, and thus leave the flux from the shunt poles undisturbed as much as possible; this will then allow of good commutation with a fixed brush position at all current values.

In practice the whole of the line current is carried round these poles, and the turns are sufficient to produce from 1 to 1.5 times the reactive ampere turns on the armature, according to the air gap. The exact proportioning of these parts is very important, for if badly designed the commutation might be even worse than if commutating poles had not been supplied. These poles have their winding always put directly in series with the armature of the machine, and after the connections have once been correctly made, they will be correct under whatever conditions the machine is to work, *whether motor or generator, or for either direction of rotation*, because for any reversal of current in the armature there will be a corresponding change of current and reversal of polarity in the interpoles. The correct connection is that which produces the polarity shown in Fig. 1 for a generator and Fig. 2 for a motor. The polarity is opposite in the two cases because the reversal of the armature current reverses the polarity of the interpoles.

Cases occur in which the ampere turns on the commutating poles have too high a value; then, instead of rewinding new spools, the device of inserting a low-resistance in parallel with the interpole winding is resorted to, and by correctly adjusting this resistance the proper percentage of the total current is diverted through it, thus reducing the ampere turns on the interpoles to the correct value.

This, however, is not to be recommended, especially in cases where the load is fluctuating, because the turns on the interpoles, being wound on an iron core, possess a large amount of self-induction which resists a rapid increase of current round the poles. When load then varies with a corresponding change in current, during the change the self-induction of the interpoles prevents a rapid change of current round them, and for the moment a greater percentage than normal passes through the low non-inductive resistance in parallel with them. The interpoles do not therefore at all times correctly compensate the current values of the armatures, which results in sparking at the brushes. The difficulty could only be overcome by winding the low resistance mentioned above around an iron core, which should have approximately the same self-induction as the interpoles; the current would then be correctly proportioned between them for all changes in value.

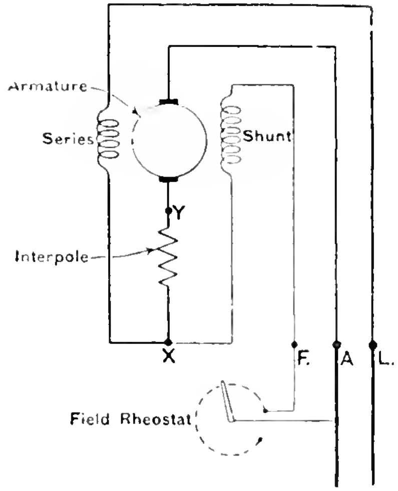


Fig. 3. Diagram of Connections for Compounded Interpole Machine

Fig. 3 shows the usual connections of interpole machines; *X*, *F*, *A*, *L* representing the terminals on the connection board of the machine. *X* serves as a terminal for the equalizer bar, if one is required, in the case of a generator running in parallel with others. *F* is the extremity of the shunt field, which is usually connected to the rheostat in the field circuit on the switchboard before being joined to the other side of the line. *A* and *L* are the armature and line main terminals coupled to the main switches. In the case of a motor the starting rheostat would be inserted between *A* and the main switch. The point *Y* is the connection of the interpole winding to one of the armature brushes; this is not brought out to the terminal board. If, therefore, the interpoles were of wrong polarity and required reversing (which would be easily detected on starting up the machine by the violent sparking when the brushes were in correct position), the connections could not be got at and the only way to overcome the difficulty would be to rock the brush gear one pole-pitch forward, thus reversing the armature relative to the interpoles.

In the case of a generator, this reversal of the armature would necessitate a reversal back again of the interpoles and armature *together* by interchanging X and A on the terminal board, thus making the relation between the armature and the shunt and series fields the same as before, and allowing the machine to build up. With a motor this reversal of the armature would reverse the rotation; and to bring back the rotation to the original, interpoles and armature together are reversed by interchanging X and A.

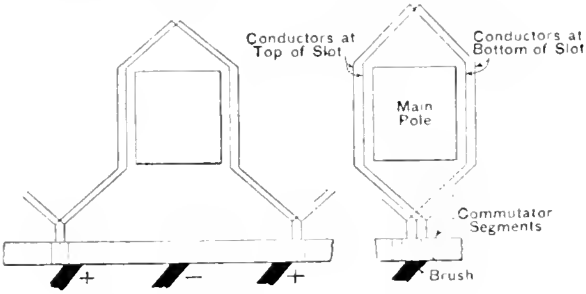


Fig. 4. Series-Wound Armature

Fig. 4a. Parallel-Wound Armature

Before considering the behaviour of these types of machines, it must be thoroughly understood at the commencement that brush position is the one all-important factor in successful operation The commutating zone of a compole machine is very accurately defined, and the smallest alteration of brush position very greatly alters the characteristics of the machines.

The electrical neutral must in the first place be arrived at. Perhaps the best method is to find the brush position on which the machines will run at the same speed as a motor in both directions of rotation for the same applied voltage. Circumstances will not allow of this always, so the following mechanical method is more common and can be relied upon to have sufficient accuracy. By reference to Fig. 4 for a series wound armature, and 4a for a parallel wound armature, the whole thing is made simple. Any armature coil is selected, and the armature is moved round until the slots in which the coil is wound are symmetrical with respect to the pole tips of a shunt pole. The commutator segments to which the conductors in this coil are connected are traced out and the brushes are moved to lie symmetrically with respect to these. This brush position can be confidently assumed to be very near indeed to the electrical neutral.

* Not the case with General Electric Machines. See Editorial.

The actual influence which interpoles have with different brush positions is very well illustrated in the following example: The machine under test was a 500 kw., 500 volt, 1,000 ampere generator, with interpoles but no series field. It was desired to run the machine on dead short-circuit with 1,000 amperes flowing. The only resistance then in circuit was that of the armature and interpoles, and it was found that with brushes on the electrical neutral the residual magnetism in the shunt poles was just sufficient to produce a voltage which caused 980 amperes to flow through the armature. When three segments forward lead were given to the brushes, the 980 amperes above were reduced to 40 amperes.

*Very often in practice, on the other hand, backward lead is purposely given to the brushes of an interpole generator when commutation will allow it; because then the interpoles are helping the shunt poles, and less shunt field current is required for any given voltage. Again, with a motor, where commutation will allow it, quite an appreciable alteration in speed can be obtained by alteration in brush position; but interpoles are not supplied very often except with variable speed motors, the regulation of which is obtained by means of resistance in the shunt field. Brush position is then very important, since other difficulties arise on high speeds which definitely fix the position of the brush gear; but these considerations will be dealt with later.

The difficulties in interpole generators are not very great. Sparkless commutation can be obtained with the brushes varying as much as two or three commutator segments; the only item which determines a fixed brush position is when the machine is required to have a certain degree of compounding. The distance of the brushes from the electrical neutral materially affects the amount of shunt field current for a given voltage, hence it will be at once seen that there is only one brush position at which the compounding at all loads will be that desired.

With interpole motors the case is different. It might be that the motor is required to be reversible; this at once determines that the brushes must be on the electrical neutral. It might be that it must run at greatly different speeds, the extreme values of which could have a ratio of 5:1; or the speed on no load must be higher than that at full load, or *vice versa*. For all these cases the interpoles require great accuracy in design to secure good results. The iron forming the pole-core should not be more than half saturated when full load current is flowing so that the flux produced is in direct proportion up to considerable overload of the current, and thus fully neutralizes the armature reactions at all loads

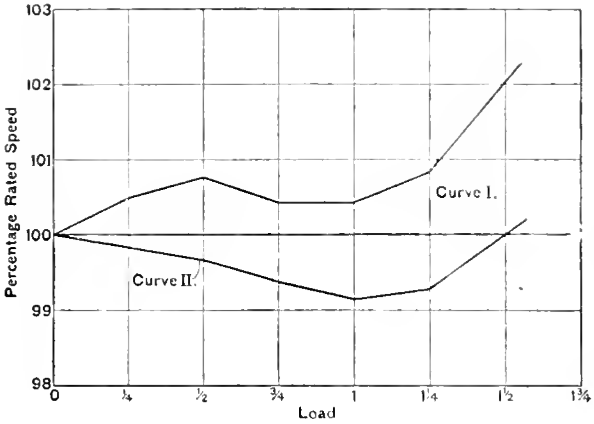


Fig. 5. Speed Characteristics of Interpole Motor
(I) Brushes in Neutral Position
(II) Brushes Given Half a Segment Forward Lead

*If possible, an interpole motor is run with its brushes on the neutral, but in many cases when the machine has become hot there might be a slight tendency for it to surge on full load, or, if not on full load, perhaps on 50 per cent overload. Besides this, the influence of the interpoles on the main field is such that the speed on full load and overload might be even higher than on no load.

Any tendency for the speed to rise on load should be remedied, because on some overload or other the machine is almost sure to surge considerably, and in the event of a heavy overload for a short period at any time it will be damaged, due to the extremely heavy surging current values or to its racing to a dangerously high speed. The only remedy for this difficulty is to give the brushes, say, half a segment forward lead (but this, of course, can not be done when the machine is reversible). The interpoles ought to allow of this and still give sparkless commutation if well designed. The additive action of the interpoles to the shunt field then keeps down the speed and at the same time keeps the field strong enough to prevent surging. Perhaps even in this case, if the speed at full load was lower than on no load, on 25 per cent overload the speed might still be higher than on full load. The machine has not necessarily a drooping characteristic at all loads; hence it is worth while to insure that the speed on 50 per cent overload is going to be very little higher, if at all, than on no load. The speed characteristic of an interpole motor of 500 volts 40 h.p., 800 r.p.m. is shown in Fig. 5. Curve I shows the speed with brushes on neutral position, Curve II with the brushes given half a segment forward lead. A good machine would usually allow of one segment forward lead being given to the brushes before sparking commences.

*A much simpler way out of the above difficulty is to supply a series winding, so that as load comes on the machine the series turns help the shunt field and keep down the speed and at the same time the machine is perfectly stable. This is done in every case with a reversible motor, in which the brushes must necessarily be fixed on the neutral. In the latter case the shunt field and series field are in permanent connection to the supply line through the main switches, of course, and the interpoles and armature together are brought out to the reversing controller. With variable speed motors the value of the shunt field current on the highest speed is very small, and in many cases in which a series winding is employed as well, the machine would safely run on top speed without any shunt field at all.

When a series winding is not employed the safety of the machine depends on this small value of shunt field current.

The connecting cables from the various terminals of the machine are often threaded in any manner through the frame between the spools, when really this simple thing is a very important consideration. These cables carry the full load current of the machine, and, lying as they do adjacent to a shunt spool, they are equivalent to half a turn practically round the spool. The influence of that number of ampere turns on the shunt spool when it is itself very weak is very considerable, and the result is that brushes collecting from conductors under its influence spark quite appreciably when all others are perfectly sparkless; there might be increase or decrease of shunt field strength, but certainly there is bad commutation. Cables of this sort should always pass between the spools in pairs, in which current passes in opposite directions.

In conclusion, a word might be said about the heating of such machines. In the first place the size for a given output has been reduced to a minimum and the space available

* Not the case with General Electric Machines. See Editorial.

is so well utilized that ventilation suffers considerably. It is safe to say that a machine whose output is limited by temperature will operate practically sparklessly at 25 per cent overload and, take 50 per cent overload for short periods without undue sparking. In many cases, too, the output can be considerably increased by the addition of a small fan on the armature shaft to aid ventilation, and by so doing the advantage of decrease in cost for a given output far outweighs any small loss in efficiency. In fact, cases often occur where, after the addition of a small fan, the efficiency is actually increased, due to the greatly reduced copper losses in the machine at the lower temperature

COMMERCIAL ELECTRICAL TESTING

PART XII

BY E. F. COLLINS

TRANSFORMERS—Cont'd.

Core Loss and Exciting Current

When a transformer is connected to a source of alternating current, a loss of energy takes place in the iron, owing to cyclic reversals of the magnetic flux. This loss of energy is known as the core loss; its value depending on the wave form of the impressed e.m.f., a peaked wave giving a somewhat lower core loss than a flat wave. It is not uncommon to find alternators giving such a peaked wave form that the core loss obtained on transformers excited by them is 5 to 10 per cent less than that obtained on the same transformers when excited from generators giving a true sine wave. On the other hand some generators give a very flat wave form, so that the core loss is greater than that obtained when sine wave is used. The core loss test is similar to the impedance test, except that voltage is applied to one winding, the other being left open circuited. Voltage should always be applied to the low potential winding in order to avoid placing meters in high potential circuits. Core loss should always be taken from a sine wave alternator and transformer connections made so that the alternator is operated at normal excitation when normal potential reading of core loss is taken.

To make this test, estimate the capacity of the meters required, connect the ammeter in circuit and take a preliminary reading of exciting current to show what meter capacity is required. Be sure to place the high tension leads so that no one can come in contact with them and that there is no danger of short circuit. The instruments should be so placed that they have no influence upon one another, and are not affected by any stray field.

A core loss curve should be taken, starting at 50 per cent of rated potential and increasing the voltage to 25 per cent above normal. To do this, hold the frequency constant and vary the voltage, taking simultaneous readings of the excitation amperes and watts core loss. Do not plot the curve as each reading is taken, but as soon as all are finished. If the curve is not smooth, repeat the test. The curve will be more satisfactory if meters can be so selected that no change in them is necessary throughout the curve. Record all meter numbers, their constants and date of calibration, temperature of iron, and numbers and ratios of potential transformers or of multipliers. Wherever possible, use the wattmeter without a potential transformer or multiplier, by connecting the transformer for the lowest potential, as this will give more reliable results.

When the normal voltage of both windings is above 5000 volts it is often more satisfactory to take core loss indirectly; that is, to read input into the secondary of a transformer used to step up to the voltage of the transformer in test. This step-up transformer should have its ratio, resistance and core loss carefully measured.

Connect the primary of the step-up transformer to the secondary of the transformer in test, putting a low reading ammeter in circuit to read the exciting current. Read volts, watts and amperes in the secondary of the step-up transformer as usual. In calculating the actual core loss, subtract the C^2R and core loss of the step-up transformer from the total wattmeter reading. While this method has its disadvantages, it is almost as accurate as that of using a potential transformer of large ratio and a current transformer and is certainly much safer. Connections for this test are shown in Fig. 48.

Parallel Run

The discussion of the parallel test is given here rather than under the heading of "ratio" or "polarity," because the heat run is the next test, and excitation voltage must therefore be provided.

Having previously tested the ratio and polarity on one of the transformers of the group, the parallel run can be made and the polarity of the others checked with the one tested; also the ratio of the remaining transformers. If the transformers differ in ratio by one-tenth of 1 per cent, the fact will be shown in the parallel run, because the test is made at the full potential of the transformer. If a transformer is one turn out, a difference of voltage between the two transformers of from 15 to 40 volts will be shown, depending upon the size of the transformer. This potential gives quite a spark and the exact amount of voltage difference may be determined by connecting a voltmeter between the two transformers.

The connections for the parallel run are shown in Fig. 49, No. 2 being the standard transformer—the one on which polarity and ratio have been taken. Only two transformers must be connected at the same time, for if voltage is on the entire set, there is more danger of some one coming in contact with the primary leads. Connect two of the transformers as shown in Fig. 49, making one side of the primary connections permanent, and arranging the other side so that the circuit may be completed with a small fuse wire of not over 3 amperes capacity. One end of this fuse wire should be carefully fastened to one end of a clean dry stick about two feet long. Close the secondary switches and by touching the frame of one of the transformers with the

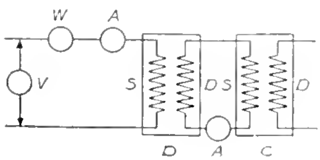


Fig. 48
Connections for Core Loss Test

fuse wire, determine whether voltage is on the transformer; a small spark indicates that the transformer is excited. Now excite the alternator, gradually bringing it up to normal potential. As soon as field is applied to the alternator, the man handling the fuse wire should begin tapping its loose end on the primary terminal of the other transformer; if no spark is seen the transformers will operate in parallel. If a small spark appears, connect a voltmeter in series and read the

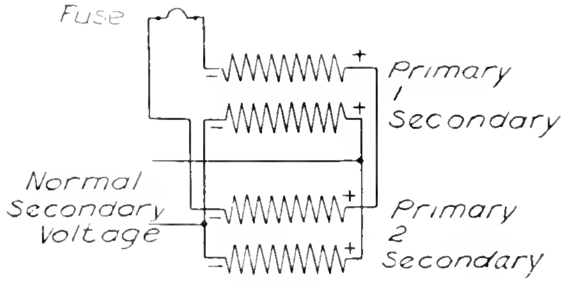


Fig. 49
Connections for Parallel Run

difference of voltage with normal potential on the transformers. If this voltage is more than one-fourth of 1 per cent of the rated voltage of the transformer, the wrong coil should be located and corrected. Instead of reading the voltage, the exchange current may be read by connecting an ammeter in the circuit instead of the voltmeter. This current should not exceed 5 per cent of the normal current. Continue the parallel tests as above, until all the transformers have been run in parallel with the one selected as standard.

If the transformer has two circuits that may be operated either in series or parallel, the parallel test should be made by connecting together the corresponding ends of these coils on one side, completing the circuit by means of fuse wire and applying full potential to the other winding of the transformer. It is just as essential that the coils of a transformer operate satisfactorily in multiple as that two transformers so operate.

Normal Load Heat Run

The heat test may be conducted in several ways, all of which are designed to approximate as nearly as possible the operating conditions of the transformers. A run with actual load might be made by using water rheostats, but as this would be very expensive, some form of motor-generator method should be used. Fig. 50 shows the connections for testing two transformers by the motor-generator method. The secondaries of both transformers are connected in multiple and then connected to an alternator which supplies the core loss and exciting current. The primaries are connected in series, opposing each other; if the transformers have the same ratio, the voltage from A to B will be zero.

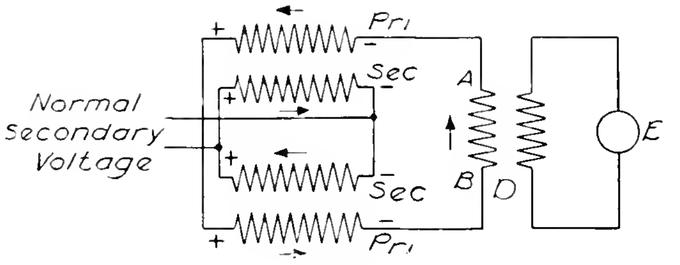


Fig. 50
Connections for Heat Run

The secondary of an auxiliary transformer D is connected in series with the primaries of the transformers in test. Alternator E connected to the primary of transformer D supplies the copper losses. The same method may be used for any even number of transformers, but it is not advisable to run more than six at one time. Fig. 51 shows connections for the heat run on three transformers, the primaries and secondaries of which are connected in delta. Across one corner of the delta, impedance voltage is impressed for the three transformers connected in series. The current circulates within the delta and is entirely independent of the secondary voltage.

The two methods outlined above require only sufficient power to supply the losses.

In arranging for the heat run, see that the alternators and transformers are of sufficient capacity to carry the load; the current necessary to supply the iron losses being equal to the sum of the exciting currents of the transformers. If the transformers have several secondary coils, connect them in series so that when the heat run is completed no time will be lost in making connections for measuring hot resistance. The alternator supplying the core loss should operate at normal excitation; the voltage required to supply the load current being equal to the impedance voltages of the transformers. If there is more than one primary, arrange to run them in series if possible. If the transformer is to have a 50 per cent overload test, add 50 per cent to the voltage already obtained.

Shop transformers should always be interposed between the primaries of the transformers in test and the alternators to prevent the breaking down of the armature and to avoid high potentials on the switchboards. "Step" the voltage either down or up, or down and up again, depending upon circumstances; but always have transformers between the alternator and the primaries of the transformers in test. Having made connections, place a man on guard to prevent any one coming in contact with the wiring; then see whether the proper load and overload can be obtained. There should be some resistance left in the field of the alternator so that as the alternator fields and the winding of the transformers heat up, the load can be kept normal.

Place spirit thermometers in the top of each transformer to read the temperature of the air escaping from the coils. Two thermometers should be used for the primary and two for the secondary windings, placing them about one inch above and just over the ducts between the coils. Also, place two thermometers on the core to read the temperature of the iron, one near the top and one near the bottom, and two thermometers to read the temperature of the air escaping from the iron. The transformers can now be loaded. With the alternator running at proper speed, the total exciting current of the transformers should be read and the secondary voltage can be checked.

Air blast transformers are usually run at full load for 50 minutes without air, in order to heat them up and thus shorten the heat run. Some transformers can not be operated for more than 20 minutes without air and they must be carefully watched to see that they do not get too hot. After the air blast is put on, it is usually necessary to keep the iron damper closed for some time to allow the core to heat up, as the copper heats much faster than the iron. The amount and pressure of air required depends on the guarantees as to temperature and to some extent on the voltage of the transformers. The large amount of insulation on the coils of high voltage transformers tends to retard radiation.

If transformers are guaranteed for a maximum temperature rise of 40° C. at normal load, and 55° C. rise after a 25 per cent overload for two hours, the air should be adjusted to give about 35° rise on the copper and 40° rise on the iron. If the iron seems too hot, increase the air pressure, partially closing the top damper; if the copper is too hot, increase the pressure and partially close the lower damper.

If the transformers are guaranteed for a maximum rise of 35° C. at normal load and 55° rise after 50 per cent overload for two hours, the air should be adjusted to give about 30° rise on the copper and 35° rise on the iron. These adjustments should be carefully made during the first hours of the heat run.

When properly adjusted the transformers should run about four hours at a practically constant temperature. Place the thermometers for measuring the room temperature near the intake of the blower so as to get the temperature of air delivered to the transformers. Read all thermometers and take the resistance on one winding of each transformer every hour. Iron temperatures may be read while the transformers are under load, since the frames are grounded. If primary leads are brought out at the top of the machine, the voltage should be cut off when taking other readings; if, however, the transformers are bottom connected, the temperatures may be read while the machines are under load. If it can be avoided, do not change the position of thermometers when taking readings.

When ready to measure resistances, shut down the blower, take off the load and measure the resistances as rapidly as possible, so as not to allow the transformers to cool off. One minute per transformers should be ample time for these readings. The rise by resistance is calculated as follows:

t = Cold temperature of coil.
T = Hot temperature of coil.
R_t = Cold resistance of coil.
R_T = Hot resistance of coil.

$$T = (238+t)\frac{R_T}{R_t} - 238.$$

$T - t$ = Rise in degrees C.

During the heat run a car ful inspection should be made for loose laminations. If any transformers are found that rattle or buzz, due to loose iron, they should be plainly tagged and a chalk mark made on the core as near as possible to the point at which buzzing was heard. The heat run and other tests should now be finished, except the double and high potential tests, which must always be taken after all repairs are made.

It sometimes happens that the iron casings are loose, causing them to rattle. Tighten up all the screws, and if this does not stop the noise, strips of felt must be placed between the sheet iron casing and the cast iron corner castings, cap and base. If this defect is

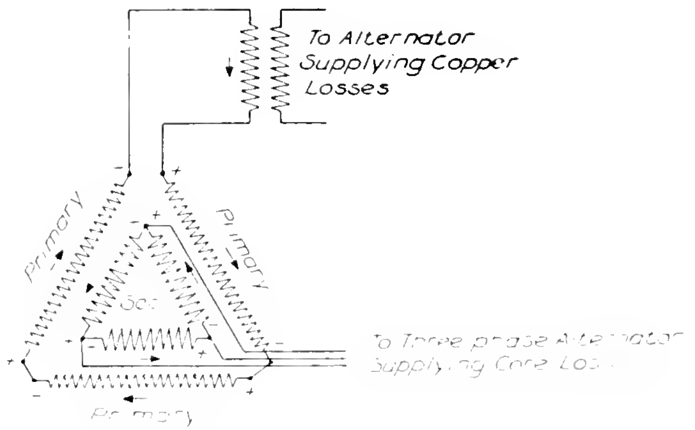


Fig. 51
Connections for Heat Run

discovered during the first part of the heat run, it should be repaired before the heat run is continued; if not, repairs will be made directly the heat run is finished. After such repairs, always apply full voltage at normal frequency to see if the trouble has been remedied. If a motor-generator method can not be used, the copper and iron heat runs may be taken separately.

To make a short circuit heat run, short circuit the secondary windings and apply normal current to the primary. When this test is finished and the hot resistances taken, open-circuit the primary, arranging the primary leads so that there is no danger of any one being injured, and apply normal voltage at proper frequency to the secondary until the iron temperatures are constant. Finish up the tests as if the heat run were taken by the motor-generator method. The same amount of air will be required and the heating will be practically the same as though both iron and copper were loaded at the same time.

At the end of the heat run measure all resistances carefully and read the thermometers. The same care should be used as when taking cold resistances, and if any set of readings indicates a doubtful increase of resistance, the readings should be checked, using a different set of meters. If the work is properly conducted, ten minutes is ample time to take a complete set of resistance readings on four transformers. A careful inspection of all soldered joints should be made to see that there is no undue heating.

When no overload is specified, the transformers must be run for 20 minutes at 50 per cent overload current to test soldered joints. This test follows that of hot resistance.

Overload Heat Runs

This test is ordinarily limited to two hours and is taken as a continuation of the normal load heat run. Engineering instructions should always specify the overload tests required.

Transformers are sometimes designed to run continuously at overloads, or may be guaranteed to operate at a certain kilowatt output at some power factor less than unity. Overload heat runs should be very carefully watched, particularly those of short duration. Special attention should be given to the length of the run, as the temperatures often rise very rapidly. At the finish of the heat run, record all temperatures and measure all resistances. The same air pressure should be used for the overload as for the normal load.

Insulation Test Double Potential Test

In this test, as well as in the core loss and impedance test, the alternator supplying the voltage should be operated at as near normal voltage as possible, so as to avoid distortion of the wave form Double potential is applied to test the insulation between turns and between sections of the coils. Since it is impossible to obtain double voltage on a transformer at normal frequency, due to high density in the iron, the frequency must be increased. Apply twice the normal voltage for one minute, followed by one and one-half times normal voltage for five minutes. The last test is taken in order to discover any short circuits that might develop during the double potential test, and yet not become apparent in the short time that the double potential is applied. The primary bushings should be cleaned before the test and the transformer guarded to prevent accidents from the high voltage circuits. Any buzzing or leakage of current should be noted.

In applying and taking off the high potential, vary the alternator field gradually; that is, do not open the field switch with a jerk, for if this is done trouble is very likely to occur. As soon as this test is taken, make the proper comments on the test sheet.

In case a transformer breaks down, the defective coil should be located and plainly marked. Then, in disassembling the machine, the coil can be easily found and the cause of the defect ascertained, thus preventing a repetition of the breakdown.

Air Readings

The method at present used is to read the velocity of the air through a standard orifice by means of an air meter. Knowing the velocity and the area of the orifice, the cubic feet per minute can be easily calculated. A large box with an opening in the bottom should be held against the transformer, using a small piece of felt as packing and being careful to allow no air to escape. The size of the orifice should be noted, and the time that the air meter is allowed to run. Always record the reading in cubic feet per minute. The air readings are to be taken with the dampers in the same position that they occupied during the heat run, and at the same air pressure.

High Potential Test

The application of a high potential to the insulation of a transformer is the *only* method for determining whether the dielectric strength is sufficient for continuous operation. Mechanical examination amounts to little and measurement of insulation resistance is equally valueless, since insulation may show high resistance when measured by a voltmeter with low voltage, but offer comparatively little resistance to the passage of a high tension current.

The insulation test which should be applied to the windings of a transformer depends upon the voltage for which the transformer is designed. The voltage to be applied should always be obtained from standing instructions, or from engineering notices. In testing between the primary and the core or the secondary, the secondary should be grounded for the following reasons: In testing between one winding and the core, a potential strain is induced between the core and the other winding which may be much greater than the strain to which the insulation is subjected under normal operation, and therefore greater than it is designed to withstand. In testing between the primary and the core, the induced potential between the secondary and core may be several thousand volts, and the secondary may thus be broken down by an insulation test applied to the primary under conditions which would not exist in normal operation. During the test, all primary leads, as well as all secondary leads, must be connected together. If only one terminal of

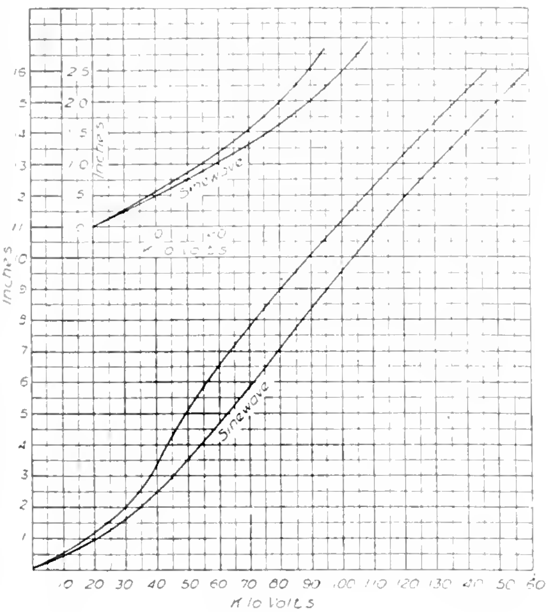


Fig. 52
Curve of Arc Distances

the transformer winding is connected to the high potential transformer, the potential strain may vary throughout the winding, and at some point may even be greater than at the terminal of which the voltage is applied. Under such conditions, the reading of the electrostatic voltmeter or the arcing across the spark gap affords no indication of the insulation strain. Indications which are best learned by experience reveal the character of the insulation under test.

The charging current of a transformer varies with its size and design. The current may be measured by means of an ammeter, placed in the low potential circuit of the testing transformer. It will increase as the voltage applied to the insulation is increased. Inability to obtain the desired potential across the insulation may be due to large electrostatic capacity, or to the inability of the high potential transformer to supply a large capacity current at the voltage desired. A breakdown in the insulation will result in a drop in voltage indicated by the electrostatic voltmeter. An excessive charging current will flow and the insulation will burn if the discharge is continued for any length of time.

For any test above 10,000 volts always use a spark gap, setting it according to the sine wave curve of arcing distances (Fig. 52). Use a new set of needles each time. Connect both ends of the primary winding to one terminal of the high potential transformer and ground both ends of the secondary to the core and frame, connecting the other terminal of the high potential transformer to the frame. Set the spark gap for the voltage to be applied and connect in the proper electrostatic voltmeter. Be sure that everything is clear, then apply the voltage, bringing it up gradually until the gap arcs over. Then decrease the voltage until the arcing ceases and again bring it up just to the arcing point, holding this voltage for one minute before gradually taking it off. A note of the charging current should be made on the record sheet.

When a transformer breaks down, the defective coil should be located by making it "smoke up." In doing this, burn only enough to show the coil. If much damage is done by smoking it may be impossible to discover the cause of the break-down.

(To be continued)

THE STEAM TURBINE

Part II

By Dr. Ernst J. Berg

The first turbine of the impulse type had but a single wheel, and while this design has been used extensively, its principal drawback lies in the fact that its efficient speeds are far higher than can be used to advantage without the introduction of gearing.

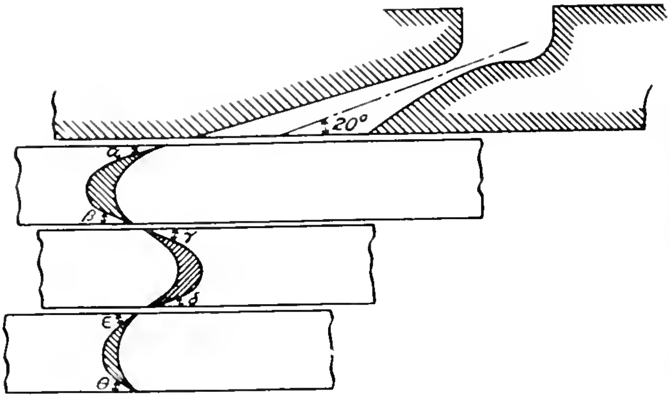


Fig. 1

To convince you of the correctness of this statement, we will proceed to determine the relations between steam velocity and available energy.

We have obviously,

$$\tfrac{1}{2} M v^2 = \text{available energy};$$

$$\text{thus} \quad v^2 = \frac{2 \times \text{available energy}}{M}$$

$$\text{or since the mass } M = \frac{W}{g} = \frac{\text{weight}}{\text{acceleration}},$$

we get, if the available energy per pound of steam is given:

$$v^2 = 2 \times 32.2 \times \text{available energy},$$

or

$$v = 8\sqrt{\text{available energy}}.$$

We have shown before that if saturated steam is expanded from 175 lbs. to 28 in. vacuum, the available energy per pound of steam is 253,000 ft. lbs.; thus, the velocity of the steam as it enters the condenser would be,

$$v = 8\sqrt{253{,}000} = 4020 \text{ feet per second}$$

If the steam were expanded to atmospheric pressure only (when the available energy is 139,500),

the velocity would be $v = 8\sqrt{139{,}500} = 2990$.

Thus in the first case the steam velocity is about twice as great as that of a modern rifle ball; in the latter case, fifty per cent greater.

If the buckets revolve at one-half the velocity of the steam, the relative velocity of the steam in the buckets is one-half the absolute steam speed. Since, however, the bucket is moving at one-half of the original steam speed, it follows that with a relative velocity of one-half and a bucket velocity of one-half, the absolute velocity of the steam as it leaves the bucket is zero; thus all velocity has been converted to mechanical work.

Since it is a little difficult to see just why the bucket velocity should be one-half of the steam velocity, it may be well to also explain it in another way.

If the buckets stand still, then the steam, entering at say 2000 ft. per sec., would recoil with a speed of 2000 ft.; if the buckets move at a speed of 500 ft. per sec., the steam would hit the bucket at 1500 ft. It would recoil from the buckets at that speed but, since during the recoil the buckets are moving at the rate of 500 ft., the remaining velocity would be only 1000 ft. per second.

If the bucket speed had been 1000 ft., the entire velocity would evidently have been converted into mechanical energy. In a turbine, however, the steam does not enter in a direct line with the direction of the motion but, for reasons of construction, there is a certain angular difference. The angle between the nozzle and the bucket is usually 20°.

The "entrance" angles, $\alpha\beta\gamma$, (Fig. 1,) depend upon the relation between steam speed and bucket speed, the higher the bucket speed in relation to the steam speed, the blunter the angle should be in order that the steam may enter without shock—and at the same time not hit the back of the bucket. For this reason, we notice that in the second wheel of a two-wheel combination, where there is little difference between the steam speed and the bucket speed, the entrance angle is much larger than in the first wheel, where there is a great difference between the velocities.

The "leaving" angles, δ, ϵ, θ, depend upon the opinion of the designer; the smaller these are, the more the energy that can be abstracted, but the higher the buckets will be to pass a given amount of steam. The rotation loss is therefore greater, which fact is evident, since with small angles the steam path is greatly restricted, as may be seen from the figure below.

Through very careful construction the single stage turbine has been operated at bucket speeds as high as 1,400 feet per second

loss in the wheel $\frac{1}{2} mv^2 - \frac{1}{2} mv_1^2 =$

$$\frac{2645^2 - 2380^2}{64} = 20,600 \text{ ft. lbs.}$$

and the rejected energy, $\frac{1}{2} mv_2^2 = \frac{1362^2}{64} =$ 28,800,

making a total loss of 62,050 foot lbs. Therefore the bucket efficiency corresponding to indicated efficiency with engines is:

$$\frac{190,950}{253,000} = 75.5 \text{ per cent.}$$

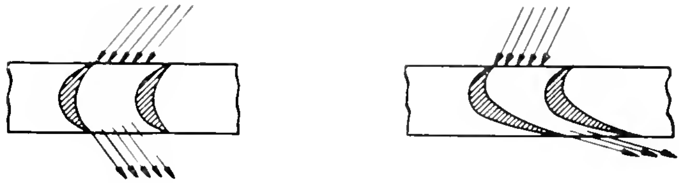


Fig. 2

(turbines of other designs do not, as a rule, go to higher speeds than 500 feet). It is of interest to all what efficiency could be expected at that speed.

Assuming, then, a speed of 1,400 feet, a nozzle loss of 5 per cent in energy, a loss in the wheel of 10 per cent of the velocity, a nozzle angle of 20°, and a leaving angle of the bucket

To overcome the difficulties connected with high rotational and linear speed, such as are necessary for good economy in the single stage turbine, Curtis introduced the multi-stage type and the use of two or more wheels in each stage. This type can most readily be understood by considering each complete turbine as made up of a number of

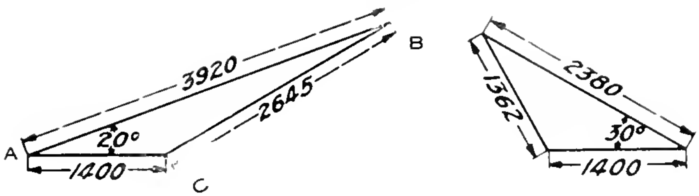


Fig. 3

of 30°, we get the diagrams of Fig. 3, which represent the steam and wheel velocities when the steam enters and leaves the bucket.

A-B is the velocity of the steam as it leaves the nozzle. It is,

$$v = 8\sqrt{0.95 \times 253,000} = 3,920 \text{ feet.}$$

A-C is the bucket speed = 1,400 feet.

B-C is therefore the relative velocity of the steam as it enters the wheel and is equal to 2,645 feet. The relative velocity of the steam as it leaves the bucket is, according to the loss assumption, 2,380 feet; therefore the velocity of the steam as it is rejected into space is 1,362 feet.

Under these assumptions, we have:

The loss in the nozzle = 0.05 × 253,000 = 12,650 foot lbs.;

smaller turbines placed in series. The pressure distribution is governed by the size of the exhaust opening in each section, which opening, as a rule, forms the nozzles for the next section.

Depending upon the pressure in each stage, the work per stage varies. With the same work per stage, in a five-stage turbine operated with initially dry saturated steam at 175 lbs. abs. pressure and 28 in. vacuum, the available energy of each stage should be:

$$\frac{253,000}{5} = 50,600 \text{ foot lbs. per lb.}$$

The shell pressures corresponding to this available energy are 75 lbs., 30 lbs., 11 lbs., 3.8 lbs., and 1 lb. abs. for the first, second, third, fourth and fifth stages respectively.

Thus, for instance, in the nozzles leading to the first stage the steam is expanded from the initial pressure of 175 lbs. abs. to 75 lbs. abs. Neglecting any losses in the nozzles, the steam velocity (which obviously is the same in all stages) as it leaves the nozzle is then:

$8\sqrt{50,600} = 1,800$ feet per second.

Two wheels running at 450 ft. per second would thus abstract all the energy in the steam.

The size of the nozzles and the expansion ratio is governed by the flow of steam through orifices. As long as the pressure at the nozzle end is less than 8 per cent of the initial pressure and the steam is dry and saturated.

Napier's law, $F = p_1 \frac{a_1}{70}$

or Grashof's law, $F = \frac{p_1^{.97} a_1}{60}$, gives results which closely agree with observed values.

Of the two laws, Grashof's seems preferable, at least at low pressures, when Napier's law gives values of flow somewhat smaller than those actually obtained. For instance, the two laws agree within about 2 per cent for pressure ranges from 80 to 200 lbs., but with a pressure of 15 lbs., Napier's law gives values about 7 per cent low and at 5 lbs. 11 per cent low.

Napier's law has the great advantage of simplicity and is therefore preferable if a constant is applied, which depends upon the initial pressure.

$$F = p_1 \frac{a_1 k}{70}$$

Where:

F = flow of saturated steam in lbs. per second.

p_1 = initial pressure in lbs. abs.

a_1 = throat area in square inches.

k = constant = 0.995 for $p_1 = 200$ lbs. abs.
= 1. for $p_1 = 175$ lbs. abs.
= 1.01 for $p_1 = 120$ lbs. abs.
= 1.02 for $p_1 = 85$ lbs. abs.
= 1.03 for $p_1 = 62$ lbs. abs.
= 1.04 for $p_1 = 47$ lbs. abs.
= 1.06 for $p_1 = 25$ lbs. abs.
= 1.08 for $p_1 = 13$ lbs. abs.
= 1.12 for $p_1 = 3.5$ lbs. abs.

The flow with superheated steam is reduced 6.5 per cent for each 100° Fah. Thus the equation becomes:

$$F = p_1 \frac{a_1 k}{70} (1 - .00065\, t_1)$$

where t_1 is the number of degrees superheat.

With moist steam the flow is increased approximately inversely as the square root of the quantity x.

Therefore the general equation of steam flow when $p_2 = 58p_1$, whether the steam is superheated, saturated, dry or moist, can be expressed by:

$$F = p_1 \frac{a_1 k\, (1 - .00065\, t_1)}{70\sqrt{x}}$$

Example:

Initial pressure, $p_1 = 100$ lbs. abs.
Final pressure, $p_2 = 50$ lbs. abs.
Superheat, $t_1 = 100°$ F.
Area, $a_1 = 1$ square inch.

We have then: $k = 1.015$, and $x = 1$.

Thus: $F = \frac{100 \times 1 \times 1.015 \times 0.935}{70} =$ 1.35 lbs. per sec.

and with steam of 3 per cent moisture the flow would have been:

$$F = \frac{100 \times 1 \times 1.015}{70\sqrt{.97}} = 1.48 \text{ lbs. per sec.}$$

When the difference of pressure is less, that is, when p_2 0.58 p_1, the flow through a given orifice is less than that given above and changes with the shape of the nozzle.

Grashof gives the following formula for saturated steam:

$$F = \frac{p_1^{0.97} \times a_1 k_0}{60}$$

Where $k_0 = 1$ for $\frac{p_2}{p_1} = 0.58$
$= 0.9$ for $\frac{p_2}{p_1} = 0.76$
$= 0.8$ for $\frac{p_2}{p_1} = 0.83$
$= 0.7$ for $\frac{p_2}{p_1} = 0.88$
$= 0.6$ for $\frac{p_2}{p_1} = 0.915$
$= 0.5$ for $\frac{p_2}{p_1} = 0.945$
$= 0.4$ for $\frac{p_2}{p_1} = 0.955$
$= 0.3$ for $\frac{p_2}{p_1} = 0.985$

This formula has been verified by Gutermuth when a non-expanding nozzle was used; however, with a nozzle having expansion he found the flow to be somewhat greater

Having determined the volume of the steam from the tables and its velocities in the various paths, we can readily proportion the actual dimensions of the buckets.

The nozzle throat area, that is, the smallest area of the nozzle, is found from the equation of the flow of steam.

The largest area of the nozzle, or what is equivalent, the expansion ratio, is also determined from the same equations, taking account, of course, of the fact that a considerable part of the steam is often converted to water by the expansion in the nozzle, and therefore the area is less than would be the case if the exhaust were dry.

The relation between bucket efficiency and bucket speed can best be shown by Fig. 4, where the bucket efficiency is plotted against

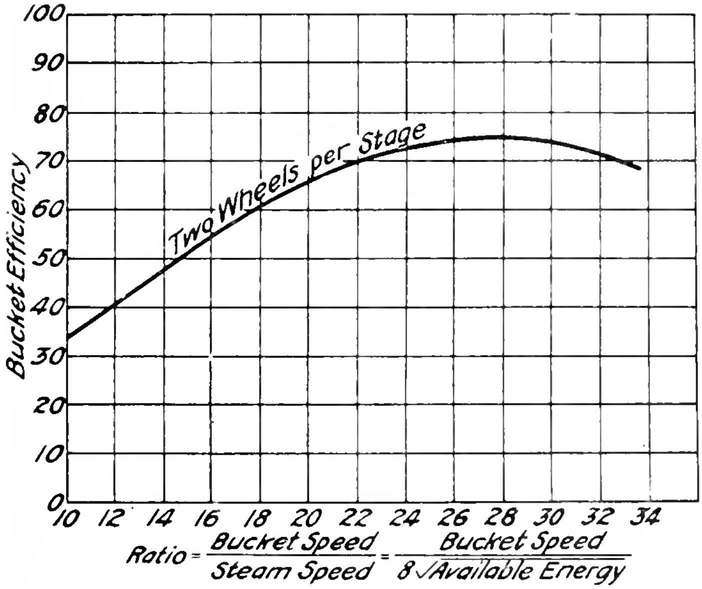


Fig. 4

the ratio of bucket speed to theoretical steam speed.

It may seem strange that with a two wheel combination the maximum efficiency is reached when the speed of the buckets is 28 per cent of the steam speed, since even if there were no losses in velocity or energy, all speed could be abstracted by a two-wheel combination at a bucket speed only 25 per cent of the steam speed. This would be the case if the action were purely of the impulse type, but as the buckets have to be constructed, there is some slight expansion in the steam while passing from the nozzle through the turbine, this expansion resulting in a velocity in the second wheel which is greater than should be expected from the pure impulse type.

Referring now to Fig. 4 if there were no rotation losses, the maximum efficiency of the turbine could be expected to be 75 per cent and the efficiency of the complete unit, including generator, say 72 per cent.

This figure has not, however, been reached at the present time. A combined efficiency of 68 per cent is as high as can be claimed by any manufacturer.

The rotation loss is often of considerable magnitude.

This loss is proportional to the third power of the linear speed, that is, the bucket speed. It is practically proportional to the square of the diameter and directly proportional to the absolute pressure.

As rotation loss formulæ are very different with different types of turbines and arrangements of buckets and diaphragms, no general equation can be given, but different constructions demand different constants.

For a two wheel combination a fair approximation can be obtained as follows:

$$KW = 0.0003\, p \left(\frac{u}{100}\right)^3 D^2$$

Where KW = kilowatt loss,
p = absolute pressure in the stage,
u = bucket speed feet per second,
D = diameter at bucket in feet.

As an instance, the rotation loss in the second stage of the five-stage turbine discussed, which runs at 750 kw. and has a bucket speed of 165 ft. is:

$$KW = 0.003 \times 30 \times 1.65^3 \times 11.8^2 = 125 \text{ kw.}$$

The total rotation loss in the entire turbine will be about 500 kw., or 3.5 per cent of the output of a 14,000 kw. turbine.

To conclude, it is hoped that this lecture gives the necessary information for the understanding of the action of steam in turbines. Of course, important features enter in the design, which can not be explained briefly or by equations, such as practical clearances around wheels, effect of highly polished nozzles and wheels, etc. These details must be studied experimentally, not only with each type of turbine, but with different sizes of each type.

INSULATION AGAINST ELECTRICAL IMPULSE FORCES

By Dr. C. P. Steinmetz

In the insulation of electric circuits for medium and high voltages a safety factor of 4 is used. That is, while normally the rated voltage comes across two insulations, the apparatus is tested with double voltage across single insulation. Experience has shown this is sufficiently high for standing indefinitely the voltages constantly existing in the circuit. Nevertheless break downs of the insulation occur, and will take place with increasing frequency, by transient voltages—that is, by electric impulse forces of indefinite voltage—and no safety factor of insulation that is permissible with a reasonable size of apparatus, can completely guard against such electric impulse forces.

The conditions are somewhat similar to those met in the mechanical strength. Stationary structures, intended to carry constant mechanical loads, may be designed rigidly with a chosen safety factor. Structures, however, which are exposed to mechanical impulse forces, the impact of moving masses, could not be safely designed in this manner. For instance, an automobile tested by loading it at standstill with three or four times the weight it is intended to carry, would not offer any certainty of standing the shocks met in operation, since the force exerted by a moving mass is indefinite; that is, depends on the rapidity of stoppage of the motion, and the rigidity of the structure. Thus an instantaneous stoppage of the motion, with a perfectly rigid mass, would give an infinite force, and where motion has to be stopped or changed suddenly, something must give; that is, the impact force must be taken up by elastic or unelastic deformation. Thus in the automobile, tires, springs, and the entire structure take up the impact force by their elasticity, while the friction clutch represents an instance of inelastic absorption of the impulse force resulting from the difference in speed of motor and car.

In electric circuits impulse forces of indefinite voltage may occur, even under apparently normal conditions of operation, due to the kinetic and potential electric energy of the system (the magnetic and electrostatic energy); and in large medium voltage systems such electric impulses have commonly been observed reaching intensities corresponding to a constant voltage striking distance of two or more times the circuit voltage.

Just as in a mechanical structure impact forces appear at the points where sudden changes of speed occur, so in the electric circuit impulse forces reach their greatest intensity at the points where the circuit constants abruptly change. Such points are the terminals of reactances, of transformers, and other inductive devices, and these are the danger points at which indefinite and sometimes more or less unlimited voltages may be expected, and should be guarded against.

Characteristic of an impulse force (as the mechanical force when suddenly stopping a motion, or the voltage when suddenly destroying electric inertia) is that the energy is limited but not the intensity or voltage. The latter is theoretically unlimited, and is higher the more rigid the mechanical structure, or the more perfect the electrical insulation. Fortunately, just as a mechanical structure can momentarily stand forces far beyond those which when permanently applied would result in a break down, so also electrical insulation can momentarily stand voltages very much higher than it can stand permanently.

For instance, a quarter inch air gap between needle points, which breaks down at 5000 volts permanently applied, may momentarily stand over 100,000 volts; oil and solid insulations show the effect of the time of application still more markedly.*

While the voltage of electric impact forces may be extremely high, their disruptive effect may, and in all probability usually is relatively low, due to their limited energy and therefore limited duration.

The energy which may appear in the impulse force depends on the stored electric energy of the system, and thus approximately on the size of the system and on the availability of this energy, that is, the (relative) resistance of the circuits. The larger the system and the lower the resistance of the circuits, the greater is the energy which may appear in these impact forces, and the greater therefore their disruptive effect. Relative to the normal insulation of the system, the disruptive effect of electric impulse forces is probably greatest in the large medium-voltage systems.

* Some data on the behavior of air and oil when subjected to momentary voltages are given in a paper on the "Disruptive Strength of Air and Oil with Transient Voltages", published in the Proceedings of the A I E E

As the economic area of electric supply is approximately proportional to the square of the voltage, the size of the system and therefore the disruptive effect of the impulse forces appearing in the system, increases approximately with the square of the voltage; while the voltage for which the system is insulated increases only in proportion to the operating voltage (and at low voltages is still higher). Thus in an 11,000 volt underground distribution system the relative disruptive effect of electric impulses compared with the insulation of the system, is very much greater than in a 2300 volt primary distribution system, due to the much larger size of the former and therefore greater energy of the impulses, and also the relatively lower resistance of the cables, compared with the 2300 volt distribution circuits. When we come to very high voltage (60,000 or 100,000), we find that at present the sizes (kw. capacities) of such systems are not larger, but usually smaller than the largest 11,000 volt distributions, the percentage resistance is usually much higher, and the normal insulation of the circuits so much higher that electric impulse forces again offer relatively less danger of disruption.

Thus it seems to follow that the necessity of guarding the danger points of the system, i.e., the terminals of inductive devices, against unlimited voltages of limited energy, is at present greatest in the medium voltage high power systems, the large central station distributions, and next to these in other high power low resistance systems.

An increase of the safety factor of insulation at the danger points of such systems, where impulse forces of relatively high energy may be expected, increases the protection but relatively, since the impulse voltage is theoretically unlimited, and very soon the practical limits of economic insulation are reached. Furthermore, with the increase of insulation (of "electric rigidity") the voltage of the impulse force may be increased, and thus somewhat its disruptive effect.

It appears that in protecting systems against electric impulses we should give up the conception of a definite safety factor of insulation against steady voltage and endeavor so to design the apparatus and the entire system that no voltage of limited energy, no matter how high, can cause any damage. Damage to apparatus and harm to the system is usually done by the main current following a transient discharge, but probably never by the transient discharge itself, that is, the energy of the impulse. Thus, if the apparatus can be designed so that the energy of the impulse can be by passed or dissipated by a momentary high voltage, without any possibility of a discharge to ground followed by a short circuit occurring, the apparatus should be safe.

The energy of an impulse may be reflected or by passed by capacity (the aluminum cell works largely in this manner); or it may be dissipated and the voltage of the impulse thereby kept down by electric deformation in the dielectric (the insulation absorbing energy by what may be called dielectric hysteresis) by glow discharge, corona, brush discharge, streamers or spark discharges from the terminals at which the impact occurs, or by leakage. The terminals of reactive devices should therefore be so arranged, that no limited power spark discharge from them can reach the ground and thereby cause short circuit; but it may be advantageous to make such arrangement that the discharge may reach some high resistance conductor, as wood, concrete, etc., which separates it from ground, as hereby the energy of the impulse could be destroyed without the danger of a short circuiting arc following.

Thus the problem of protection against electric impulse forces seems largely to be one of the design of apparatus, and therefore does not yet allow of a general solution, but requires each problem to be taken up individually by choosing such a design that a static spark from the terminals of the apparatus can not cause a short circuit.

In the design of reactive devices for high power medium voltage systems, the protection against electric impulse forces is a far more important and serious problem than the insulation against the normal circuit voltage or against the internal voltages originating in the apparatus.

DEVELOPMENT OF ELECTRICAL DRIVE IN THE MILLS OF THE PROXIMITY MANUFACTURING CO., GREENSBORO, N. C.

By John P. Judge

The Proximity Manufacturing Company of Greensboro, N. C., operates two large cotton mills for the manufacture of indigo blue denims.

Caesar Cone, President Proximity Manufacturing Co.

The company was organized in 1895 by Messrs. Moses H. and Caesar Cone, and associates. The Proximity mill was erected and started in 1895, its equipment including 20,000 spindles and 1000 looms. A double spinning shift was instituted, and the looms were operated only in the day time. According to the custom at that time, the power house closely adjoined the mill, a 750 h.p. Corliss engine being belted directly to the head shaft in the spinning room and separately belted to jack shafts between engine room and weave shed.

As the business of the concern increased, additions to the equipment were made until it was found that the engine was carrying about 20 per cent overload and to get satisfactory draft a fan had to be installed in the stacks. In 1900 the owners determined that better results could be got by restoring the engine to its rated load, and after a thorough investigation, decided to install a separate engine with generator to drive the weave room. This was the first step taken by the company towards its present extensive system of electric drive. The equipment consisted of a 250 kw., 100 r.p.m., 600 volt, three-phase, 40 cycle generator direct coupled to a Corliss engine, the set being erected in the power house alongside of the first engine. Three 100 h.p. motors were installed in the basement of the weave room, each motor being belted to four shafts. Two of these motors are shown on Fig. 1. In ten years continuous service the total expense chargeable to these motors has not exceeded $100.00. The only change made in this motor equipment was that automatic oil switches were substituted for the air brake switches and fuses originally installed.

Before this installation was made, careful readings were taken on the engine to determine the amount of power used in the weave room. Similar readings were taken after the motors were installed (the number of looms having been increased 10 per cent during the

Fig. 1 View in Basement Showing Motors for Operating Machines in Weave Room Located on Floor Above. Proximity Mill

meantime), which showed that almost exactly the same amount of power was required as before, but with an increased production of 15 per cent; it having been found possible to operate the looms faster with the motor drive. It was also found that for the same total output formerly carried on one engine, the two engines consumed less steam and required less coal, and incidentally the fan was not required in the stack.

In 1902 the owners decided to build a larger mill about two miles from Proximity; this mill now being known as the White Oak mill. The site is an ideal one, being well elevated and surrounded by a thick growth of pine and oak. A considerable tract of woodland is set aside as a park for the benefit of the operatives.

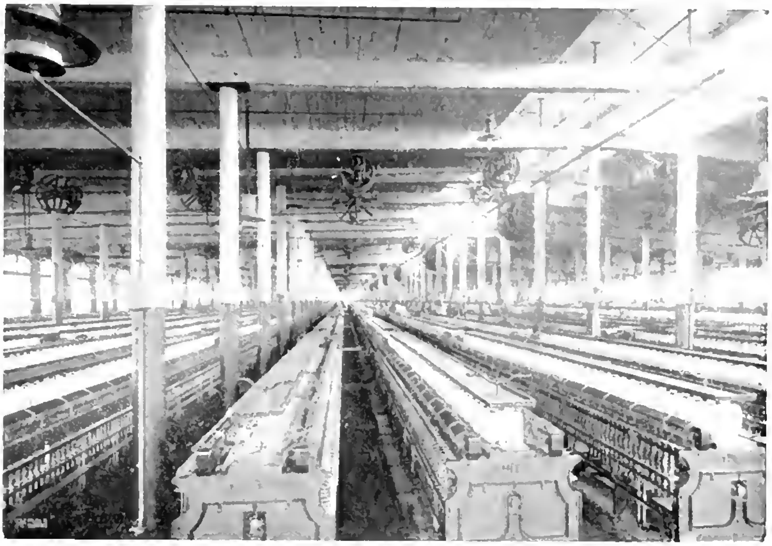
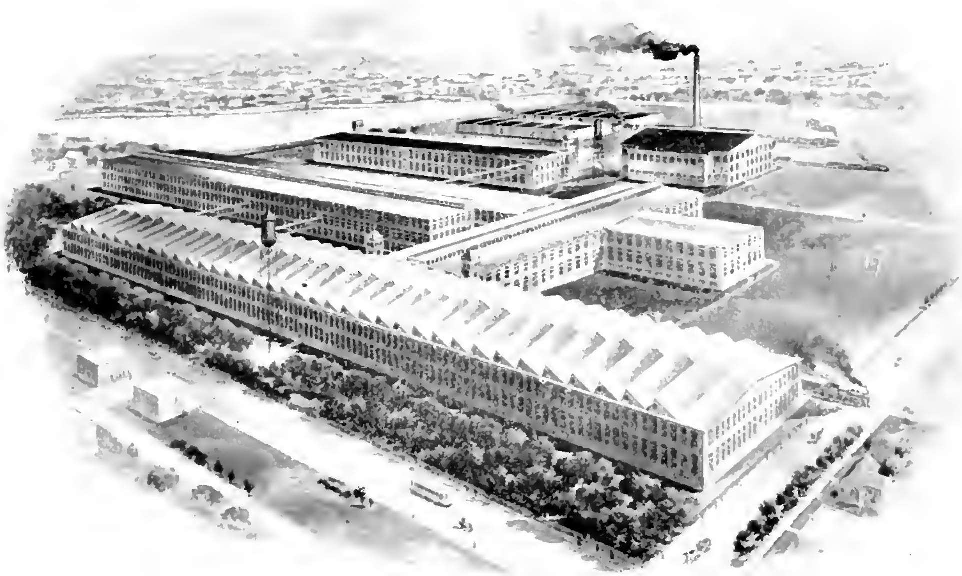


Fig. 3. Second Story of Spinning Building Containing 60,000 Spindles Operated by Seven 200 H.P. Motors Mounted on Ceiling. White Oak Mills

This mill has 60,000 spindles and 2000 looms, with the necessary preparatory machinery and dye house. The main buildings comprise a two story picker building, 312 ft. by 78 ft.; a two story spinning building, 750 ft. by 155 ft.; a weave shed, 904 ft. by 180 ft.; a dye house, 312 ft. by 105 ft.; and a power house, 264 ft. by 136 ft., with two radial brick stacks 176 ft. high, one with a 12 ft. flue and one with a 9½ ft. flue.

Fig. 2. Second Story of Picker Building Showing 200 H.P. Motors Suspended from Ceiling Rafters. White Oak Mills

The owners' experience at the Proximity mill had convinced them of the advantages of electric drive, and the White Oak mill was therefore laid out for that system of power distribution. The power house was placed to the west of the other buildings, as the land slopes in that direction, giving good facilities for the delivery of coal to the boilers and for handling the condensing water. One-half of the building is devoted to the boiler room, which contains 26 Heine water tube boilers, 16 of 200 h.p. and 10 of 250 h.p. each. The other half of the building, which is separated from the boiler room by a fire wall, is the engine and generator room, with a considerable offset for the switchboard. Two generating units were installed when the mill was built, each unit consisting of a 1250 kw., 600 volt, three-phase, 40 cycle generator direct coupled to a 2000 h.p. Corliss engine operating



White Oak Mills, Proximity Manufacturing Company

at 75 r.p.m. At the same time, there was also installed one motor-driven and one steam-driven exciter, each of 50 kw. and each capable of exciting the two generators. All feeds are carried in an underground tunnel from the switchboard to the several buildings.

Fig. 2 is a view in the second story of the picker building. The two motors shown are each of 200 h.p., 480 r.p.m., and are directly connected to the line shaft by two flexible couplings. In the first story there are three motors totalling 200 h.p., which operate the openers, etc. The first story of the spinning building contains two motors of 200 h.p. each, which operate the cards, drawing frames, slubbers and speeders. The second story contains spinning frames aggregating 60,000 spindles, together with warpers, etc., all of which are driven by four motors, each of 200 h.p., mounted on the ceiling and belted to countershafts as shown in Fig 3.

The looms in the weave shed are driven from below, the motors and shafting being located in the basement. In this building there are four motors, each of 150 h.p., 600 r.p.m., belted to four shafts. Fig. 5 shows some of

Fig. 4 Switchboard and Exciter in Power House, White Oak Mills

the motors in basement of weave room. It will be noted that this building is equipped in precisely the same manner that the weave room at Proximity was equipped five years before—good evidence that the owners were well satisfied with their first experience.

The dye house of this mill is unusually large and admirably appointed. The dyeing machinery is operated by one motor, which is of 100 h.p., a similar motor being used for driving the slashers in another section of this building. This mill is operated single shift.

In 1907 it was decided to enlarge the power house at White Oak and drive the Proximity mill therefrom, abandoning the mechanical drive, which had been retained there, except for the weave room. At the same time it was concluded to abandon night work at Proximity. This necessitated doubling the capacity of the yarn-making machinery at that mill; a new two story building 430 ft. by 130 ft. being erected for the purpose. A new dye house was also constructed and other improvements made, bringing the equipment of this mill up to 45,000 spindles and 1500 looms.

In the power house at White Oak there were added two 1500 kw., 600 volt, 40 cycle, three-phase generators, each coupled to a 2250 h.p. Corliss engine. The four units are shown on page 434, and the switchboard in Fig. 4. This view also shows the motor-driven and steam-driven exciters. When this last enlargement was made, a motor-driven exciter of 125 kw. capacity was installed.

Fig. 5. Ground Floor of Weave Room Showing 150 H.P. Motors Operating Machinery on Floor Above

To transmit the required power to Proximity, it was necessary to step up the voltage at White Oak and to step it down at Proximity. Consequently, three single-phase, 40 cycle, 1000 kw., 600 15,000 volt water cooled transformers were installed in a brick building just outside of the switchboard room at White Oak, and a steel tower line was carried to Proximity.

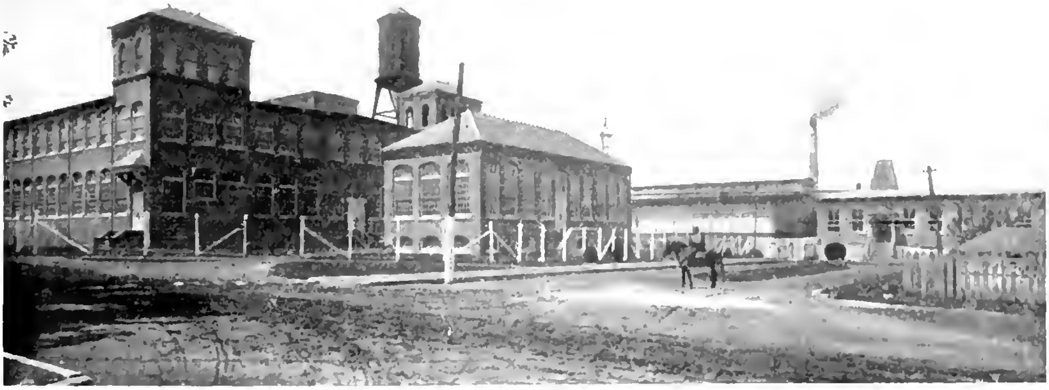


Fig. 6. Office and Substation, Proximity Mill

A substation for transformers and switchboard was also erected at Proximity; this building, which is 75 ft. by 30 ft., being shown in the foreground in Fig. 6. One end of this building is partitioned off by a heavy brick wall, and in the section so enclosed are placed three 40 cycle, 1000 kw., 15,000/600 volt, single-phase transformers and the lightning arresters, the transformers being located on a level with the ground. This section is full height of the building, giving ample room for high voltage connections. Fig. 7 shows the main section of this building. Besides the switchboard, a 250 kw. rotary converter is installed, which furnishes current for the direct current arc lamps, formerly

Fig. 7. Substation at Proximity

served by a separate engine-driven generator. The handle of the 15000 volt automatic oil switch controlling the primary of the transformers is also shown at the end of the switchboard, the switch being located in the transformer section.

Switchboards in Power House

The switchboards are of black enameled slate, and are of standard General Electric design: each generator panel equipment including a Thomson recording wattmeter, as does also the panel controlling the line to Proximity mill. On each feeder panel is an indicating wattmeter, and at the end of the board is a generator voltage regulator. These meters are read daily and a careful log is kept, by means of which the engineers are enabled to check the power output against coal consumption and also against the production of the mills. Very interesting and useful data is thus secured.

The electrical equipment is all of General Electric manufacture, and includes:

Two 64 pole, 1250 kw., 75 r.p.m., 600 volt generators.

Two 64 pole, 1500 kw., 75 r.p.m., 600 volt generators.

One 48 pole, 250 kw., 100 r.p.m., 600 volt generators.

One 50 kw., 125 volt marine set (exciter).

One 50 kw., 125 volt motor-driven generator set (exciter).

One 125 kw., 125 volt motor-driven generator set (exciter).

One 15 kw., 125 volt motor-driven generator set (exciter)

Six 40 cycle, 100 kw., 15,000/600 volt water cooled transformers.

One 6 pole, 250 kw., 250 volt, 3-wire rotary converter.

819 arc lamps.

and the following standard 40 cycle, Form "L" (wound rotor), 550 volt motors:

Ten 200 h.p.	Five 100 h.p.
Nine 175 h.p.	Two 75 h.p.
Three 150 h.p.	One 60 h.p.
Four 125 h.p.	One 50 h.p.

These mills are probably the largest consumers of cotton in the South, using approximately 60,000 bales per annum.

All mechanical and electrical problems are under the supervision of the General Superintendent, Mr. R. G. Campbell, and his assistants, Messrs. U. S. Greer, steam engineer, and W. J. Dorworth, electrical engineer.

CURVES OF REACTIVE POWER

By V. Karapetoff

Professor Electrical Engineering, Cornell University

Overexcited synchronous machines are frequently used for raising the power factor of a load, in order to reduce the line current and consequently the size of generators and transmission lines; by so doing the voltage regulation and the efficiency of the whole plant are improved. In some cases it is advisable to run overexcited synchronous machines without any load connected to them, simply to supply the magnetizing current for other apparatus fed from the same line; in this case these machines are called synchronous condensers.

From the curves on the attached curve-sheet the necessary size of a synchronous condenser, or the reactive kilovolt-amperes which must be supplied by a synchronous machine in order to correct the power factor from a given value to another given value, can be determined.

Example:

A power house supplies a load of 7500 kw. at a power factor of 80 per cent lagging. How many reactive (wattless) kilovolt-amperes must be furnished by a synchronous condenser in order to raise the power factor to 90 per cent leading?

Solution:

Select the curve (Fig. 3) which crosses the axis of abscissae at 80 and follow it beyond

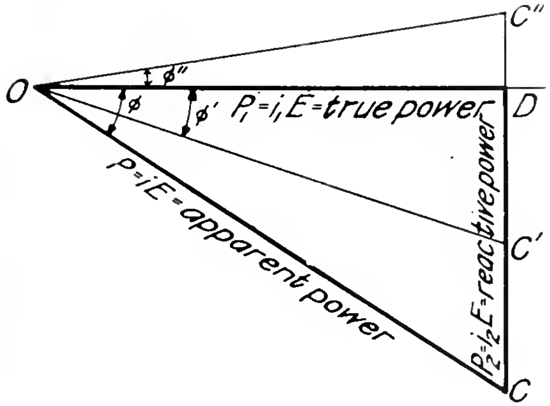


Fig. 2.

the bend. To the abscissa of 90 per cent the corresponding ordinate is 1230 kv.-a. (per 1000 kw.); hence the required size of the synchronous condenser is $1230\times7.5=9225$ kv-a.

In the same example, in order to raise the power factor to unity, $750\times7.5=5625$ kv-a. are necessary. To raise the power factor to 95 per cent lagging, only $420\times7.5=3000$ kv-a.

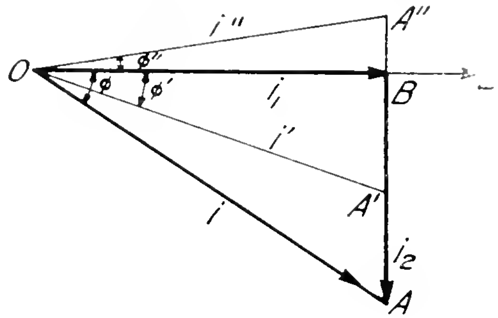


Fig. 1.

are required. The curves show that to correct the last few per cent of power factor require the most reactive power. This follows from the fact that the cosine of an angle varies very slowly with small angles: a power factor of 95 per cent implying a phase displacement between the voltage and the current of over 18 degrees.

Having determined the required reactive power from the curves, the rating of a synchronous motor is obtained by combining vectorially (at right angles) the useful power and the reactive power (Fig. 2). Thus, if the input into the motor must be, say, 5000 kw., and besides this, the motor has to supply 3000 kv-a. for compensating low power factor, the motor is rated at

$$\sqrt{5000^2+3000^2}=5830 \text{ Kv-a.}$$

at a power factor of $\frac{5000}{5830}=86$ per cent leading.

The curves were calculated and plotted as follows: In Fig. 1, let $OA (=i)$ represent the vector of the total current before the corrective reactive power is applied. Let i_1 be the energy component of the current and i_2 the wattless component; ϕ is then the angle of phase displacement between the current and the voltage. Multiplying all the three sides of the triangle by the line voltage

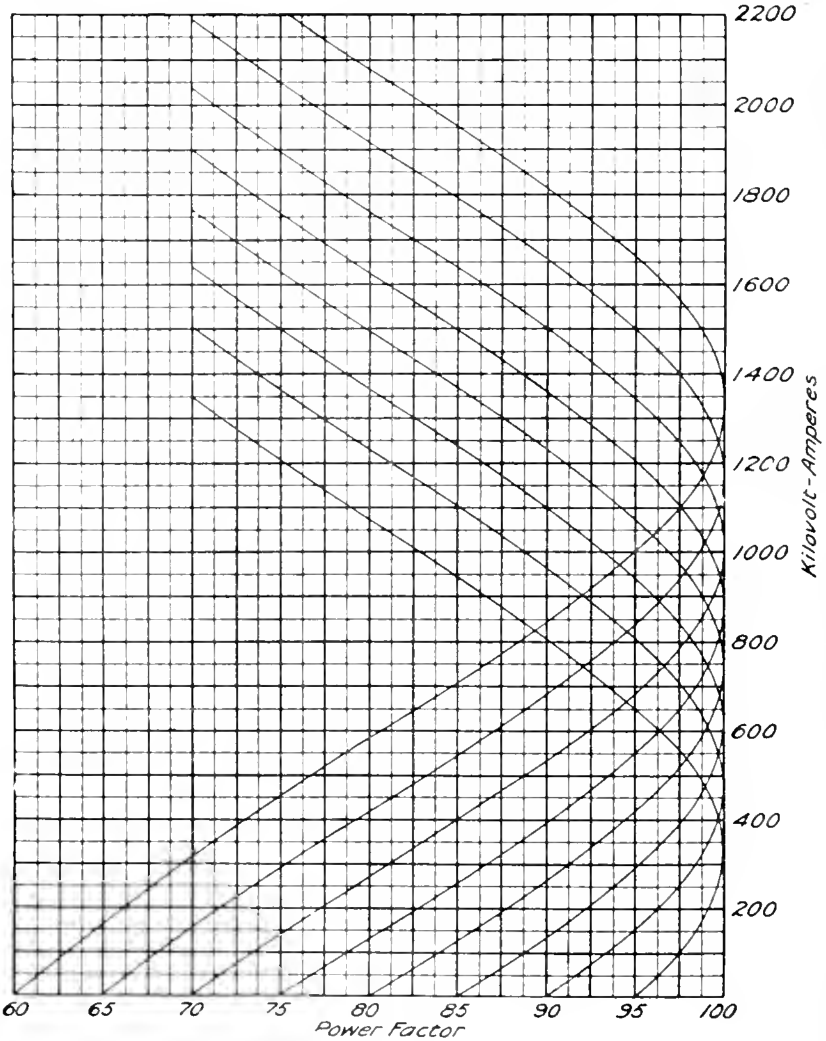


Fig. 3

E, the triangle of power (Fig. 2) is obtained. It is understood, of course, that the vectors of the currents are multiplied by the *numerical value* of the voltage, and *not* by the vector of the voltage. In Fig. 2 the hypothenuse represents the apparent power, the horizontal side the true power, and the vertical side the reactive power. If I is in amperes and E in kilovolts, P and P_2 are in kilovolt-amperes, and P_1 is in kilowatts. From Fig. 2 we have:

$$P_2 = P_1 \; tan \; \phi;$$

or, the reactive power per 1000 kw. of true power

$$P_2 = 1000 \; tan \; \phi \qquad (1)$$

Let now a leading wattless current AA^1 be taken by a synchronous motor or condenser. The generator current is then reduced to OA^1, and the reactive power supplied by the generator to $DC^1 = P^1_2$.

The new phase angle is ϕ^1, and we have:

$$P_2^1 = 1000 \; tan \; \phi^1 \qquad (2)$$

The reactive power taken by the synchronous motor is obtained by subtracting *eq.* (2) from eq. (1), or

$$CC^1 = \triangle P_2 = 1000 (tan \, \phi - tan \, \phi^1) \qquad (3)$$

This is the formula used in calculating the curves of reactive power. If the reactive power taken by the synchronous motor or by a condenser is so large that the generator current OA'' leads the voltage, formula (3) becomes

$$\triangle P_2 = 1000 (tan \, \phi + tan \, \phi'') \qquad (4)$$

In other words ϕ' in formula (3) must in this case be considered negative.

The following table shows the method of obtaining a few points on the curve corresponding to the initial power factor of $cos \; \phi = 80$ per cent lagging. For this power factor the angle $\phi = 36° \; 50'$; $tan \; \phi = .749$.

These values of P_2 are plotted against the corresponding values of $cos \; \phi'$ as abscissae.

	LAGGING			LEADING	
$Cos \; \phi' =$	0.90	0.95	1.00	.85	0.75
$\phi' =$	25° 50′	18° 10′	0°	−31° 50′	−41° 20′
$Tan \; \phi' =$	.484	.328	0	−.621	−.880
$\therefore P_2 =$	265	421	749	1370	1629

The other curves are obtained in a similar manner, beginning with different values of the initial power factor $cos \; \phi$.

MOTOR OPERATED BOAT HAUL AND FERRY

By W. D. Bearce

Coincident with the increasing tendency to install electric drive for all industrial purposes, there is an equal tendency to make use of electricity for all sorts of labor saving devices. While the electrical operation of a boat haul, an example of which is here illustrated, is not an uncommon application of electric power, its employment for the propulsion of a ferry boat is rather a novel feature.

The boat house of the Edison Club, Schenectady, N. Y., is located on an arm of the Mohawk river, opposite a large island upon which the club has obtained ground for tennis courts, a baseball diamond, etc. The use of any kind of bridge is impractical on account of high water and ice in the spring; for the same reason the boat house had to be placed about 25 feet above and 50 feet back from the river at its normal water level. As may be seen from the illustrations, all the auxiliary apparatus is simple in construction, being of the home-made variety.

Fig. 2. Arrangement for Operating Ferry Boat

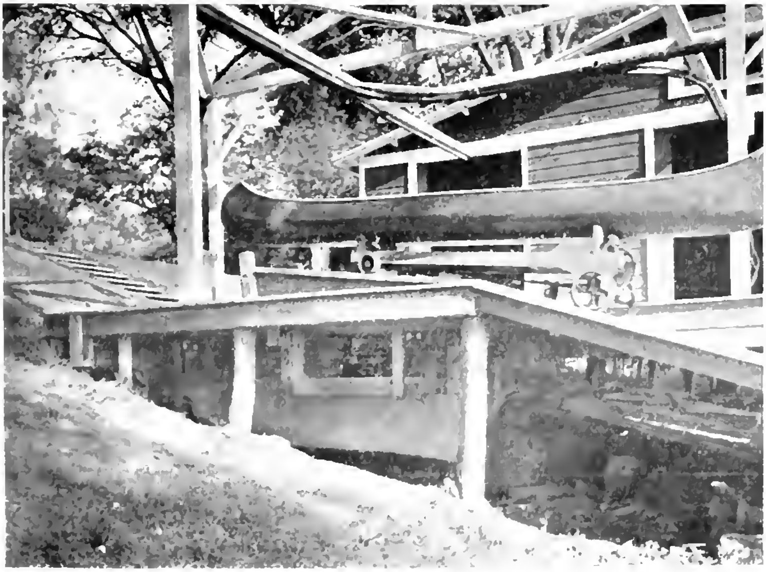


Fig. 1. Mechanism of Motor Operated Boat Haul

Three-phase current was available from local power mains; a two horse-power motor was therefore belted up to a suitable drum for operating the boat haul. This apparatus is supported from the under side of the platform as shown in Fig. 1; this arrangement allowing a rope to pass from the drum up through the platform to the car. An improvised brake, shown in the extreme left of the figure, is mounted on the shaft with the drum and equipped with a solenoid and plunger for releasing.

The movement of the car is controlled by a three-pole double-throw switch so connected that when thrown down current is sent through the solenoid, releasing the brake and allowing the car and its load to descend by gravity. By opening the switch the brake is operated and the car brought to a stop. Throwing the switch up connects both solenoid and motor to the supply mains, thereby revolving the drum in the opposite direction.

For supplying motive power to the ferry-boat operating between the main land and the island, another 2 h.p. induction motor was adapted to the frame of an old suction pump, the pistons being replaced by a drum. Back gearing reduces the speed to a low value and the driving rope, through suitable pulleys, takes half a turn on the drum. The slack rope is taken up by a comparatively heavy idler, shown at the left of the picture.

When an extra strain is exerted, as at starting or in case of any obstruction, the taut rope lifts the idler, thus allowing the drum to slip under the rope. A single rope carrying balanced weights at each end, operates a double throw reversing switch which can be operated from either side, or from the boat. Stop blocks on this rope automatically bring the ferry to a stop at either landing.

NOTE

In preparing copy for Fig. 11 of Mr. Baum's article on Fire Damp Apparatus, appearing on page 406 of the September issue of the REVIEW data which is essential to an understanding of the diagram was omitted. For the sake of clearness, we republish the diagram, together with the necessary key.

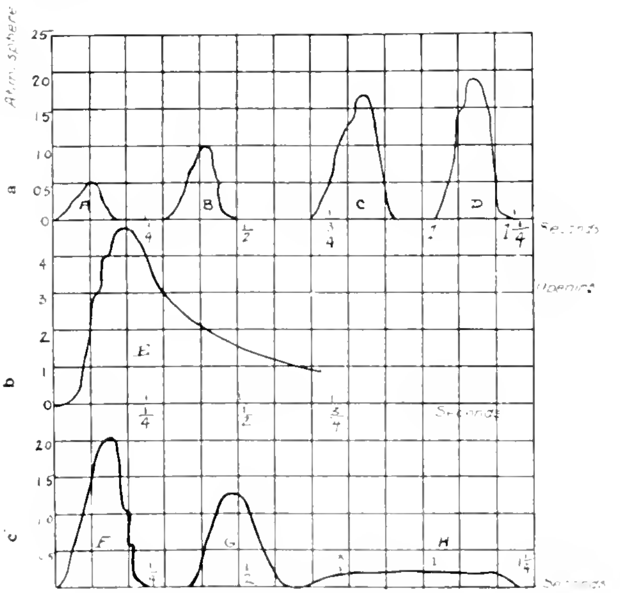


Fig. 11, a and b. Pressure Corresponding to Various Cross Sections of Openings for Rich Mixture and Same Position of the I nition Point, c, Pressure Corresponding to Distance of Ignition Point from Opening for Same Mixture and Size of Opening

A, opening, 2.72 sq. in.
B, opening, 2.22 sq. in.
C, opening, 1.24 sq. in.
D, opening, 1.02 sq. in.
E, opening, 0.28 sq. in.
F, ignition in back.
G, ignition in center.
H, ignition in front.

OBITUARY

Mr. Theodore P. Bailey, Assistant Manager of the Philadelphia Office of the General Electric Company, died at his home in Mt. Airy, Philadelphia, on Saturday, August 20th, as the result of a delayed operation for appendicitis.

Mr. Bailey was born in Covington, Ky., August 17, 1856, and was educated in the public schools of Princeton, Ill. Completing his school course, he engaged in newspaper work in the latter town and later took up the study of stenography, securing a position as court stenographer, first at Morris, Ill., and then at Joliet, Ill. While engaged in this work, Mr. Bailey made a study of law and in 1881 was admitted to the bar at Ottawa, Ill. In the following year he moved to Chicago and entered the employ of the Thorn Wire Hedge Company, at the head of which was General A. K. Stiles. General Stiles and Norman T. Gassette were the original promoters of the Van De Poele Electric Company, and in 1883, through the influence of the former, Mr. Bailey became associated with this concern, and from that time on devoted his attention to electrical matters.

In 1885 he accepted a position with the Chicago office of the Thomson-Houston Electric Company, acting as Western representative of that concern and, after its merger with the General Electric Company, continued in charge of the street railway work of the Chicago office, later becoming assistant manager of the office.

In 1905 he resigned his position with the General Electric Company to enter the railway contracting business as Vice-President and General Manager of the L. E. Myers Company, of Chicago. He remained with this concern until 1907, when he accepted a position with the automobile department of the St. Louis Car Company. In the fall of 1908 he again entered the employ of the General Electric Company, as assistant manager of the Philadelphia office.

Mr. Bailey was one of the first men to introduce electric railways in the West, and for many years was one of the most widely known men in the street railway circles of that section. Among the principal installations in which he was interested were those at Des Moines, Iowa; Omaha, Nebr.; Topeka, Kans.; Ottawa, Ill.; St. Louis, Mo.; Kansas City, Mo.; Minneapolis, Minn.

At the time of his death Mr. Bailey was a member of the Chicago Automobile Club, Chicago Athletic Club, White Marsh Country Club, and an associate member of the American Institute of Electrical Engineers.

GENERAL ELECTRIC REVIEW

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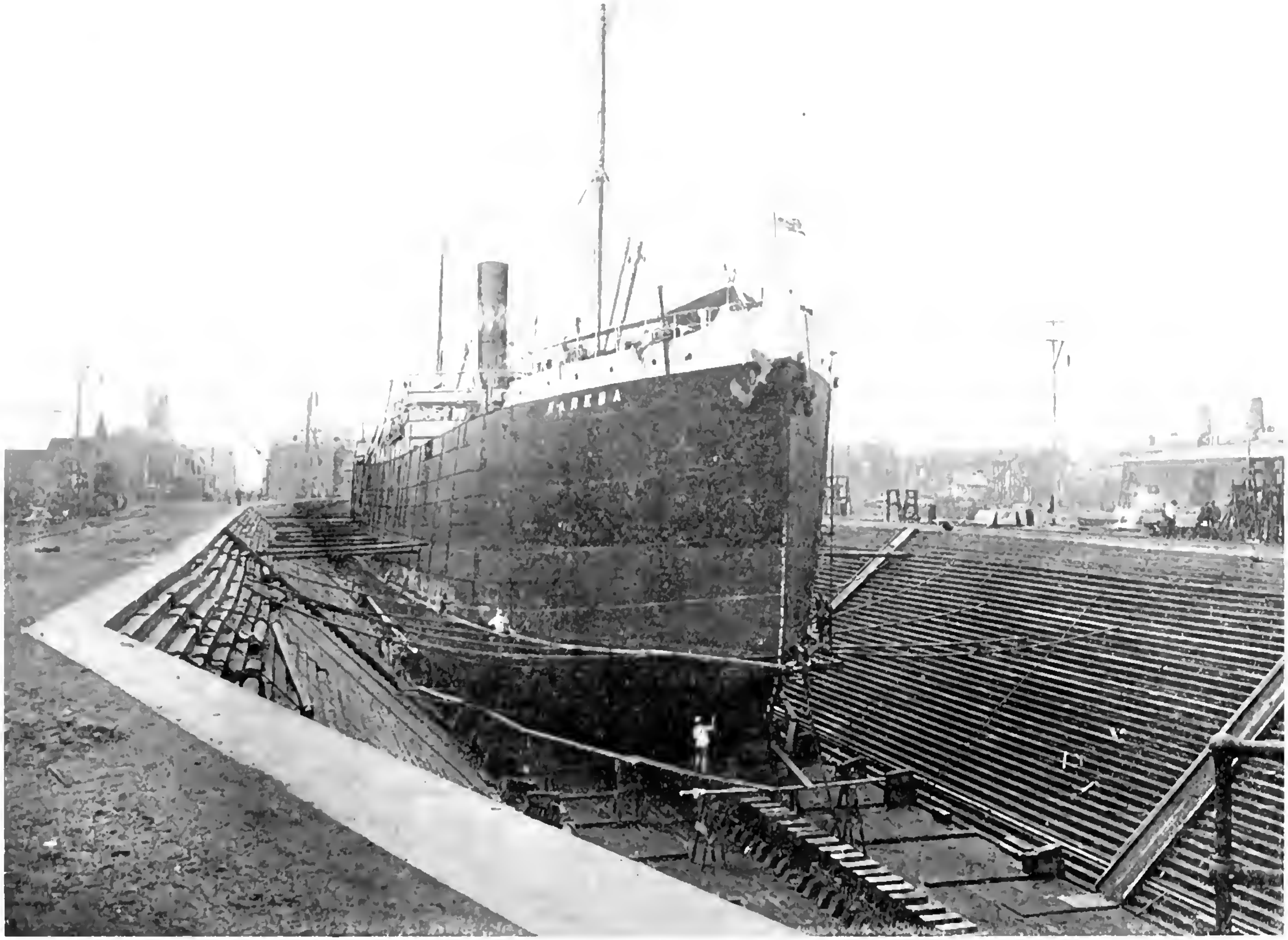


A Dry Dock of the John N. Robins Company, Erie Basin, Brooklyn
(See Page 513)

GENERAL ELECTRIC REVIEW

THE OSCILLOGRAPH

In order to properly design electrical apparatus, or, in fact, apparatus of any variety, the first essential is a knowledge of the phenomena in connection with which the apparatus is to operate. In the case of electrical phenomena, however, the acquisition of this knowledge has been fraught with difficulties, on account of the exceeding rapidity with which the phenomena vary. Thus no ordinary voltmeter, ammeter or galvanometer is capable of following the wave of a rapidly varying electric current or pressure and recording the wave form or making it observable, the inertia of the moving parts rendering their movements too sluggish.

The need of some satisfactory means of accomplishing such results was early recognized and a number of different instruments were invented with this end in view. These instruments were of two classes; in the first, which could be employed only with recurrent phenomena, no attempt was made to have a moving element keep pace with the variations of the phenomena, but during the repetitions deflections were obtained indicating the successive values, the curve being either automatically drawn by means of these deflections or plotted later from the resulting data. This "point by point" method was first described by Joubert in 1880; it is the method employed in the Hospitalier's ondograph, Rosa's curve tracer and the General Electric wave meter.*

Obviously the use of these instruments is restricted to those phenomena that are many times repeated; they cannot, of course, cope with so called transient phenomena; for this purpose recourse must be had to the second, or *continuous*, class of instruments—those containing a moving element having a natural period short enough to enable the element to keep pace with the variations of the phenomena examined. The first instrument of this class was devised by Prof. Elihu Thomson in 1881, and was followed by a number of others; and though none of these were adequate to modern practical requirements they were the forerunners of the present oscillograph.

This instrument—which is to electrical apparatus what the indicator is to the steam engine—was first described by Blandel in the *Comptes Rendus*, April, 1893. In its modern design it is made in two forms, the vibrating iron strip and the vibrating loop type. The latter, which is the form most frequently used, consists, fundamentally, of a pair of fine silver wires or ribbons stretched at considerable tension and placed between the pole pieces of a powerful electromagnet, the ribbons carrying a minute mirror on which a beam of light is directed. The current to be investigated is passed through these ribbons, which, due to the field in which they are placed, are thus caused to twist. The beam of light from the mirror is in consequence deflected in proportion to the degree of torsion of the ribbons at every moment. The movements of the spot of light may be viewed by a revolving mirror, thus showing the wave form of the actuating current; or, it may be allowed to impinge upon a moving photographic film, in which case a permanent record of the wave is made.

In the second form of this instrument, the conducting vibrating loop is replaced by an iron band, which does not carry the current under examination—this being passed through two auxiliary coils which are placed on either side of the iron strip and cause it to twist.

In order that the oscillograph may meet the demands put upon it by modern engineering, the following characteristics are essential: The moving element must have a natural period that is relatively small as compared with the periods of the wave forms to be

*For detailed descriptions of these instruments, together with the different forms of the oscillograph, see paper by Louis T. Robinson, Trans. A.I.E.E., Vol. XXIV, p. 185, *et seq.*

investigated; it must have critical damping; the instrument's self induction must be negligible; it must possess sufficient sensibility to respond to small currents; and, finally, the working parts must be accessible and susceptible of repair with ordinary care.

The article by Mr. Robinson in the present issue shows what advances have been made along these lines, and to what a degree of perfection the instrument has arrived. It has passed out of that class of laboratory instruments that on account of their delicacy are restricted to the use of experts and has taken its place among practical commercial instruments. Through its perfection an instrument of incalculable value has been placed at the command of engineers. In scope and the universality of its application it is like no other instrument, the investigations and tests for which it may be employed being almost endless in their variety.

WASHINGTON, BALTIMORE & ANNAPOLIS 1200 VOLT D.C. RAILWAY

In this issue we publish a somewhat extended account of the 1200 volt equipment of the Washington, Baltimore & Annapolis Railway, which has replaced the original 6600 volt alternating current equipment.

It is of interest to note that the weight of the present cars shows a reduction of about twenty tons each as compared with that of the older ones, and that the same schedule speed is being maintained as formerly, while the seating capacity has only been reduced from sixty-six persons per car to fifty-four. This reduction in weight, after allowing for the change in seating capacity, is due to the inherent differences in the alternating current and direct current equipments, and the consequent elimination of the transformers, etc.

The use of lighter cars has effected a reduction of forty per cent in the power bills, while the same service is maintained. The cost of power reduced to a ton mile basis shows that a saving of about ten per cent per ton mile is effected in favor of 1200 volts direct current.

Formerly the authorities would not permit the heavy cars to operate over the city tracks of Washington, owing to the insufficient strength of the yokes employed in the conduit system; it is only since the introduction of the new equipments that the interurban cars have been able to obtain running rights over the Washington city tracks. This has resulted in very material benefits to the Washington, Baltimore & Annapolis Railway Company.

The detailed description of the 1200 volt switchboards will be read with interest by all those who have been waiting to see what would become standard practice in this direction, while the satisfactory manner in which the two 600 volt rotary converters have been operating in series to give 1200 volts at the trolley will dispel the doubts of those who were looking for trouble in this direction.

That the change from alternating current to direct current was effected with no interruption to the traffic is a matter of satisfaction and congratulation to all parties concerned.

CATENARY LINE MATERIAL

Until within the past half dozen years, during which time rapid development has taken place in electric traction, the overhead equipment of electric roads was well nigh uniform—as indeed was trolley equipment in general, being almost universally supplied with direct current at 500 to 600 volts; but, with the growth of interurban traction and the employment of large cars operated at high speeds, the former overhead equipment was no longer adequate to meet the requirements of the new service.

Among other things, the unequal elevation of the trolley wire at the center of spans and points of support introduced difficulties in current collection that were not manifested at the lesser speeds formerly employed. To meet this difficulty, the catenary type of construction was introduced, this being briefly a method of suspending the trolley wire in such a manner as to practically eliminate the sag. For this purpose, a cable or wire, called a messenger, is strung above the trolley wire. This cable hangs in a catenary curve, and from it, the trolley wire is hung at frequent intervals by means of hangers which are made of such varying lengths as to support the trolley wire as nearly horizontal as possible. In this way the sag, which is objectionable in the trolley wire, is transferred to the messenger cable where it can do no harm.

The article by Mr. Hoffman in this number discusses the various advantages and disadvantages of catenary suspension, and includes a valuable table giving the relative costs of the catenary and direct suspension construction.

THE OSCILLOGRAPH

By L. T. Robinson

General Electric Standardizing Laboratory

The oscillograph is no longer an experiment, or even a device that would be exhibited of itself as having any special interest. In the hands of a number of investigators it is already a standard instrument for every day use and is doing its daily work with accuracy, reliability and satisfactory speed.

The difficulties which for a time existed in connection with the successful repair and renewal of the various delicate parts of the instrument have practically been overcome and the instruments are now supplied in such form that they can be successfully handled and repaired by any one who possesses ordinary skill in the handling of instruments in general.

The oscillograph has been found useful in connection with viewing and recording waves of current, potential, and magnetic flux, as well as for investigating a great variety of transient phenomena such as the rise and fall of current in a circuit when a short circuit is made through a fuse, rise of voltage when opening the field of a direct current generator, the form of current wave or the wave of voltage on either side of rectifying apparatus, the waves in ignition circuits in gas engines both with magnetos and batteries, etc., etc.

The alternating current wave in telephone circuits can also be shown, as well as other waves of a similar nature which, by means of auxiliary apparatus, can be reduced to current or potential waves in an electrical circuit.

Various occurrences in connection with transmission lines during switching, or when disturbances are caused by lightning, have been successfully investigated by means of this instrument.

These are only a few of the many things that can be studied with the aid of the oscillograph; to make it quite plain what

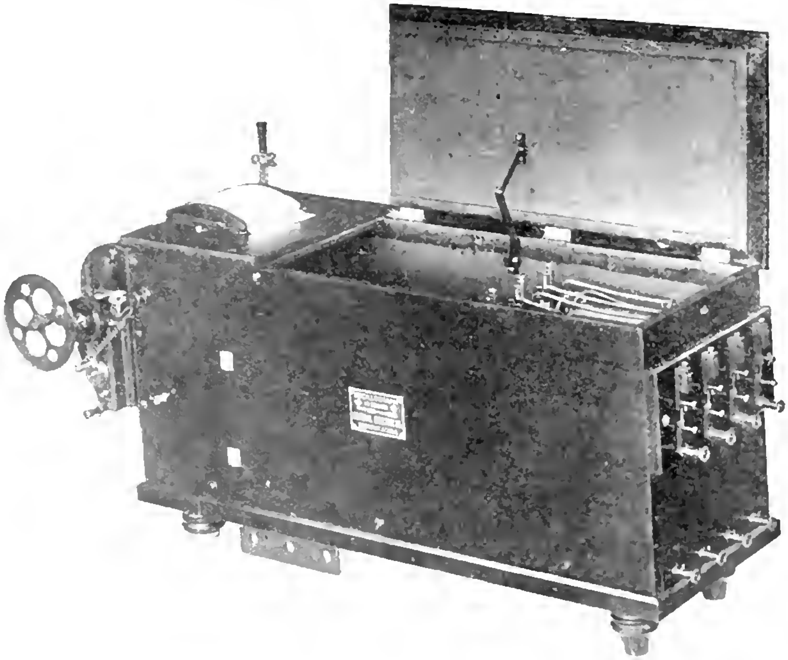


Fig. 1. Oscillograph in Case

can be done with the instrument, the period, sensibility, etc., that can be given to commercial instruments will be spoken of somewhat in detail.

The vibrating strip type of oscillograph with field supplied by an electro-magnet has a free period of oscillation of the moving system of about $\frac{1}{5000}$ of a second. With this period the resistance of the working element is, approximately, $1\frac{1}{4}$ ohms, and with the standard arrangement of parts gives a deflection of 1 mm. with from 0.005 to 0.007 ampere.

A reasonably large record of a wave—one that would be of suitable size for examination or analysis—would extend for 20 mm. on each side of the zero line, and would require a current of 1/10 to 1/7 of an ampere, or $12\frac{1}{2}$ to 17 or 18 milli-watts of energy.

It is also possible to reduce the total resistance of the moving system to $\frac{1}{4}$ ohm and yet retain precisely the same characteristics of the moving element, as far as frequency, current sensibility, etc., are concerned. When these low resistance vibrators are employed, the only disadvantage which accompanies their use is that a little more time is required in restraining the vibrators, because the conductors leading into the moving strips must be attached by soldering near the bridges instead of to the ends of the strips as in standard arrangements. When the low resistance vibrator is used the energy consumed in a vibrator is reduced to $2\frac{1}{2}$ to $3\frac{1}{2}$ milli-watts.

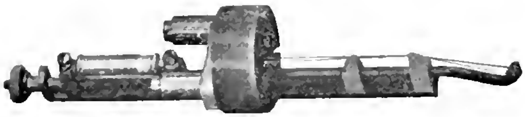


Fig. 2. Vibrator

The vibrators may be energized from shunts when larger currents are to be measured, and series resistances up to any required amount may be included in series with the vibrators when it is necessary to measure voltages of large value.

Current and potential transformers may also be made use of to extend the range of the instruments. If the requirements of the investigation demand the measurement of currents much smaller than those which may be directly measured by the vibrator, small current transformers may be made use of to step up the current before it is passed through the vibrators; remembering, of course, that the total energy required is not reduced below the $2\frac{1}{2}$ to $3\frac{1}{2}$ milli-watts that would be required for direct operation, but is slightly increased to the extent of the losses in the small transformers used. The amount of energy required may be more than that which is available in some places where oscillograph records would be of interest, but on the other hand it is not generally appreciated that the energy required for successful operation is as small as it is.

The standard arrangement of the oscillograph comprises a method for viewing waves as well as for photographing them on a drum around which a strip of sensitized film has been placed.

In general the viewing arrangements are not useful except in connection with phenomena which are repeated indefinitely at regular intervals in phase with some alternating current supply which may be used to operate the small synchronous motor that rocks the mirror to give the abscissæ on the viewing screen. Arrangements are provided whereby this viewing apparatus can be quickly removed from the path of the beam and the apparatus for making the photographic record brought into use.

In certain special investigations it may be desirable to use a long film drawn continuously in front of the light spot to receive the record, or an arrangement whereby a large drum could carry several feet of film. The usual length of film employed is one foot and this has come so near to satisfying all requirements that no other standard arrangement has been built. The film may be exposed for one revolution, beginning at the joint in the film, or instantly after one revolution, starting at any place.

The films may be rotated at a speed as high as 1200 feet per minute, it being quite possible to obtain a satisfactory record of an irregular wave of 30 or 35 mm. amplitude each side of zero at this speed.

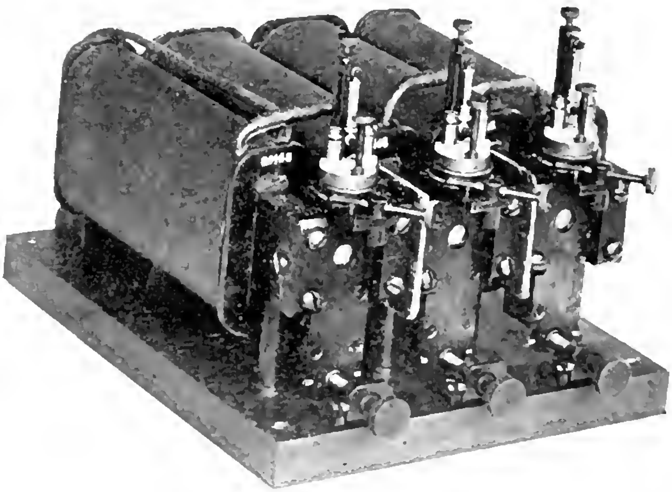


Fig. 3. Oscillograph Galvanometer

There is no question but that many investigations demand a much higher period than can be commercially obtained in the vibrating-strip type of oscillograph. Several attempts have been made to obtain this higher period in other designs—notably that in which the moving system consists of a vibrating band of iron. In this type, periods as high as 50,000 a second have been recorded. The highest period that could be called possible with the vibrating strip type is approximately 10,000 a second, and the dimensions of the parts, even at this frequency, would certainly be so small that the handling of the instrument would not be convenient. However, this apparent advantage in periods which may be secured by means of the single vibrating iron strip is generally of no practical advantage, because the field necessary to deflect a strip is considerable and must be produced by inductive windings through which the current to be investigated must be made to pass. The difficulty is that a current having a frequency high enough to require such a small period in the moving system could not well be passed through the inductive winding of such an oscillograph.

It is also well to call attention to the fact that the period of the moving system and the speed at which the film can be operated are usually not the limiting features in obtaining photographic records. At the present time the limitations of oscillograph records at high speed and high frequency are found in the intensity of light which it is possible to get through any optical system, and the ability of any film to record the passage of the light spot. Careful attention to the details of the arc lamp and to the adjustment of all the parts in the light path will give a good record under the most severe conditions, but at the present time the question of light may be considered to be the limiting feature. In this connection the arc lamp may be briefly mentioned. Experiments have definitely shown that a large arc is not better than a small one for the purpose. For this reason the present practice is to use an 8 or 10 ampere partially enclosed arc regulated by hand. Automatically regulated, 25 or 30 ampere arc lamps have been used and still find some advocates, but there is no doubt that there is a general tendency to favor the hand-fed lamp of small ampere capacity. The latter is less expensive to operate, gives as good results as the automatic lamp when the latter is at its best, and the little attention required to feed the lamp by hand as the records are made is more than compensated for by the fact that any automatic lamp will sometimes regulate poorly, causing failure to get a proper record when the test can not be conveniently repeated.

With regard to the range of frequency that can be accurately taken care of with the oscillograph, experiments on machines of

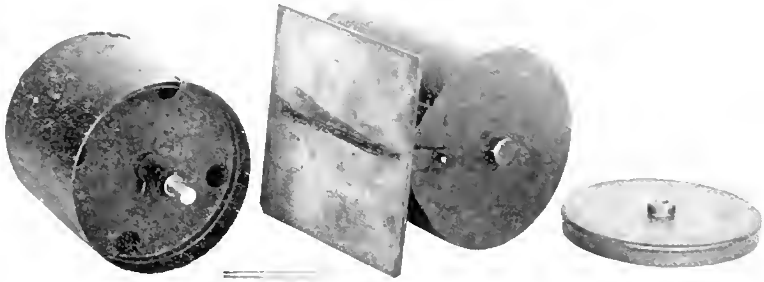


Fig. 4. Film Holder

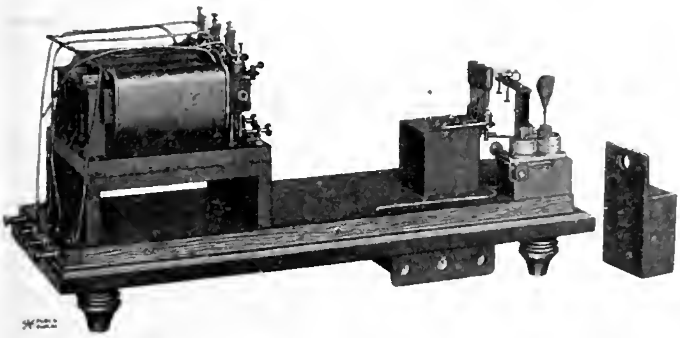


Fig. 5. Internal Arrangement of Oscillograph

comparatively high frequency have shown that it can respond with accuracy to a frequency of about one-half that of the free period of the undamped vibrator. This means that with the ordinary standard type of instrument frequencies as high as 3000 may be recorded; if, however, such a current or voltage has harmonics they will not be accurately recorded, but will usually be indicated up to the third and may be to the fifth harmonic, provided that these harmonics are quite prominent in the true wave. To obtain accurate measurements of the higher harmonics they should, of course, be regarded as the true frequency of the circuit. For example, on a 60 cycle circuit an ordinary vibrator should record correctly as high as the 49th or 51st harmonic, which, of course, is beyond what would usually be of interest. With the same degree of exactness, the 5th harmonic of a 600 cycle circuit could be recorded. As the recording of a 600 cycle wave at the highest film speed that can conveniently be obtained, namely, 20 feet per second, gives 2½ complete waves for every inch of the film, it may be seen that 600 cycles is about the limit in fundamental frequency that can be recorded where the form of the wave must be accurately known. At this point the mechanical limitations to the film speed, the free period which can be given to the vibrator, and the speed at which the photographic impression can be obtained are all fairly well in accord. If the speed of photographic impression could be materially increased there is every reason to believe that the other limiting features could be increased by a like amount.

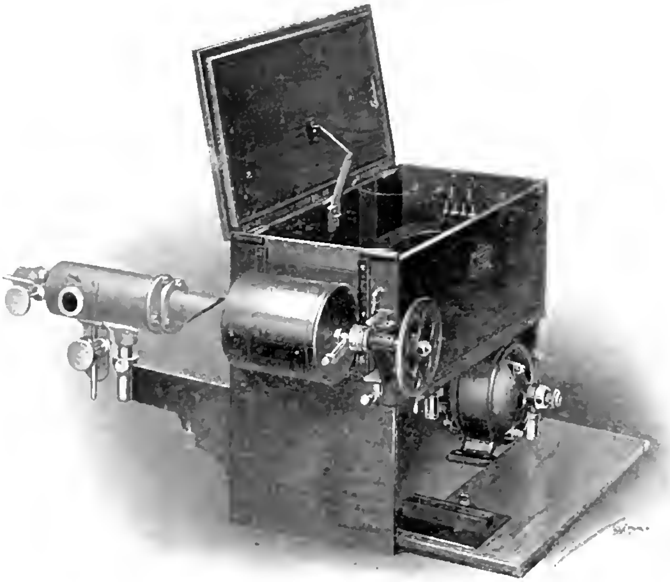


Fig. 6. Permanent Magnet Oscillograph

The insulation within the instrument allows of the employment of potentials as high as 2300 volts between vibrators, or between any vibrator and ground. If higher potentials are to be employed, some method must be used which limits the potential between vibrators to not more than 2300 volts. Conditions where high voltage circuits must be used may be met by employing instrument transformers, or under certain conditions high resistances may be included in the vibrators, the whole instrument being near ground potential. It is also possible to insulate the whole instrument, together with a small storage battery for exciting the field from ground. This arrangement has been successfully employed in several cases.

In certain cases where it is difficult to insulate the exciting circuit of the electromagnetic field, and where there is no direct current available for field excitation, it has been found useful to provide oscillograph galvanometers with permanent magnets. These have been made with single vibrators and also with two vibrators, but the two-vibrator instrument can not have more than a few volts between the vibrating strip and the frame, or between the two moving elements. On account of the fact that the permanent magnet can not create as strong a field as that which can be obtained by means of the electromagnet, the sensitiveness is somewhat reduced in this form of instrument. The ampere sensibility is about 0.01 or 0.007, depending on whether two vibrators or one are included in the field of the permanent magnet. The resistance of the vibrator for the permanent type is the same as that for the electro-magnetic; in fact, the standard vibrators which are used in the electro-magnetic type may be used with the permanent magnet.

The galvanometer with permanent magnet may be arranged for use in the box provided

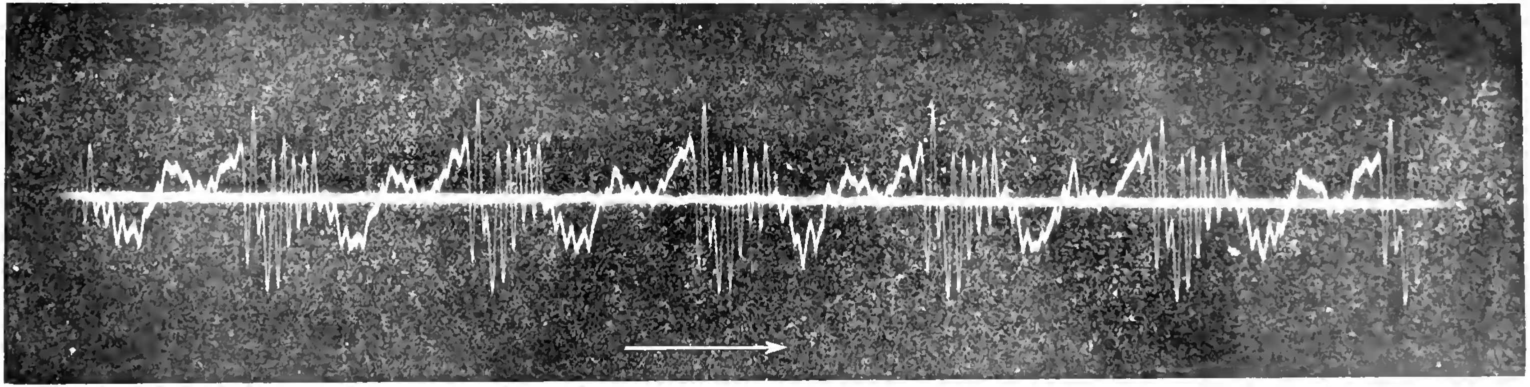


Fig. 7. Oscillograph Record of Current in Telephone Line Corresponding to Sustained Vowel Sound "i," as in Machine ; Voice Pitched at A 110

Above Record Shows About Six Cycles, Total Time Approximately .055 Seconds.

Record by John B. Taylor

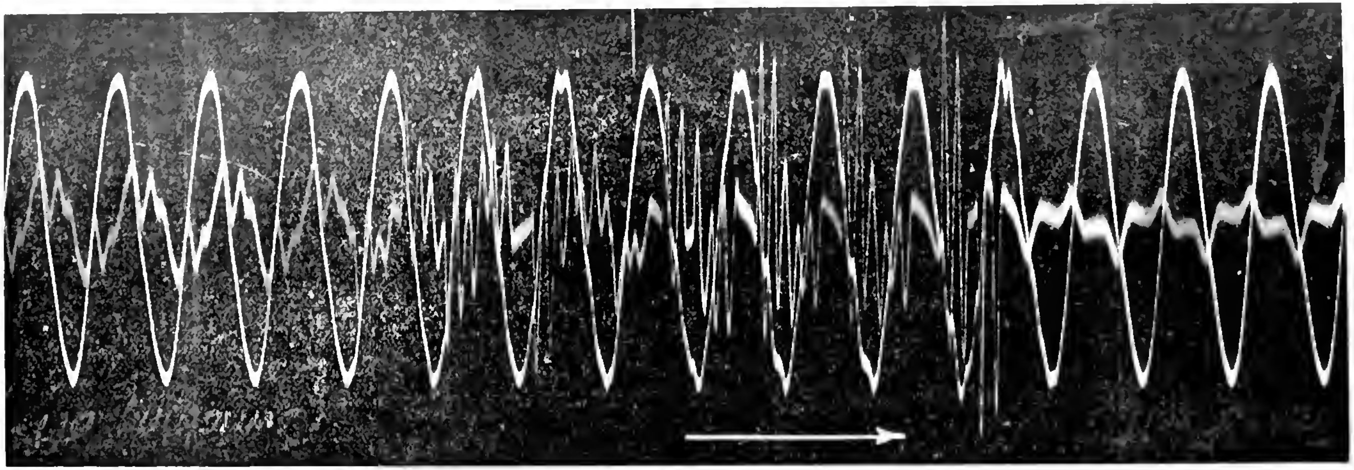


Fig. 8. Switching 100,000 Volt Line off Transformer, Showing Surge in Transformer. 25 Cycles

Record by G. Faccioli

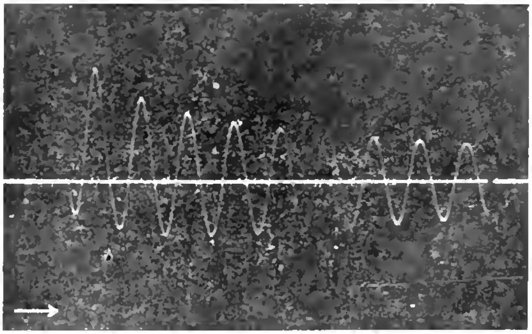


Fig. 9. First Rush of Current from an Alternator when Short Circuited, Showing Unsymmetrical Initial Wave of Current, Becoming Symmetrical after a Few Cycles. 25 Cycles

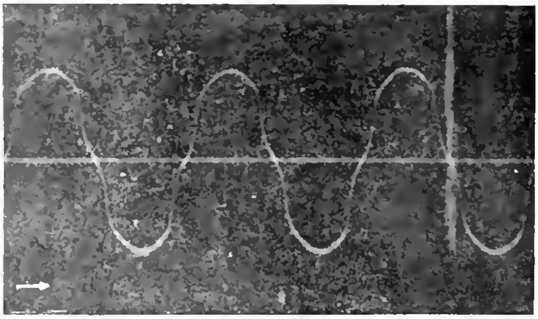


Fig. 10. Wave of Electromotive Force Obtained from Narrow Exploring Coil on Alternator Armature, Indicating Distribution of Field Flux. The Terminal Electromotive Force of the Alternator is Very Nearly a Sign Wave. 60 Cycles, About 17 Volts

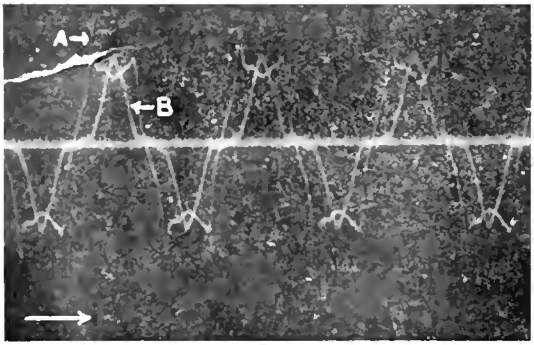


Fig. 11 The Waves of Voltage and Current of an Alternating Arc. (A) Voltage Wave. (B) Current Wave Showing Low Power Factor of the Arc without Apparent Phase Displacement 60 Cycles

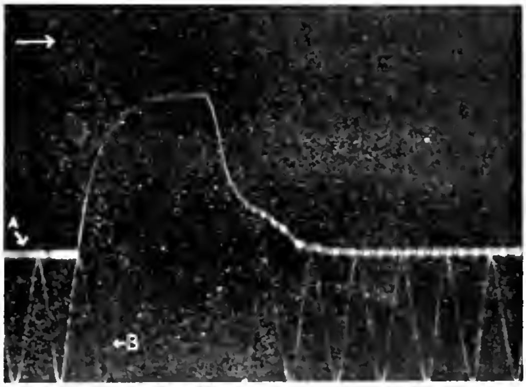


Fig. 12. Rupturing 650 Volt Circuit. (A) Current Wave, 60,000 Amperes Maximum; (B) 25 Cycle Wave to Mark Time Scale

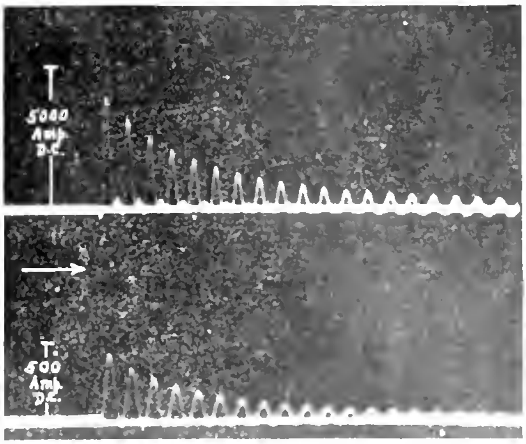


Fig. 13. First Rush of Current from Alternator when Short Circuited, Showing Unsymmetrical Current Wave as in Fig. 9, Also Wave of Field Current Caused by Short Circuit Current in Armature Upper Curve, Armature Current, Lower Curve, Field Current

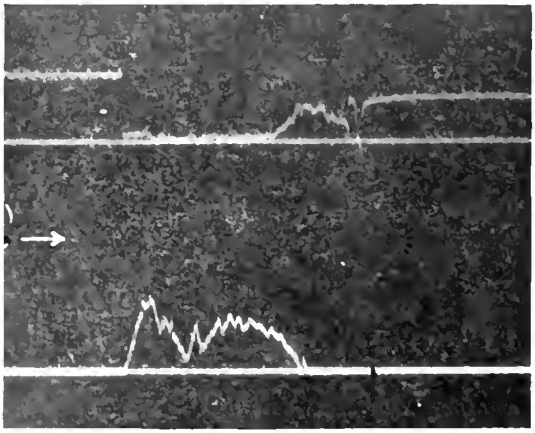


Fig. 14 Short Circuit Current on Direct Current End of Rotary Converter, 21,500 Amperes Maximum Upper Curve, Direct Current Voltage; Lower Curve, Direct Current Amperes. Duration of Short Circuit About 1/10 Second

for the standard galvanometer with electromagnet, and in this way may form part of the standard equipment. This would make the most complete kind of an outfit. The permanent magnet galvanometer is, however, usually assembled in a different box which has no synchronous viewing attachment, but which allows the wave to be viewed by means of rotating mirrors that can be turned by hand. The arc lamp for this outfit is made to pack in the box and the whole forms a semi-portable outfit which for some work is more convenient than the complete standard equipment. For laboratory use or for any sort of investigation work where a considerable variety of tests must be covered, the standard arrangement of box with electro-magnetic galvanometer will be found far more useful in its application.

As already stated, a construction for the moving part of the instrument that will admit of easy renewal and repair is very desirable.

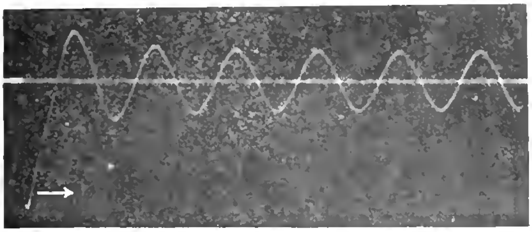


Fig. 15. Mazda (Tungsten) Lamp Showing Rapid Decrease to Normal Current as Filament Heats Up. 25 Cycles

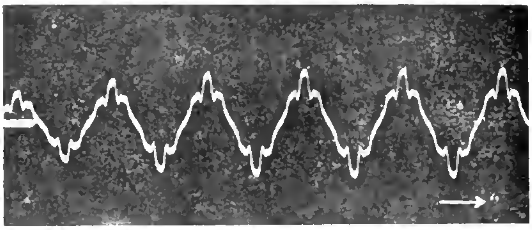


Fig. 16. Carbon Lamp, Showing Rapid Increase to Normal Current as Filament Heats Up. 25 Cycles

(The difference in wave form is due to the fact that the electromotive force waves of the machines on which the tests were made were different, and not to any action on the part of the lamps themselves.)

Reference to Fig. 2. will show that this feature has been very fully cared for, as there is a free space all around the vibrating strips and mirror on all sides, so that the mirrors can be readily attached to the strips or new strips put in place.

In most cases, the interpretation of results which have been recorded by the oscillograph requires definite knowledge of the manner in which the event recorded took place with reference to the time scale. It is usually most convenient to have this time scale read from left to right on any prints that are made, the direction of the time scale being indicated by an arrow, as shown in the records given. The practice should be avoided of having the arrow indicate the direction of the film in passing by the light spot or any other relative motion which may not be the same on all oscillographs and which might, under some circumstances, be different on a given instrument at different times.

It is also important when taking oscillograph records that are to be used for reproduction to use care in the adjustment of the optical system (the lamp, etc.) so that clear records may be obtained which may be reproduced as prints or halftones by direct process without being redrawn. It is usually possible to get negatives which will make good prints or reproductions and it is advisable at all times to use the necessary care to produce such negatives. If the record on the negative is drawn over before prints are made, a great deal of the original value of the record is destroyed. Aside from the fact that such doctored records usually do not appear well, it is seldom possible for any one to follow the line on a negative with ink without departing appreciably from the true path described by the light spot. This variation from absolute truth in the reproduced record may seem of no consequence to the person who is preparing the print, but the record of some important happening in connection with the test may be destroyed. Many phenomena of interest and value, that had no connection with the results which were being sought for, have been found to be clearly recorded on oscillograph films.

To illustrate the variety of work which can be done with the instrument the accompanying reproductions of records are given, together with a brief description of the conditions under which each was taken. These records, together with the detailed statements which have been made on the energy required to operate the instrument and the frequencies for which it is suitable, will give any one who is interested in the applications of the instrument a better idea of what may be done with it than could be had in any other way.

WASHINGTON, BALTIMORE & ANNAPOLIS 1200 VOLT D.C. RAILWAY

By John R. Hewett

The Washington, Baltimore & Annapolis Railway is of more than ordinary interest, both on the score of its having been converted from a 6600 volt single-phase to a 1200 volt direct current road, and on account of the class of service it is providing. The system comprises two divisions, the first consisting of a double track, high speed line connecting Washington, D. C., with Baltimore, Md. The plans for this portion of the system have been under consideration for a number of years, but the property only passed into the hands of the present company in 1905, and the work of electrification as a single-phase road was completed in two years from that date. The second portion of the system is a single track road connecting Annapolis Junction with Annapolis. The traffic to Annapolis is large, owing to the Naval Academy, which is one of the most important naval depots of the United States. This road was formerly known as the Annapolis, Washington & Baltimore Railway and was in operation as a steam road nearly eighty years ago. The equipment of this road is now similar to the double track road connecting Washington with Baltimore.

The map, Fig. 1, shows the route taken by both lines and also the location of the power house and substations.

Every detail of the road and its equipment has been designed with the view of giving a high class, high speed service. The city running necessarily takes up a disproportionate part of the running time, but the schedule on the interurban section, which is as high as 44 miles per hour, compensates for this and the run from terminal to terminal takes but 85

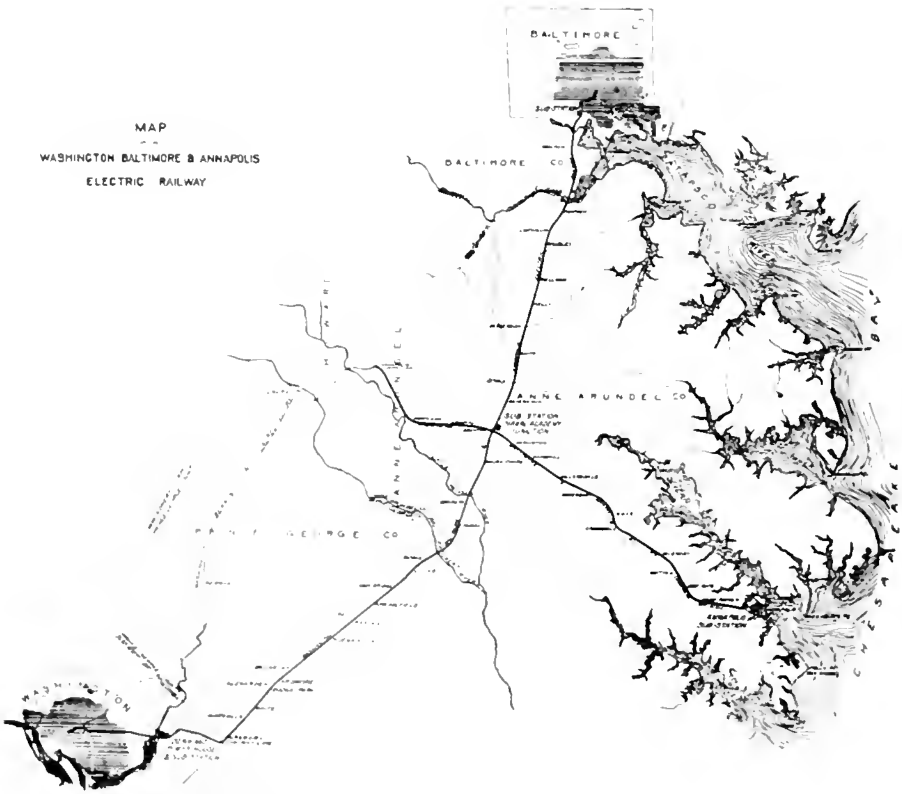


Fig. 1. Map of the Washington, Baltimore & Annapolis Railway

minutes. The steam road service between Washington and Baltimore is good, there being a very great number of trains per day, and it is therefore imperative that the electric lines should give an attractive schedule.

The electrical equipment of all the substations and cars was manufactured by the General Electric Company.

General Scheme of Electrification

Fig. 2 will give a good idea of the general scheme of electrification, and will also show the distances between the more important points.

The energy for operating the Washington, Baltimore & Annapolis Railway is generated by Curtis turbines in the Bennings power house of the Potomac Electric Power Company and is delivered to the Bennings substation at a potential of 6600 volts.

Figs. 3 and 4 respectively, are diagrams of the transmission lines and of the feeders and trolley. These together with the explanatory key to Fig. 2 render a written description in detail unnecessary.

Substations

There are five substations located at the following points: Ardmore, Naval Academy Junction, Baltimore, Annapolis and Bennings. The diagrams and map will show the relative positions of and the distances between these substations, as well as the manner in which they are connected electrically.

Bennings Substation

The function of the Bennings substation is to receive the power which is generated at the Potomac power house at 6600 volts, transform it to 33,000 volts, and distribute it at this potential to the duplicate transmission lines which feed the other substations of the Washington, Baltimore & Annapolis system. There are no 1200 volt feeders from this substation.

Ardmore Substation

The Ardmore substation is the only one which was

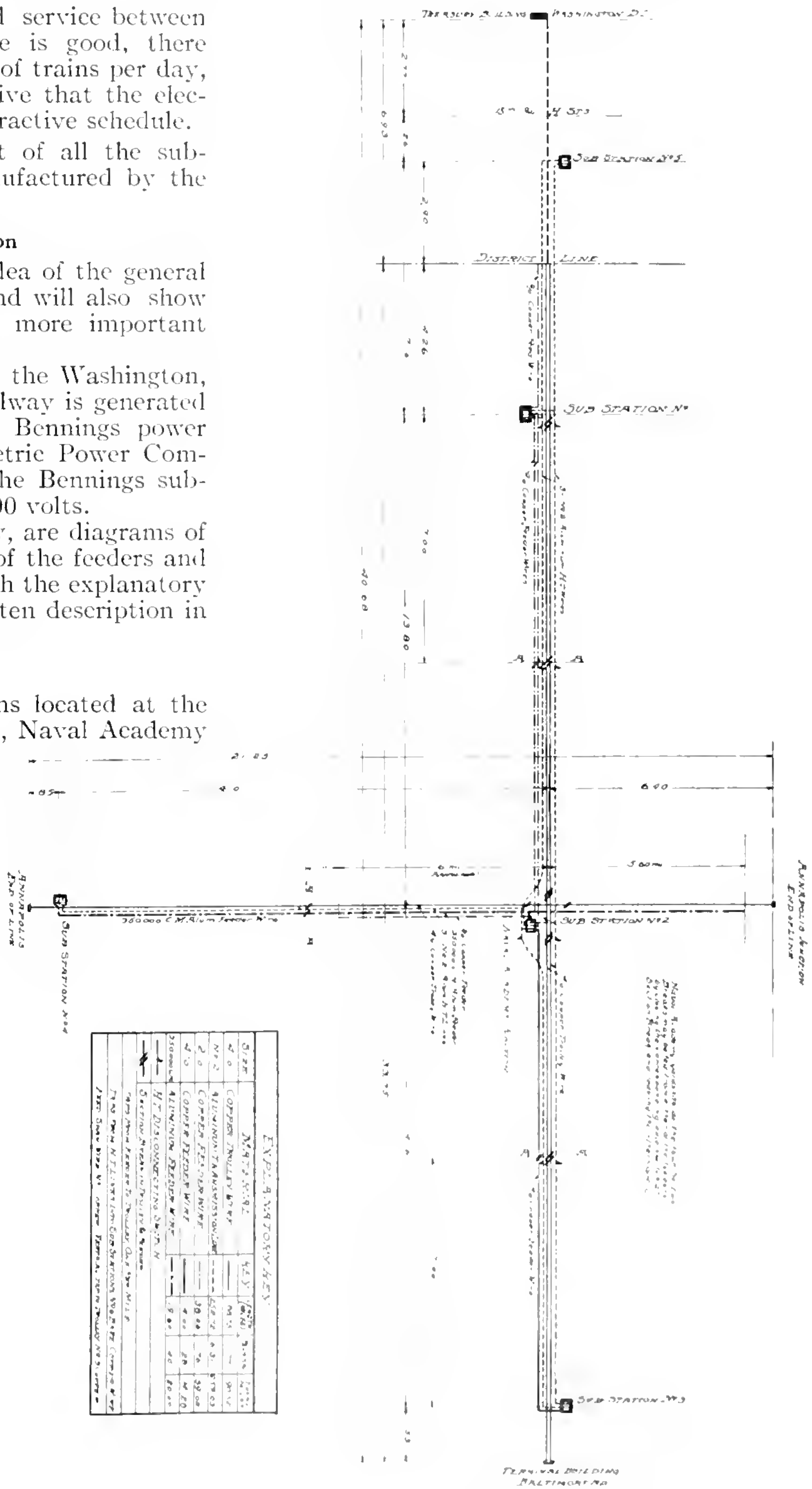


Fig. 2. Wiring Diagram of the Washington, Baltimore & Annapolis Railway

built for the 1200 volt system, the single-phase substations in each of the other cases having been altered to suit the new conditions.

This substation is a red brick structure and is divided into a machine room and a high tension compartment, the former containing the rotary converters, reactances and switchboard, and the latter the transformers, oil switches, lightning arresters, etc. Figs. 5 and 6 are interior views of these sections.

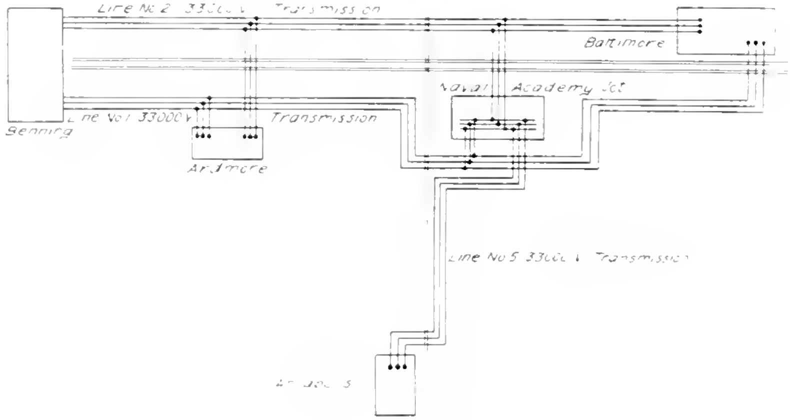


Fig. 3. Diagram of Transmission Line

Both of the 33,000 volt transmission lines are tapped into the Ardmore substation, and switching arrangements are provided to permit of either or both of the lines being used at the same time. The potential is stepped down from 33,000 to 370 volts and fed to the rotary converters, whence it is fed in both directions to the trolleys and feeders at 1200 volts.

Naval Academy Substation

This substation is situated near the car barn and is constructed with a reinforced concrete frame filled with red brick panels.

The substation proper is divided into two portions; namely, a common room for the transformers and rotary converters, and the high tension compartment. A small annex houses the boiler and pumping machinery that supplies the heating and sprinkler system for the car barns. An air compressor for car barn use is also installed here.

Both transmission lines are tapped into this substation and 1200 volt feeders extend from it in the direction of Washington, Baltimore, Annapolis and Annapolis Junction.

Figs. 7 and 8 are interior views of the machine room and high tension compartment respectively. One of the rotary converters is not shown in Fig. 7. Fig. 9 is an exterior view of the substation, while Fig. 10 was taken from the roof to show the manner of carrying the leads from the transmission line vertically down to the transformers. It also shows the horn gaps used in conjunction with the electrolytic lightning arresters.

Baltimore Substation

The Baltimore substation is a brick structure and is situated at the outskirts of Baltimore near Scott Street. The exterior of this building, and also a good view of the external high tension wiring, are shown in Fig. 11. The illustration on the first page

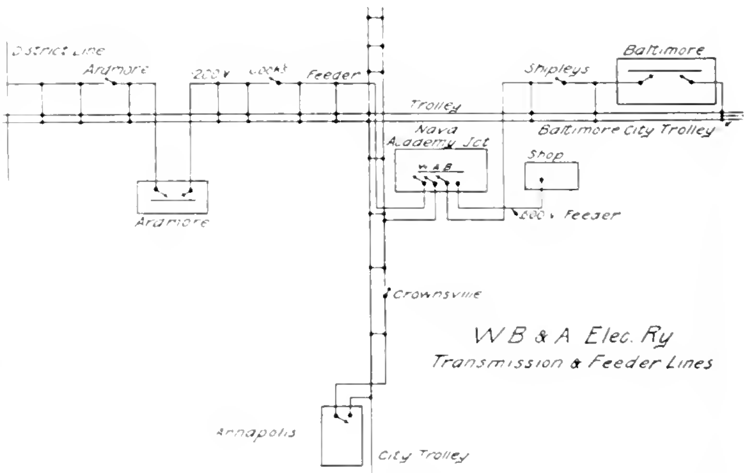


Fig. 4. Diagram of Trolley and Feeder Lines

of cover gives an excellent idea of the switchboard which controls the output of the substation. This board consists of two rotary converter panels and two feeder panels, the high tension alternating current panel being located at the opposite side of the machine room and shown in Fig. 12.

Annapolis Substation

The Annapolis substation is in the center of Annapolis and includes under one roof substation, express depot, waiting room and ticket office. This substation contains two 300 kw. rotary converters and three 160 kw. transformers.

The functions of this substation are considerably simplified since the change from alternating current to direct current, owing to the fact that the City of Annapolis permits the use of the 1200 volt trolley.

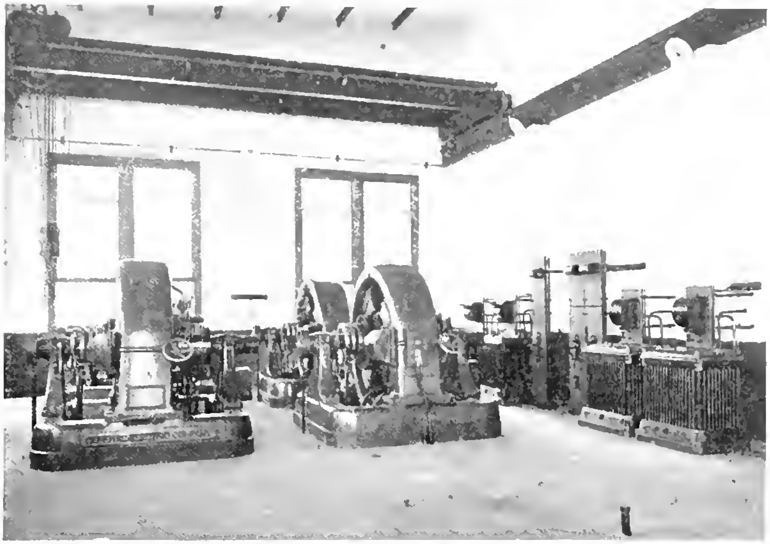


Fig. 5. Main Section Ardmore Substation

Substation Apparatus

The following table gives the number of rotary converters and transformers installed in the various substations. It should be noted that provision is made for two additional rotary converters and three additional transformers in both the Ardmore and Baltimore substations, while at Academy Junction one spare rotary converter is already installed and provision is made for the addition of a second.

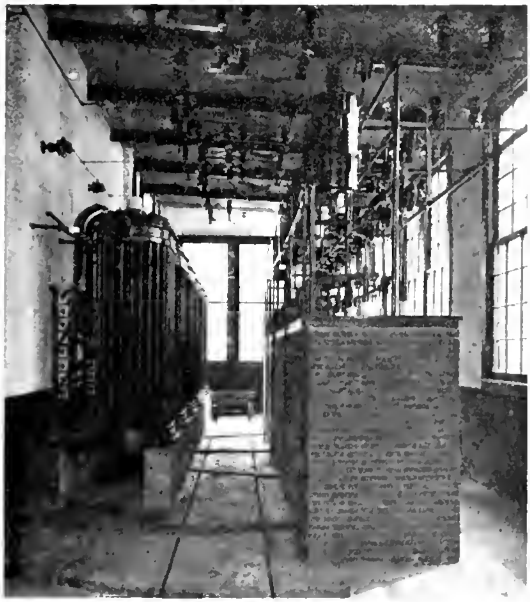


Fig. 6. High Tension Compartment Ardmore Substation

SUBSTATION APPARATUS

	Rotary Converters		Transformers	
	Number	Capacity Kws.	Number	Capacity Kws.
Bennings	1	500*	7	800
	1	1000*	1	1100*
			1	550*
Ardmore	4	300	6	160
Academy Junction	5	300	7	160
Baltimore	4	300	6	160
Annapolis	2	300	3	160

*Units marked thus are for operating the District line.

These rotary converters are all three-phase, four pole, 300 kw. units running at 750 r.p.m. and designed for a full load direct current of 500 amps. They are, practically speaking, standard 600 volt rotary converters with additional insulation to permit their operation in series to give 1200 volts. They are compound wound with their shunt fields excited from the individual machines and the series fields of each pair are connected in series on the grounded side. A speed limiting device and magnetic oscillator are provided on each machine, and the metallic graphic brushes employed on the alternating current side decrease the amount of carbon dust and make lubricating unnecessary, at the same time eliminating the wear of the rings. The direct current brush rigging is supported directly on the magnetic frame, in order to remove as far as possible from the commutator all metal on which an arc would hold in case a flashover should occur at any time.

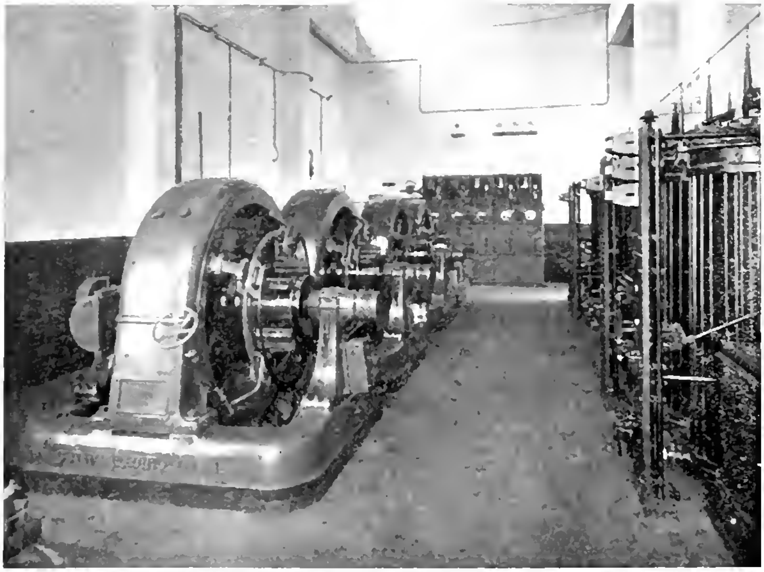


Fig. 7. Main Section Naval Academy Substation

These rotary converters have given the most excellent satisfaction in operation and no difficulty of any kind has been experienced with two machines operating in series.

The reactive coils each have a capacity of 45 kv-a., are oil cooled, and have standard starting switches with protecting covers mounted on the top.

All the transformers with the exception of those installed in the Bennings substation, which are of 800 kw. capacity, are 160 kw. Type H machines, similar in design. They are wound for 33,000 volts on the high tension side and for 370 volts on the low tension side. The primaries are Y-connected and are provided with four $2\frac{1}{2}$ per cent taps, while the secondaries, which are double, are delta-connected and have 50 per cent starting taps.

The switching arrangements are of special interest, as the high tension direct current boards are of standard General Electric design, specifically made for 1200 volt work, two machines in series.

The direct current switchboard of the Baltimore substation is illustrated on the cover. This board consists of two machine panels and two feeder panels, each machine panel being for one pair of rotary converters.

The two 600 volt rotary converters are connected in series as previously stated, the series fields of both machines being connected between the armature of the low machine and ground. This arrangement makes necessary only one circuit breaker, one lever switch, and one ammeter and voltmeter on each panel. The lever switch is placed on the bus side of the circuit breaker so that when the switch is open it is possible to work on the circuit breaker without danger while the positive bus is alive.

The circuit breakers have standard carbon contacts

Fig. 8. High Tension Compartment Naval Academy Substation

with an increased length of break for 1200 volts, while the lever switch is made of standard 600 volt parts. Both the circuit breaker and lever switch have the current carrying parts mounted at the top of the panel out of reach, while their operating handles are on the lower panel. The mechanical connection between the handle and switch is made by an insulating rod. Fireproof arc chutes are provided around the circuit breaker and lever switch at the top of the panel.

The circuit breaker is arranged so that the handle always returns to the inward position, while the handle of the lever switch alongside it stands out when the switch is open. In order to distinguish between the two handles, which are identical in appearance, the circuit breaker is mounted inverted so that its handle points downward. For tripping the circuit breaker by hand an insulated trip rod is arranged to operate on the tripping pin of the breaker.

Fig. 10. High Tension Wiring on Roof of Naval Academy Substation

The rheostats are operated from the front of the board by means of a handwheel which turns a mechanism designed in such a manner as to permit of the regulation of the machines individually or collectively at will. The ammeters are of the d'Arsonval type and provided with insulated covers; the wattmeters are also insulated to suit the higher voltage. The voltmeters are standard 600 volt instruments of the permanent magnet type with 1200 volt scales, potential receptacles being provided so that the voltage of each or both machines may be read. Multipliers are used in the plugs so that the 600 volt instruments give the correct readings for the higher potential on the 200 volt scale.

Fig. 9. Naval Academy Substation

The circuit breakers, lever switches and ammeters on the feeder panels are similar to those on the machine panels. The circuit breaker is connected to the bus and lever switch on the line side. One two-point 1200 volt potential receptacle on the line side of the lower switch allows of reading the trolley voltage before the feeder is cut in.

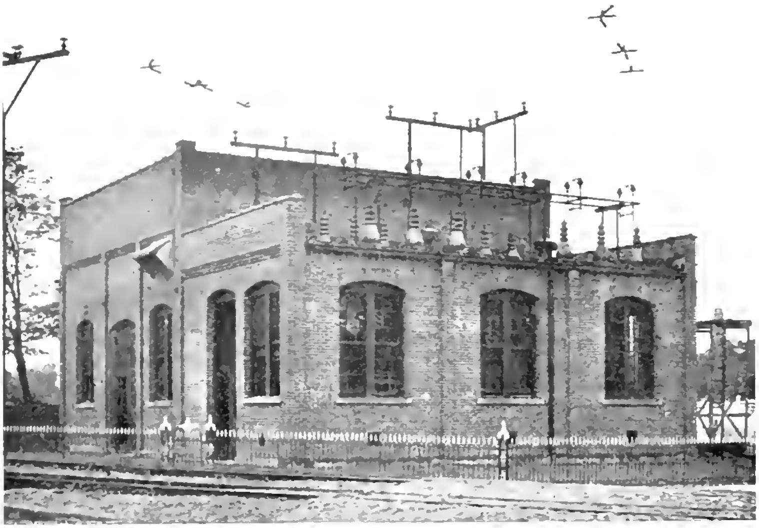


Fig. 11. Baltimore Substation

All the panels are made in three sections, 24 in. wide, the top section being 40 in. in height, the middle section 31 in., and the bottom section 28 in. All bolt heads on the front of the board are covered with insulating caps.

The rotary converters are started from the alternating current side, the starting switch being mounted on top of the reactance cover. Field break-up switches are mounted on the yokes of the rotary converters.

Cars and Equipments

The rolling stock consists of 17 straight passenger cars, 13 combination passenger and baggage cars, 1 express car and 3 freight cars or locomotives—33 equipments in all. Of these cars all were new when the 1200 volt system was installed, with the exception of three of the combination cars and two of the freight equipments, which were converted from single-phase to 1200 volt direct current.

Passenger Equipments

The equipments on the 30 passenger cars are all identical, each comprising four 75 h.p. motors and a full complement of Type M control, designed to operate on both 600 and 1200 volts direct current. These motors are of the commutating pole type and have given most excellent results in service. The schedule which the cars have to handle in this particular instance is very severe, but the motors have shown a wonderful record, especially in the direction of brush wear.

The control is of the relay automatic type, as arranged for train operation, and is intended to give full speed on 1200 volts and half speed on 600 volts. The local conditions call for many special features in the control apparatus. The operation in the city of Baltimore calls for 600 and 1200 volt single trolley, and the interurban run from Baltimore to the District line for 1200 volt single trolley. From the District line to 15th and H Streets in Washington there is a 600 volt

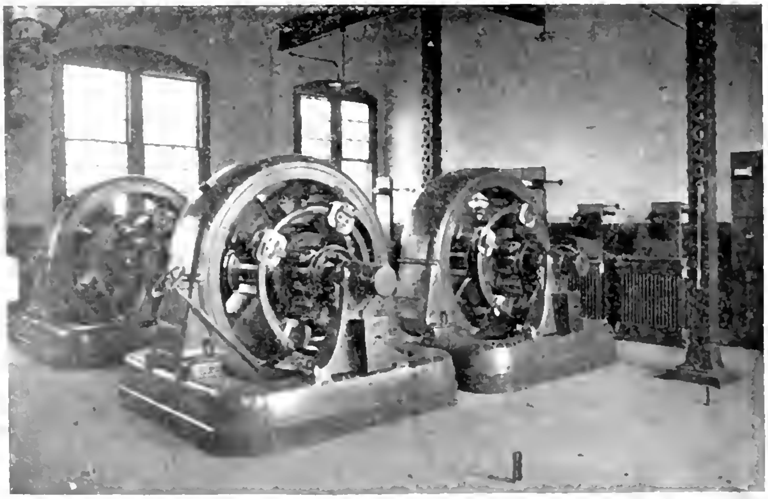


Fig. 12. Interior of Baltimore Substation

double trolley, while from 15th and H Streets to the Treasury Building, 600 volt double conduit plows are used. Hence the equipment is arranged to operate on 600 and 1200 volt single trolley, and on double trolley and double conduit plows.

The transfer of circuits from single trolley to double trolley is accomplished by using the negative trolley pole and hooks for switches as well as current collectors, and when a change from single to double trolley is made, all that is necessary to be done is to put the negative pole in contact with the second trolley. The transfer of circuits from trolley to conduit plows is made by a double-pole double-throw switch operated either by hand or air. This switch is provided with a magnetic blowout so that it can be opened when alive. When operated by air it is so interlocked with the controller that the control handle must be in the "off position" before the switch can be operated.

The air compressors for the air brake equipments have a capacity of 25 cu. ft. of free air per minute and are provided with the usual air compressor governors. These compressors are provided with motors wound for 1200 volts and are arranged to run at half speed on 600 volts.

The heaters and air compressors are operated directly from the trolley.

A dynamotor is provided for furnishing 600 volt current for the lighting circuits during 1200 volt operation, but on the 600 volt section of the road the lights are fed directly from the trolley. The transfer of these circuits is accomplished by a suitable relay directly under the control of the motorman.

Service Equipments

The service equipments comprise in general the same apparatus as the passenger cars, with the exception that the motors are of 125 h.p. each and the control is of the hand operated type.

Car Bodies

All of the car bodies were built by the Niles Car & Manufacturing Company. The straight passenger and combination passenger and baggage cars are similar in all important details, the only notable difference being that the smoking compartment in the combination cars is reduced in length to provide for a baggage compartment.

All the cars present a handsome appearance; they are painted a dark green and are double ended. The more important dimensions and weights are given below.

Length over all	50 ft.
Length over body	40 ft.
Width over all	8 ft. 9 in.
Height from sills to top of roof	9 ft. 4½ in.
Height from track to top of roof	12 ft. 9½ in.
Weight of car body	28,500 lb.
Weight of trucks (each)	10,000 lb.
Weight complete ready for service	78,000 lb.
Type of truck	Baldwin class 78–25 A
Distance between truck centers	28 ft. 8 in.
Wheel base of truck	6 ft. 6 in.
Diameter of wheels	36 in.
Seating capacity	54

The following table will show the more important details of the service equipments or locomotives, the first column of figures referring to the two converted equipments and the second column to the new one.

Length over all	54 ft.	50 ft.
Height over all	14 ft. 1 in.	14 ft. 1 in.
Width over all	9 ft. 6 in.	8 ft. 8 in.
Weight of body	30,000 lb.	27,000 lb.
Weight of trucks (each)	13,000 lb.	13,000 lb.
Weight complete	86,000 lb.	83,000 lb.
Distance between truck centers	33 ft.	26 ft.
Wheel base of trucks	7 ft. 6 in.	6 ft. 6 in.
Diameter of motor wheels	37 ft.	37 ft.

Figs. 13, 14 and 15 show respectively a three car train, a five car train and a freight train.

Overhead Construction

The overhead construction throughout the interurban section of the line is of the catenary 9-point suspension type. A double bracket construction has been adopted on the main line between Washington and Baltimore and a single bracket construction on the line from Annapolis Junction to Annapolis. The trolley wire is of 0000 grooved copper, while the messenger, which is of special high strength steel, consists of seven strands and has a diameter of ⅜ in.

The standard spacing of the poles is 150 feet but the distance varies at curves and on other special work. The poles are 35 feet in length, with a diameter at the top of from 6 to 8 inches. They are buried for a depth of 6 feet in the ground and are set at a slight inclination to the track.

The trolley is suspended 19 feet from the rail level between Washington and Baltimore and 22 feet from the track on the Annapolis Division. The distance between the two trolleys on double track work is 11 feet.

The brackets, which are of a T section, are 10 feet 6 inches in length and are attached to the poles by a flange and two lag screws.

All of the messenger insulators, straight line insulators, steady braces and hangers are of General Electric Company's standard pattern. The messenger insulators are of interest inasmuch as they have grooved petticoats, the function of which is to prevent the insulation from breaking so as to ground the line.

The theory which has been found to hold good in practice is that, should an insulator be damaged by gun shot or stone throw, it would not break in such a manner as to destroy the insulation of the line, but would be fractured at one of the grooves and there would still remain sufficient insulation to prevent a short circuit.

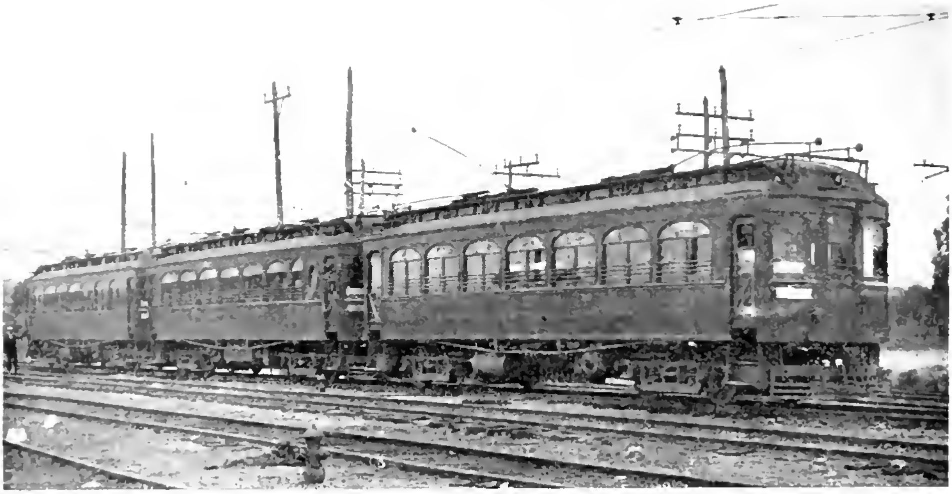


Fig. 13. Three Car Train

In the tunnels near West Port the trolley wire is supported by cross wires thoroughly insulated with fish tail and hickory strain insulators. The cross suspended wires are fastened to U bolts built into the cement structure and supported in the center by other U bolts. The messenger is insulated and anchored at both ends of the tunnel.

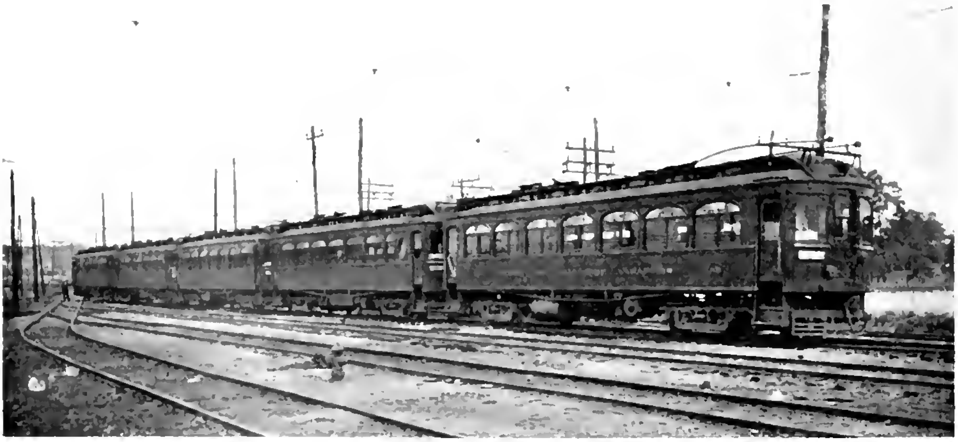


Fig 14 Five Car Train

Section insulators are used where the 1200 volt trolley and 600 volt trolleys meet. The City of Baltimore now permits 1200 volt trolley as far as Lombard and Green Streets, and the City of Annapolis permits 1200 volt trolley running entirely around the town.

The general appearance of the catenary construction will be seen in Fig. 16.

Protection against lightning is afforded by a wire strung along the top of the trolley poles and grounded every fifth pole. Both sets of poles are protected in this manner on double track road. The ground leads are carried under ground and connected to the running rails.

Transmission Line

The transmission line is in duplicate (6 wires) between Bennings and Baltimore, and single (three wires) between Academy Junction and Annapolis. It consists of No. 2 aluminum wires strung on the same poles that carry the trolley. The potential is 33,000 volts at 25 cycles.

Telephone System

The road is equipped throughout with a duplicate telephone system, one line being used exclusively for giving train orders from the dispatcher's tower at Naval Academy Junction to cars at the terminal stations and to the different booths situated along the line. The telephone wires are carried on the same poles with the high tension transmission and trolley wires and are transposed every fifth pole.

Track

The line from Washington to Baltimore is of double track throughout and is provided with crossovers at intervals of about three miles. A telephone booth is situated at each crossover. The distance from the Baltimore terminal to the Treasury station at Washington is 40.54 miles and the total mileage of the system on a single track basis amounts to 88.87 miles.

The rails are of T section, weighing 80 lb. per yard and are laid in lengths of 33 feet. The gauge of the track is standard.

The Annapolis division, which is 20.05 miles long, is laid with similar rails for the major portion of the distance.

There is one curve of 8 degrees under the B.& O. Railway but excluding this there are no curves of over 4 degrees. The entire interurban section has a private right of way; the track is well ballasted with gravel and in every respect is excellent for high speed travel. Standard rail joints are used, and the 000 bonds employed are of the twin terminal type. Cross bonds are used for all special track work and at intervals of about half a mile.

Fig. 15. Express Car and Freight Train

A feature of specified interest from a railroad point of view, and one that greatly conduces to the maintenance of a high speed schedule is that there are only two grade crossings on the entire road between Washington and Baltimore, all the roads and public highways having been raised across the railway at considerable expense.

Car Barns

The car barns are situated at Naval Academy Junction and are provided with every facility for the upkeep of the rolling stock. The building is constructed with a reinforced concrete frame filled with red brick panels. It is divided into a paint shop, washing and inspecting room, machine shop, carpenter shop, blacksmith shop, store room, locker room and offices. The machine shop is well equipped with lathes, drills, saws, etc., all of which are driven by General Electric direct current motors.

Fig. 16. View Along Right of Way

The heating system is very complete and the fire protection is exceptionally good; a pressure tower with a capacity of 50,000 gallons having been constructed for fire protection. The pits are heated to expedite the work of repairing and inspection during the winter months. A very efficient form of transfer table is used in the machine shop, with the aid of which a truck can be replaced in 28 minutes, this being a very creditable performance.

The potential used throughout the yards is 1200 volts and that in the car barns 600 volts.

It is perhaps worthy of note that a special oil house was built, since it was believed that a well equipped oil house is essential to high speed operation.

In addition to the above car barns a barn with a capacity of ten cars has been built at Lombard Street, Baltimore, to facilitate the maintenance of the schedule by a local storage of cars.

Terminal Facilities

The terminal facilities of the Washington, Baltimore & Annapolis Railroad are admirably situated in their respective cities and are of such a nature as to provide for the comfort and convenience of the traveling public.

The station at Baltimore is a red brick building located between Park Avenue and Liberty Street, and has entrances on both streets. It is also bounded by Marion Street. It consists of a waiting room and a ticket office with a track laid through one portion of the building. The administration offices of the company occupy the upper floor.

The Washington terminal is now near the Treasury building and nine ticket offices are provided in Washington between the old White House terminal and the Treasury. The White House depot, which was formerly used as a terminal for the Washington, Baltimore & Annapolis cars when a single-phase road, is now only used for the storage of cars.

At Annapolis the waiting room, ticket office and substation are all in the same building.

A waiting room is provided at Naval Academy Junction for the convenience of passenger changing cars at this point.

COMMERCIAL ELECTRICAL TESTING

PART XIII

BY E. F. COLLINS

TRANSFORMERS—Continued

THREE-PHASE AIR BLAST TRANSFORMERS

Special Tests

The order of tests on three-phase air blast transformers is the same as for the single-phase type. The mechanical construction of the coils is identical with that of the single-phase type; but as the air paths through the iron are longer, the air pressure required is slightly higher.

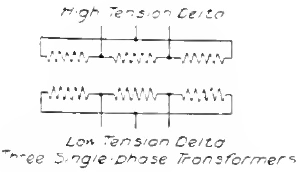


Fig. 53

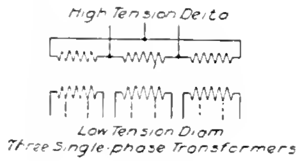


Fig. 54

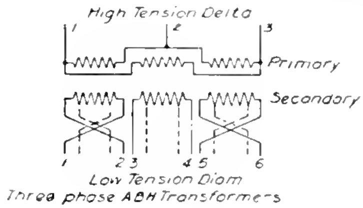


Fig. 57

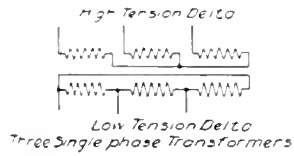


Fig. 55

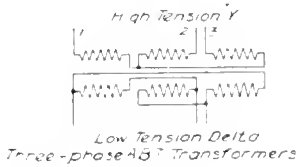


Fig. 58

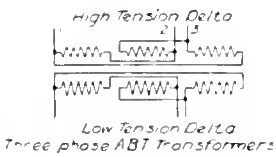


Fig. 56

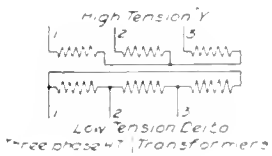


Fig. 59

Connections for Polarity on Three-Phase Transformers

Cold Resistances

The general instructions given for measuring the resistance of the single-phase type apply to three-phase transformers, but since the primary circuits are opened for the heat run, the resistance of each set of coils should be measured. If the secondary coils are permanently connected in delta, the resistance between each set of leads should be measured. If the secondary coils are arranged for diametrical connection, measure the resistance of each set of coils. Note on the record sheet how these readings are taken, so as to avoid confusion in measuring and recording hot resistances.

Polarity

The determination of polarity on three-phase transformers requires much care. The diagrams allow a comparison to be made of the various standard connections. Figs. 53, 54 and 55 are three-phase connections for three single-phase transformers, and Figs. 56, 57, 58 and 59 are connections for three-phase transformers.

In determining the polarity of three-phase air blast transformers, see that the primary and secondary coils are connected as shown. (Figs. 56 and 57.) Supply direct current to primary lines No. 1 and No. 2 to give the proper deflection on the voltmeter, then transfer the voltmeter lines to the secondary, connecting the line that was on No. 1 primary to No. 1 secondary, and the line that was on No. 2 primary to No. 2 secondary. Now break the primary current and if the polarity for this phase is correct, a positive kick will be obtained. Repeat this process for the two other phases and if they all agree with the first one, the polarity is correct. A sketch should be drawn on the record sheet, showing how the polarity test was made.

The polarity test on three-phase transformers also determines whether there will be a change of rotation of phase in transforming from one potential to the other. To determine the polarity of transformers connected as shown in Fig. 57, supply current to primaries 1 2 and take deflection on secondary 1 2; this should show reversed polarity. With current on 1–3 primary the deflection on 3 4 secondary

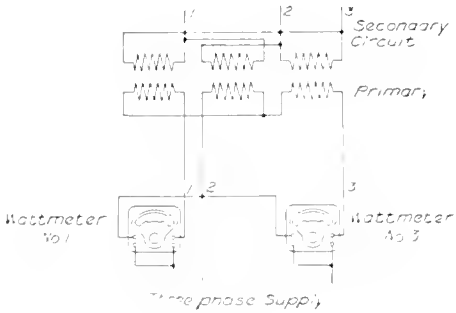


Fig. 60. Connections for Impedance Test

should be positive. With current on primary, the deflection on 5 6 secondary should be reversed.

Ratio and Checking of Taps

Whenever possible, a three-phase transformer should have ratio and taps checked on each phase separately. If this is not practicable, care must be taken to see that both primary and secondary voltages are read on the same phase. When these measurements can not be taken single-phase, three-phase voltage must be applied. If the ratio appears to be wrong, connect both windings in delta, apply full voltage to the secondary, and read the exchange current in the primary delta. This current should not exceed 6 per cent of full load current.

Impedance

For this test, connect the transformer according to Fig. 60 and follow the same general instructions as given for the air blast type. Calculate the current corresponding to the primary voltage of the transformer as follows: primary current $= \frac{\text{capacity in watts}}{\text{line voltage} \times \sqrt{3}}$

Connect in two wattmeters of the same capacity, as shown in Fig. 60. The ratio of the two potential transformers or multipliers should be the same. The algebraic sum of the readings of the wattmeters will represent the impedance loss of the transformer. The sign of the readings must be carefully noted, since the reading of one wattmeter may be reversed. To test for this, open line No. 1 and if the reading for wattmeter No. 3 is positive, the needle will drop to some value above zero. If the needle drops off the scale below zero, the reading must be recorded as negative. If the first meter tested reads positive, the sign of the other meter should be determined by this method.

An impedance curve should be taken from 50 per cent to 125 per cent full load.

In making the short circuit test on ABH (Fig. 57) transformers, each phase must be short circuited independently of the other. In taking readings, hold the current constant in one line from the testing table. Read the three-phase volts and the two wattmeters. Hold the voltage constant across one phase and read the current in the other phases.

Core Loss

In the core loss test, wattmeter readings are taken in the same manner as for the impedance test. The same precautions must be observed in regard to fastening up the primary leads so that there is no chance of danger. Take core loss curve from 50 per cent to 125 per cent normal voltage.

In ABH transformers, with the middle points of each phase connected together to form a neutral for a three-wire direct current system, some confusion may result as to the proper method for measuring core loss. If the neutral connection is broken (as is sometimes necessary for the heat run), the secondaries may be connected in delta and three-phase voltage applied. This voltage is the same as the diametrical voltage, or that of each phase. If the neutral can not be broken, the secondaries may be connected in Y, the neutral connection forming the Y point. In this case the voltage corresponding to the normal voltage of the transformer will be $\frac{\sqrt{3}}{2}$ times the diametrical voltage. It should be remembered that the middle set of coils should be connected so as to be reversed with respect to the other two, in order to obtain the proper magnetic flux in all parts of the core.

Hold the voltage constant and take readings as in impedance test. There will be a slight unbalancing of the magnetizing currents due to the unequal magnetic reluctances in the different parts of the core. For this reason the alternator for core loss tests must be operated at normal voltage so as to balance the three-phase voltage as nearly as possible.

Parallel Run

The parallel run checks ratio and polarity on a three-phase transformer in the same way that it does on a single-phase transformer.

Connect the secondary circuits of the two transformers in multiple, and the primaries as shown in Fig. 61.

Connect between A and A' and try the fuse wire from B to B'; if no spark is obtained, connect from B to B', leaving the first connection, and try the fuse wire from C to C'. If no spark results here, the parallel run is satisfactory. The voltage must be taken off before any connections are changed.

Heat Run

The method described for three single-phase transformers is the one ordinarily used. If two or more transformers are to be run simultaneously, connect the transformers in multiple on the secondary side and the primaries all in series. The same general instructions for the heating of single-phase transformers will apply; in fact, each phase of a three-phase transformer must be treated as a single-phase transformer. Use as many thermometers on one three-phase transformer as on three single-phase transformers. A higher pressure is necessary to force air through the ducts

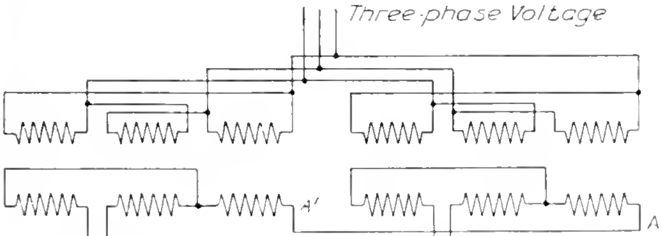


Fig. 61. Connections for Parallel Run, Three-Phase

in the iron of the three-phase transformer than in the single-phase, and the damper must be carefully adjusted.

In calculating the voltage required to supply the primary current for the heat run, the following rule may be used: If the primaries are connected in delta, multiply the impedance voltage by three; if the primaries are connected in Y, multiply the impedance voltage by $\frac{3}{\sqrt{3}}$. If overload is required, add 50 per cent for 50 per cent overload and 25 per cent for 25 per cent overload.

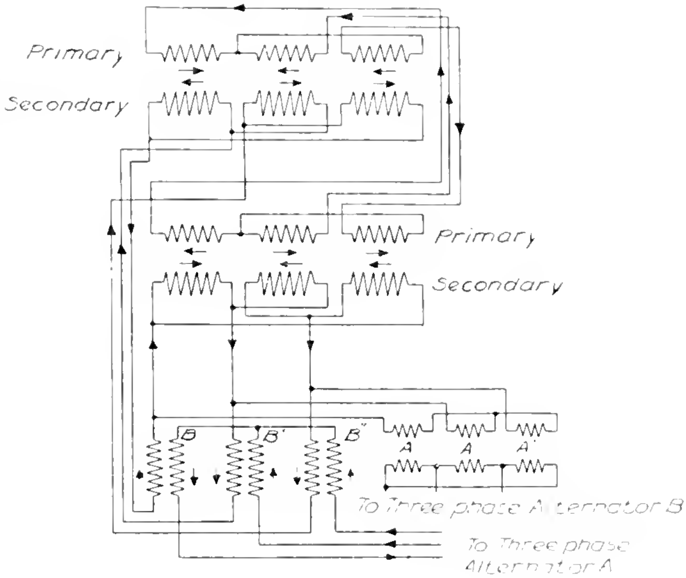


Fig. 62. Connections for Heat Run, Three-Phase

If it is impracticable to open the primary connection in order to take the heat run by applying three-phase voltage, to the secondaries and single-phase current to the primary, the following method may be used: Connect the transformers as shown in Fig. 62. Auxiliary transformers A, A', A'' are used to supply secondary voltage, and transformers B, B', B'' as series transformers to supply the impedance voltage to the secondary circuits. The voltage necessary to supply full load current is twice the impedance voltage of one transformer. The impedance voltage is the same percentage of the total voltage, irrespective of the circuit to which it is applied. The figure shows two three-phase alternators, one supplying core loss and exciting current, and the other the copper losses. When two alternators are used they must be run at nearly the same frequency, otherwise the superposition of the impedance voltage on the core loss voltage will impart a slight swing to the meter needles. Instead of the three transformers B, B', B'', a three-phase transformer or an induction regulator may be used. If a regulator is used, all the losses may be supplied from one alternator.

Double Potential Test

If any repairs or alterations are required, such as making primary delta or Y connections permanent, or connecting up the secondary neutral, the double and high potential tests should be omitted until everything is completed. If double potential can not be obtained from a three-phase alternator on account of the high magnetizing current, the test can be made on one phase at a time. Double potential should always be followed by one and one-half times normal potential for five minutes.

High Potential

The high potential should always be applied after all changes have been made, such as tightening loose iron, connecting primary delta or Y. The polarity should always be tested after the delta or Y connection has been made.

Other tests, such as overload heat run, hot resistance and air readings, are made in a manner similar to that followed for single-phase transformers.

OIL-COOLED TRANSFORMERS

The order of tests on oil-cooled transformers is the same as that for air blast transformers. The transformer should, if possible, be filled with oil at least four hours before starting the tests; If not possible, the cold resistance, polarity, ratio, checking of taps and impedance tests may be taken before. Under no condition, however, must an oil-cooled transformer of over 10,000 volts be operated at normal potential without being filled with oil, as the coils have only one taping, and the insulation may therefore break down.

Cold Resistance

If the transformer has not been filled with oil, a thermometer should be suspended inside the tank to measure as nearly as possible the temperature of the windings. If filled with oil, record the temperature of the oil. Always use a spirit thermometer to obtain the temperatures inside the tank. As the leads are not brought out in the same manner as in the air blast type, the circuits should be carefully checked before starting the tests.

Heat Run

The methods and connections used are practically the same as for air blast transformers, except that oil-cooled transformers should be started at an overload, so as to heat them up rapidly and thus shorten the run. Where practicable, they should be run with 50 per cent excess current for two hours, and 50 per cent excess voltage for three hours. In some cases the time of overload run must be shortened, though occasionally a longer time is required. When normal voltage is applied, the alternator must be operated at normal voltage.

During the heat run, a careful search should be made for oil leaks in the tank and oil gauges. If the transformer has been filled so full of oil that it is likely to overflow, draw off some oil. The leads coming from the transformer must not siphon the oil. In locating thermometers on the outside of the tank, place one at the top, about the height of the oil line, and on very large transformers, one near the bottom of the tank, always using the putty provided. As it is not possible to get the temperature of the core, the oil temperature must be carefully obtained. Whenever possible, place one thermometer near the center of the transformer so as to measure the temperature of the oil as it comes from the coils. The bulb of the thermometer should be about two inches under the oil. Place one thermometer in the oil about three inches from the side of the tank.

Oil-cooled transformers usually require a very long heat run, varying from six to fifteen hours, depending on the size. The heat run should be continued until the temperature rise is less than one degree in two hours. Do not make a short circuited heat run on an oil-cooled transformer if it can be avoided; if unavoidable, make a short circuited heat run on the coils to constant temperature, then take double potential for one minute, one and one-half potential for five minutes, and one and one-quarter potential for three hours.

High Potential or Insulation Test

Many oil-cooled transformers are built for 50,000 to 100,000 volts and require a correspondingly high insulation test. The wiring from the high potential transformer to the transformer to be tested should be arranged so that no one can possibly come in contact with it. It must be securely strung to prevent its falling on any one.

The voltage applied is controlled either by varying the field of the alternator supplying power to the low potential side of the testing transformer; or, if the power is taken from the constant potential shop circuit, by a single-phase potential regulator. The spark gap should always be used and, if the power is supplied from a separate alternator or is controlled by a potential regulator, a high resistance consisting of two or more glass tubes filled with clean water should be placed in series with the spark gap. This limits the flow of current across the gap at the instant of arcing over and prevents a sudden discharge of the transformer windings.

The transformer windings act as the plates of a condenser; if suddenly discharged, or brought to the same potential, adjacent turns may easily short circuit. The same phenomenon occurs when potential is suddenly applied to a transformer. To reach the interior of the windings, the charging current must either follow the conductors, or break down the insulation between adjacent turns. The end coils are therefore all strongly reinforced to prevent short circuits. The general instructions already given for high potential test on air-blast transformers also apply here.

Double Potential

On transformers built to operate at 50,000 volts or over, the double potential should be the last test applied, in order to discover if any breakdown has occurred between turns under the high potential test.

OIL AND WATER-COOLED TRANSFORMERS

Oil and water-cooled transformers are identical in construction to the oil-cooled type, except that, instead of being placed in corrugated tanks to radiate the heat, they are placed in smooth tanks and have a cooling coil immersed in the oil to carry away the heat generated by the losses. The cooling coils are usually made of wrought iron pipe made up in coils of proper size by the pipe manufacturers. In special cases, however, where salt water is used for cooling, copper pipes are employed to avoid the action of the salt on the cooling coils. In most transformers these coils are placed in the upper half of the tank, but sometimes the cooling coils are made of flattened brass or copper tubing, placed between the primary and secondary coils. In large water-cooled transformers with low secondary voltages, the secondary winding is made of flattened copper tubing, through which water circulates.

The tests on water-cooled transformers are the same as for other types, but special instructions are necessary for handling the water. The oil in the transformers should completely cover the cooling coils. The cooling coils are tested by the plumbers to several hundred pounds per square inch, but they should also be tested by the testing department at the water pressure available. Allow water to flow through the coil until no air is left; then close the overflow, allowing the pressure to rise. Note whether there are any leaks, and if not, close the inlet valve. If the pressure drops rapidly, a leak is present. If the outside plumbing and valves are tight, test the oil at the bottom of the tank for water by drawing some off in a test tube. If water is present, it will settle to the bottom of the tube. If water is found, the cooling coil must be taken out and repaired. If however, the pressure does not fall, leave the transformer under pressure for two hours. After all the tests are finished, the oil should be tested for water. With wrought iron pipe very little trouble is experienced.

Make all tests except the heat run according to the instructions already given for other types. At the start, run at normal rating without water until a rise of 20° C. by resistance is reached. The oil should have a rise of about 15° C. The ingoing water should be heated up to 20° C. by using a steam heater; this is about the average temperature found in practice. The water should then be adjusted so as to have 10° C. rise. Temperature readings should be made every fifteen minutes, in order that the quantity of water may be properly adjusted without loss of time. As soon as the transformers have nearly reached constant temperature, the quantity of water should be noted and a record made every half hour. The water may be weighed or measured.

The amount of water required is estimated as follows: One gallon of water will require about 2650 watts to raise it 10° C. in one minute, or one gallon of water raised 10° C. in one minute will carry away the heat generated by 2650 watts loss.

For a rough estimate, use one gallon of water for each 2500 watts loss—a small portion of the heat will be radiated from the outer surface of the tank. When the load is taken off the transformers for resistance measurements, always shut off the water. Complete the tests as on other transformers, making careful inspection for oil leaks. As the leads of many of these transformers are brought out through the cover, care must be taken, when making connections to avoid dropping tools on the porcelain bushings.

These transformers are usually made for very high voltages, and are often filled with oil that has been specially refined. The tank is exhausted of air while the transformer is hot, and the hot oil allowed to slowly flow in at the bottom of the tank. To heat up the winding of these transformers, put one-half the full load current through the primary winding, carefully measuring the cold resistance. Take readings every half hour and calculating the rise of temperature by resistance. When a rise of 50° C. is reached, decrease the current to maintain the temperature while the tank is exhausted of air.

In water-cooled transformers with secondary coils made of flattened copper tubing through which the water flows, the amount of water flowing through each section should be measured if all the sections are fed from the same water head. If each section has a regulating valve, these valves should be fully opened. Put on a low reading pressure gauge, hold the pressure constant by means of the valve in the main pipe and carefully measure the quantity of water from each section for a given time. Record the pressure and quantity per minute through each section. Never apply a pressure of over 10 pounds per square inch to a transformer of this type, as there is danger of opening the soldered joints. In taking overload heat runs, always use the same amount of water as for the normal load heat run.

Oil-cooled and oil and water-cooled transformers built for voltages above 75,000 have special high tension leads which are oil filled. These leads must be carefully filled with oil before potential is applied to the transformer, and they must be kept filled. They should be carefully watched for leaks.

(To be Continued)

THE CURTIS TURBINE*

By Charles B. Burleigh

The Curtis turbine was first introduced to the commercial public in its larger sizes, from 500 to 5000 kilowatts capacity, and since with the large turbines an excessive weight in moving member must be dealt with, these large machines were originally designed of the vertical shaft type. For this reason many have conceived the erroneous idea that the characteristics of the Curtis turbine necessitated the vertical form of construction; whereas in point of fact the Curtis turbine is equally well adapted for both vertical and horizontal arrangement of the shaft. In this respect the manufacturers of this turbine occupy a unique position in the turbine field in that they are prepared to offer, in accordance with the demands of local conditions both horizontal and vertical types. This being the case it may be of interest to discuss some of the characteristics of the two types and some of the limiting features of turbine design.

A comparison of the speed of the rifle bullet and the velocity of a jet of water will give the reader a partial conception of the problems that confronted the turbine designer, and presents a sufficient excuse for the delay in the development of a piece of apparatus that was conceived about 120 B.C.

With the hydraulic turbine it is the exception when the motion of the fluid is in excess of 200 feet per second, for the velocity of a jet of water at 150 pounds pressure per square inch (which corresponds to a head of 346 feet) is approximately 149 feet per second; while steam expanded from 150 pounds pressure per square inch to the pressure of the atmosphere attains a speed of 2950 feet per second, and if expanded into a 28 inch vacuum, can attain a velocity of 4010 feet per second.

In the impulse turbine, the steam expands in a separate nozzle or nozzles that are so arranged as to give it direction and bring it at expansion pressure and expansion velocity in contact with the buckets secured to the periphery of the rotating wheel, from which it rebounds, as an elastic body, with the same velocity as that with which it *strikes* i.e., with a velocity equal to the difference

*The calculations in this article are theoretical and disregard friction, losses due to angle of nozzles, etc., etc. *Editor.*

between the velocity of the steam and that of the buckets.

In other words, where steam that has been given a speed by expansion of 4000 feet per second, is brought in contact with the impulse bucket so secured as to be incapable of movement, it rebounds at a speed of 4000 feet per second.

Do not understand that the steam would not tend to actuate the stationary bucket, for it would, since the pressure on the bucket is greater when the bucket is stationary and is reduced as the bucket moves away from the steam, the steam pushing the bucket under the latter condition with a force which is proportional to the relative velocities of the steam and the bucket.

The steam delivered by the nozzle is moving so fast that it has no trouble in keeping up its push on buckets that are moving at a high speed. Thus as the velocity of the bucket is increased the steam is able to follow it, and up to a velocity equal to that of the steam itself tends to push it forward; if the speed of the bucket reaches that of the steam the latter would simply follow without pushing at all. It should be remembered that it is the relation of the velocity of the steam to the resistance offered by the bucket to movement of the bucket that determines the bucket's speed.

On the other hand, if the impulse bucket be allowed by the governor to move at a speed of 1000 feet per second, and the steam moving at a speed of 4000 feet per second be brought in contact with it, the steam will give up a portion of its energy to the bucket and leave it at a speed of 2000 feet per second, hence losing velocity by an amount equal to twice the wheel velocity.

Steam enters the bucket at velocity V_1, following the arc of the bucket, and, neglecting losses, the velocity which is left is V_2.

As stated, the energy of a moving body is one-half the mass times its velocity squared, thus the energy possessed by the steam as it goes into the bucket is $\frac{MV_1^2}{2}$, and since the mass of the steam has remained unchanged, its energy as it comes out is $\frac{MV_2^2}{2}$; the energy given up to the bucket is therefore: $\frac{MV_1^2}{2} - \frac{MV_2^2}{2}$. This has been given up to the buckets because the steam was pushing while the buckets were moving.

If the buckets had been stationary it would have simply changed the direction of the steam without material loss of energy, as it would have entered at a velocity of V_1 and left it at practically the same velocity; in this case no work would be done.

To take the full energy out of the steam, the wheel velocity must equal one-half the velocity of the steam jet; or as before, if the expanded steam moves at a speed of 4000 feet per second and is brought in contact with an impulse bucket moving at a speed of 2000 feet per second, thus losing velocity by an amount equal to twice the bucket velocity (2000 feet per second), its energy will all be given up to the bucket.

From the foregoing it is easy to determine the best speed conditions. When the bucket is stationary the push is greatest and the bucket's velocity is zero; and when the speed of the steam and that of the buckets are equal the bucket's velocity is greatest and the push is zero; at both of these extremes the work done is zero.

There is a point between these two extremes where the effect will be maximum. That point will be where the energy remaining in the steam after it has passed through the bucket will be the least.

Now let us assume that V_1 is just twice the velocity of the bucket; then, subtracting this bucket velocity from the steam velocity, we have as a remainder the relative velocity of the steam with respect to the bucket ($\frac{1}{2} V_1$), or the speed at which the steam overtakes the bucket. Consider for an instant that this relative velocity of the steam is the initial or actual velocity, and that the bucket is stationary; then, from what has been said, the steam would rebound from the bucket at a velocity equal to the initial velocity, or $\frac{1}{2} V_1$. However, the bucket actually has a velocity equal to the relative velocity, and the steam in striking rebounds *with respect to the bucket* at a velocity equal to the relative velocity, but with an *actual* velocity equal to zero. When, therefore, the velocity of the steam is twice that of the bucket, the steam delivers all its energy to the buckets.

In an impulse turbine therefore, such as the Curtis, with a given pressure range per wheel, the wheel velocity at best efficiency is only about 50 per cent of what it is in a reaction turbine, and 70 per cent of what it is in a combination turbine which alternates between impulse and reaction effect.

It is not possible to get efficiency with a single turbine wheel of the reaction type, while with a single wheel of the impulse type good efficiencies have been obtained by using extremely high peripheral speeds.

While hydraulic turbines are always designed with a single wheel, for the reason that the highest heads available produce in fluids velocities which correspond to moderate efficient wheel speeds, in the steam turbine it is not possible to make effective use of the total energy of the steam by a single wheel, and a number of wheels in series have to be used in order to efficiently utilize the extremely high velocities resulting from the steam expansion.

That is, the rotor velocity is reduced by subdividing the total pressure range into a number of successive stages.

In the combination impulse and reaction turbine each expansion or pressure stage requires a revolving wheel and a stationary guide wheel. The latter acts as a nozzle wheel in which the steam expands, acquiring a velocity equal to the velocity of the revolving wheel.

At the entrance into the revolving wheel this velocity is transferred to the wheel on the impulse turbine principle, and the steam in passing through the revolving wheel expands again, leaving it with wheel velocity; that is, the revolving wheel of the Parsons type is substantially an impulse wheel at the entrance and a reaction wheel at the exit side.

In the impulse turbine, in which the expansion of the steam is carried out separately from the transformation into mechanical rotation, a further and still more effective means of speed reduction is presented by the use of several velocity steps in each stage; that is, by imparting the velocity of the current of steam to a number of successive wheels composing a single revolving disc, by means of stationary guide wheels.

Since in a revolving wheel of an impulse turbine the steam velocity is reduced by an amount equal to twice the wheel velocity and a single wheel per stage must revolve at one-half the steam velocity, two wheels per stage must revolve at one-quarter the steam velocity and so forth. It follows, therefore, that the use of several wheels per stage is a most effective means of reducing the rotor speed; or inversely, when the rotor speed is given, of reducing the total number of revolving wheels. A two-wheel stage can thus take care of twice the steam velocity (or, four times the steam energy) of a single-wheel stage, and therefore, replaces four single-wheel stages. In other words, the speed reduction of the rotor is proportional to the number of wheels per stage; that is, to the number of velocity steps, but is proportional to only the square root of the number of stages; that is, the number of pressure steps.

The simultaneous use of pressure steps, or expansion stages, and velocity steps, or number of wheels per stage, leads therefore, to a construction requiring only a very small total number of wheels, which is carried out in the Curtis type of impulse turbine.

To illustrate: assume a total steam velocity from boiler to condenser of 4000 feet per second. Allowing a 10 per cent velocity loss, the available velocity would be 3600 feet per second, and two stages of three wheels per stage, or a total of six revolving wheels, would give a spouting velocity of the steam per stage of $\frac{3600}{\sqrt{2}} = 2550$ feet per second, and therefore a wheel velocity of $\frac{2550}{6} = 425$ feet per second.

With a wheel velocity of 425 feet per second, a single impulse wheel would efficiently utilize only $2 \times 425 = 850$ feet per second steam velocity, and $\left(\frac{3600}{850}\right)^2 = 18$ stages or successive steps of expansion would be required, that is, 18 revolving wheels, each with a set of expanding nozzles, etc.

With a wheel velocity of 425 feet per second, in a reaction type $\left(\frac{3600}{425}\right)^2 = 72$ successive expansions would be necessary; that is to say, if this condition could be realized, 36 revolving and 36 stationary wheels would be requisite.

In the Curtis turbine, two methods of subdividing the steam energy are available; pressure steps or stages, and velocity steps or wheels per stage. Obviously, a single pressure step or stage with a considerable number of successive wheels, or a large number of stages each with a single wheel, could be used, but either of these extreme arrangements would be inefficient, and the relative distribution of work between pressure steps and velocity steps depends upon considerations of efficiency.

The main losses in a steam turbine are:

(1) Wheel friction.

The wheels revolve in an atmosphere of steam, which has a remnant velocity several times greater than any tornado that ever devastated the country. This loss decreases with the decreasing number of wheels; hence it is a maximum, other things being equal, with the reaction type of turbine, and diminishes with a decrease in the total number of wheels; that is, with an increase in the number of wheels per stage.

(2) Bucket friction, or friction in the steam passages in revolving wheels and guide wheels.

This loss depends upon the relative velocity of steam and wheel, hence it is a minimum in the reaction turbine, where the average relative velocity is only half the wheel velocity.

In a single wheel impulse turbine, the relative velocity is equal to the wheel velocity, and increases with increasing number of wheels per stage, that is, an increasing number of velocity steps. It is this loss which finally limits the number of wheels permissible per stage.

(3) Nozzle losses—which at first decrease with decreasing pressure range (that is, decrease with decreasing work done per nozzle, or in other words, with increasing number of stages) but then increase again, due to the lesser accuracy of operation which results with very many successive nozzle wheels.

(4) Steam leakage from stage to stage. Leakage losses are very much greater in the reaction turbine, where pressure differences exist between the intake and discharge side of each wheel and are dependent on the percentage of radial clearance and the bucket area. These leakages become small with impulse turbines, and disappear entirely in an impulse turbine using many wheels in a single stage.

If, therefore, we consider the losses as a function of the total number of revolving wheels, some losses—such as (1) and (4)—increase while others—such as (2)—decrease with increasing number of wheels; the problem of turbine design is to determine that intermediate point at which the total sum of the losses is a minimum, that is the efficiency is a maximum.

The foregoing conditions have been given the most careful consideration in the design of the Curtis turbine with the result that, irrespective of the shaft position, the smaller sizes from 7 to 35 kilowatts are of the single pressure step or expansion stage and multi-velocity step type. This construction eliminates entirely leakage losses (4), and greatly reduces nozzle losses (3), at the same time presenting extremely moderate wheel and bucket losses (1) and (2).

The former are further reduced to a minimum by the use of but one wheel having secured to its periphery (by a method later described) three rows of moving buckets, which function in the same manner as would three independent wheels and eliminate a large proportion of the skin friction. This arrangement, in conjunction with two rows of intermediates or re-directing buckets, constitute the interior equipment.

The intermediate sizes of turbines, from 100 to 500 kilowatts are of the double pressure step, or expansion stage variety and multi-velocity, or two or more wheels per stage type; while the larger sizes, from 750 kilowatt units upward, are usually for land purposes of the four or five pressure stage type and of the double velocity, or two-wheel per stage, design.

In the smaller sizes three rows of moving and two rows of intermediate buckets are employed; in the intermediate sizes four rows of moving and two rows of intermediates, and in the larger sizes eight or nine rows of moving and four rows of intermediates are used.

Perhaps a detailed description of one of the smaller size non-condensing units will best convey to the reader the extreme simplicity of the Curtis design. We will take for example a unit of 25 kilowatts capacity, which is designed to operate from 150 lbs. steam, exhausting against atmospheric pressure.

As previously stated in this size we shall select the single pressure step or single expansion stage, multi-velocity step type. With this design there will be no leakage losses, minimum nozzle losses and moderate wheel losses.

In our steam pipe, which must be large enough to properly supply the unit, we shall locate a metal screen to prevent boiler scale or other foreign matter from entering the machine.

We shall next provide a main admission valve for shutting off or turning on the steam to the steam chest. This chest must be sufficient to accommodate the several admission valves controlled by the governor, the position of which determines the amount of steam admitted to the machine.

Each of these valves controls the flow of steam through one or more expanding nozzles, which deliver the steam from the steam chest to the interior of the machine and are of such design as to expand it from boiler pressure to atmospheric pressure, thus giving to the steam a velocity of 2950 feet per second.

Atmospheric pressure of course, exists throughout the interior of the machine, and the steam delivered by the nozzle or nozzles is obviously of the same pressure, for which reason it is dependent upon the nozzle to give it direction; the nozzle angle is therefore carefully arranged to give that direction which will bring the steam in contact with the moving bucket without shock or sudden change of direction.

Since the area within the turbine and the admitted steam are of the same pressure, there is no more tendency for the steam to change its direction and attempt to escape into an atmospheric of its own density than there would be for a stream of water delivered by a hose nozzle into the atmosphere, to change its direction until it was brought in contact with some medium other than the atmosphere of such shape as would redirect it previous to its losing its velocity. For this reason you will appreciate that the efficient delivery of the steam by the nozzles to the buckets is in no way dependent on an exceedingly close proximity of the bucket to the nozzle, or in other words, fine clearance has no effect on efficiency.

The machine is equipped with some five or more expanding nozzles arranged successively, so that their delivery ends from practically a continuous opening some eight or more inches in length, separated by division walls, the width of the nozzle opening corresponding closely to the length of the bucket with which the steam is to be brought in contact.

The expanding nozzles are worked out in a bronze plate designed to bolt to the steam chest.

The governor of the machine, which in the smaller sizes is an extension of the shaft and rotates with it at shaft speed, thus doing away with the necessity of intermediaries, is of the flyball type.

In the intermediate and large sizes of turbines the valves permitting the entrance of the steam to the nozzles are controlled by a governor and consequently the volume of admitted steam is dependent on the load on the machine.

With a very light load on the unit but one of the valves would be open, controlling but one or two of the expanding nozzles, admitting a volume of steam corresponding to the area presented by the throat of the nozzle and delivering it to the interior in a short belt of a width approximately equal to the length of the delivery end of the nozzle or nozzles that are open.

As more load is imposed on the machine, successive nozzles are opened by the action of the governor and the admitted steam belt thereby lengthened until the extreme overload point is reached.

It will be seen that regulation is accomplished by lengthening or shortening the belt of admitted steam.

It will also be noted that all steam admitted to the machine flows continuously through the unit and that no losses occur due to alternate heating and cooling; further than this, under no condition of load does the belt of admitted steam surround more than a small fraction of the machine periphery.

(To be Continued)

THE ELECTRICAL EQUIPMENT OF THE JOHN N. ROBINS CO. ERIE BASIN, BROOKLYN

By G. S. Rose

The shipyard of the John N. Robins Co., at Erie Basin, Brooklyn, is, in point of tonnage handled, the largest shipyard in this country devoted to repair work. The yard covers twenty-three acres and harbors five dry docks, the largest of these being capable of handling a vessel 600 feet in length. Three of these docks are of the floating type, the remaining two being of the graving construction.

The floating dock is submerged by allowing the water to enter its pontoon base and hollow sides. The vessel to be repaired is then floated in on top of the structure and the water pumped from the hollow portions, the dock rising and lifting the vessel out of the water. All three of these docks are emptied by electrically driven pumps located on the dock itself.

The graving type of dock consists of a walled slip, the base of which is below the level of the sea, with a movable dam or caisson at one end of the structure. To dock a vessel, the slip is filled with water to the same level as that upon which the ship to be repaired is floating. The vessel then enters the slip and the floating gate or caisson is securely fastened in place and made as watertight as possible. The water is then pumped from the slip, leaving the vessel high and dry. Fig. 1 shows one of these docks pumped dry and ready to be flooded to receive the ship, which may be seen floating on the bay in the distance. The supporting blocks which are pulled under the vessel to support it while being repaired can be seen along the base of the dry dock. The illustration on page 482 shows a vessel in dry dock with the supports in place. It is this graving type of dock in which we are particularly interested.

Fig. 1. Graving Type Dry Dock, Pumped Dry

In the shipyard considerable power is needed, not only to remove the water from the slips but to drive the machine shops, furnish the lighting and run the compressors for supplying air to the drills.

Three years ago Mr. Wm. T. Donnelly, a consulting engineer of New York City, was retained as engineer for this property. At that time the yard was supplied with power from one of the old type plants, consisting of a large boiler plant supplying steam to some twenty steam engines located in various parts of the yard; these engines, with one exception, being of the non-condensing type. Mr. Donnelly recognized the fact that the plant was out-of-date and uneconomical, and considered the installation of an up-to-date power plant with electrical distribution, with the alternative of taking power from a large central station. The results of this investigation confirm the claims made by large central stations, that they can furnish power for an installation of this sort cheaper than it can be generated in a smaller individual power plant. The operation of pumping the docks would give a very heavy peak load of short duration when compared with the average power consumed in the yard. This would mean, of course, a heavy initial expense involved in a plant large enough to handle the heavy peak loads; and besides, a very low load factor. For a large station supplying principally lighting service, with a load factor in the neighborhood of 35 per cent, a customer using approximately 265,000 kw-hrs. per month was indeed a prize. Arrangements were finally made whereby The Edison Electric Illuminating Company of Brooklyn contracted to supply The John N. Robins Co. with power at three-phase, twenty-five cycles, 6600 volts on a maximum demand basis.

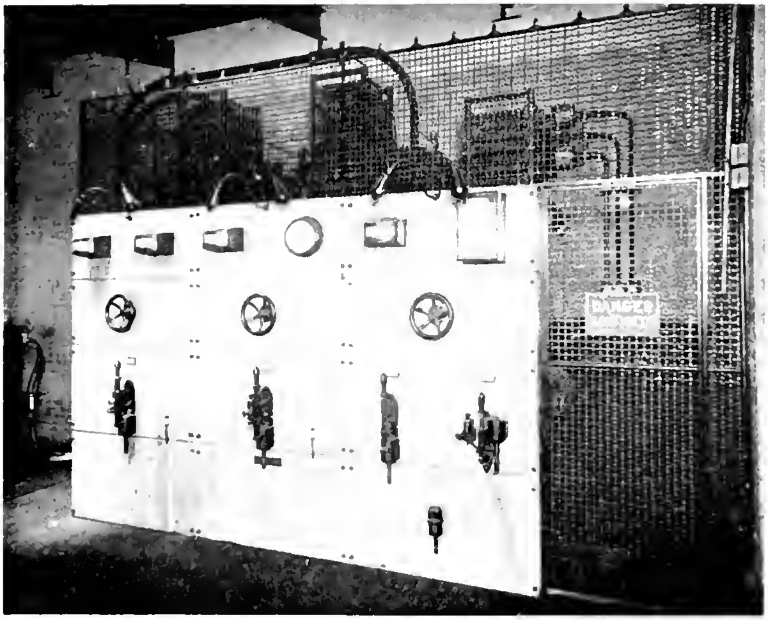


Fig. 2. Switchboard for Controlling Pump Motors

In changing to electric drive, a large distributing board was necessary to take the power from the Edison system and distribute it to the various parts of the yard. Space was a primary consideration and an unusually compact and complete switchboard was installed for this purpose. This board is of General Electric manufacture, the oil switches of which are of the well known "K" type, three-pole, single throw construction, mounted in cells directly back of the panel. Each switch is equipped with an inverse time limit relay, opening the switch when under overload. In addition to the protection against overload, an auxiliary shunt coil was added to the mechanism so that a switch may be opened by remote control from the point in the yard to which the feeder runs. In case of trouble around the yard, this arrangement allows the operator to disconnect his circuit by opening the main feeder switch, without having to get in touch with the operator at the main switchboard. Wattmeters are installed on all of the various circuits so that the amount of power used can be readily analyzed; these wattmeters, which are of the recording polyphase induction type, are designed for switchboard work and are of the very highest grade. A duplicate set of busbars was installed in order to make a flexible arrangement and at the same time allow the operator to work on one set of bars while the other is supplying power to the yards.

Two of the largest feeders from the distributing board run to the motors that are used to drive the vertical pumps which pump the water from the slips of the graving docks. These units consist of two 350 h.p., three-phase, 6600 volt, 25 cycle vertical type induction motors, each direct connected to a vertical type 30 inch centrifugal pump. These motors are designed with wound rotors and are furnished with starting resistance which is connected in series with the rotor winding when starting. This resistance increases the starting torque and limits the initial rush of current to the machine when it is connected to the line. The motors are supported on ball bearings located at the top of the machine and supplied with oil by means of centrifugal oil deflectors.

In the old system of direct connected steam-driven pumps, between two and three hours were required to remove the water from the graving docks; depending, of course, upon the size of the vessel in the slip. In changing to electric drive Mr. Donnelly figured on enlarging the water mains and increasing the amount of water which could be handled in a given time. The time required to empty the docks with the two motor-driven pumps is from one and one-quarter to two hours, depending upon the size of the vessel in the slip.

In addition to the two pumps that are used intermittently, a small vertical motor-driven pump, similar to the larger pumps, was installed to operate continuously and handle the leakage which is bound to accumulate in the slips. This vertical pump is driven by a 50 h.p., 440 volt, 25 cycle three-phase induction motor equipped with wound rotor and starting resistance. The motor is operated from a step-down transformer, it being undesirable to wind a machine of this size for 6600 volts.

A blue Vermont marble switchboard was installed to control the above motors and is shown in Fig. 2. This switchboard presents an unusually attractive appearance. The oil switches are of the same type as those used on the main distributing board, and in addition to being automatically opened under overload, they are equipped with automatic release for no voltage conditions. The load on the pumps increases inversely as the head against which they are delivering water and in order to indicate an overload condition before the oil switch is tripped, a relay is inserted which is so connected as to ring a gong and thus notify the operator. If the load on the pump is not relieved, the oil switch will be tripped. The controllers that are used to vary the resistance in the wound secondaries of the motors are interlocked with the switch mechanism so that it is impossible to throw in the oil switch unless all the resistance is in the rotor circuit. Ammeters are placed in the various circuits and a voltmeter is installed to indicate when the bus is alive.

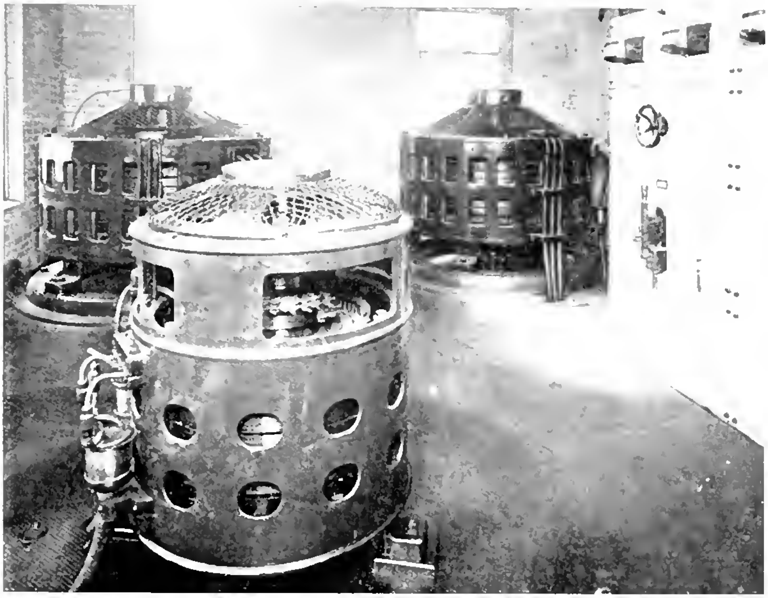


Fig. 3. Two 350 H.P. Induction Motors in Background
50 H.P. Induction Motor in Foreground

The shops of the yard have been changed from the old belt drive with long lines of shafting to motor drive with the group arrangement. The shops are very large and complete, and comprise a large machine shop with tools for handling cylinders and crank shafts of large ships, a smaller machine shop, a boiler shop with large rolls, a copper and sheet metal shop, a blacksmith shop equipped with steam hammers, and a carpenter shop complete with joiner and woodworking machinery. Power in all of these shops is supplied by the General Electric squirrel cage induction motors, started by means of compensators with self-contained oil switches.

The installation nicely illustrates the present tendency of large central stations designed primarily for lighting purposes to increase their load factor by soliciting power customers of the largest class.

CATENARY LINE MATERIAL

By R. L. Hoffman

The advent of increased speeds and operating voltages on electric railways demanded that radical improvements be made in the existing overhead system, with the result that the catenary form of construction was developed. The advantages of this method of suspension are found principally in its adaptability to longer spans in the cross span and bracket construction; for instance, spans of from 125 ft. to 175 ft. are possible with catenary construction as against 80 ft. to 100 ft. with direct suspension. (Fig. 9). Also, by the use of structural steel bridges or supports, spans of from 240 ft. to 300 ft. are practical. The line can readily be insulated for any practical operating voltage and the contact wire can be made as nearly level as good operation requires, dependent on the type of collecting device to be used. All rigid or hard spots are eliminated and vibrations in the contact wire produced by the passing collectors are free to travel in either direction indefinitely. In direct suspension these vibrations are confined to a single span and are damped at the point of support, causing the wire to become fatigued and to break at this point. Catenary construction further provides safe clearances for the insulators and for the guy wires from the collecting devices, and by using copper in the messenger or supporting cable, the necessity of erecting an additional feeder cable is obviated.

Fig. 1. One-Point Suspension

On 600 volt direct current lines the principal advantage of catenary construction is the elimination of trolley trouble at high speeds, owing to the flexibility of the construction; on interurban roads, therefore, the life of the wheel and contact wire is greatly increased. With the exception of the strain insulators, the material used for 1200 volt work is the same as that used for 600 volt work, and consequently lines operating on both potentials need carry only those repair parts common to both systems.

To make the table applicable for 1200 volt construction it is only neccessary to add a certain amount for additional insulation, which consists of the substitution or addition of proper strain insulators.

The following amounts should be added to give proper values for 1200 volt construction:

Direct suspension
- Bracket construction $40.00
- Span construction . . 40.00

Catenary suspension
- Bracket construction $10.00
- Span construction . . 10.00

COMPARATIVE COST PER MILE OF 600 VOLT TANGENT TRACK OVERHEAD CONSTRUCTION

POLE SPACING: Direct Suspension 100 Feet; Catenary . . . 150 Feet	DIRECT SUSPENSION		CATENARY—THREE-POINT	
	Bracket	Span	Bracket	Span
Line material	$144.51	$98.85	$144.16	$100.54
4/0 grooved trolley wire	540.00	540.00	540.00	540.00
Steel anchor, guy and span cable	45.00	150.00	21.00	100.50
Messenger cable			91.80	91.80
8 in. by 35 ft. poles	265.00	530.00	180.00	360.00
Erecting poles	185.50	371.00	126.00	252.00
Mounting brackets	13.25		9.00	
Cross spans and back guys		212.00		144.00
Stringing wire and clamp	75.00	75.00	200.00	200.00
Install anchors	100.00	100.00	50.00	60.00
Misc. extras	150.00	150.00	150.00	150.00
	$1518.26	$2226.85	$1511.96	$1998.84
Curves plus 10 per cent	151.83	222.69		
Curves plus 15 per cent			226.80	299.84
	$1670.09	$2449.54	$1738.76	$2298.68

For similar installations, the first cost per mile of material as compared with direct suspension is approximately the same, while the labor item is greater for catenary construction.

The subsequent maintenance, however, is much less for catenary construction, as there is no wear on any of the supporting parts; and, since the contact wire is free to yield under the upward pressure of the collector, pounding and arcing with their injurious effects to the wire are eliminated, thus reducing to the minimum the possibility of a break.

Among the first efforts in catenary construction was a one point suspension with the contact wire supported from the messenger cable midway between the messenger supports, as shown in Fig. 1. This arrangement was somewhat similar in principle to direct suspension, except that the point of suspension had considerable flexibility which in recent installations has been shown to be desirable.

Further developments have brought out the three point suspension with the messenger supported every 150 ft.; the points of suspension for the conductor therefore being 50 ft. apart. The distance between the messenger and the contact wire at point of support is 22 in. and the sag in the messenger cable 16 in. A $\frac{7}{16}$ in. steel messenger cable having a breakage strain of 9000 lbs. is used, and the stress

Fig. 2. Three-Point Suspension

in messenger and contact wires is kept between 2000 and 2500 lbs. This construction has proven so satisfactory for wheel collector operation that it has been accepted as standard for interurban installations. (Fig. 2.)

The original installation of the 3-point suspension, which consisted of 180 miles of line, has proven very satisfactory from an operating standpoint. The hanger used consisted of a standard three-screw clamping ear and a malleable iron sister hook casting connected by a cold rolled steel strip $\frac{5}{8}$ in. wide by $\frac{1}{8}$ in. thick. The prongs of the sister

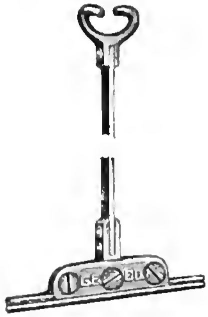


Fig. 3. Sister Hook Casting

hook casting were bent around the messenger cable as shown in Fig. 3. This same form of hanger has been used on a side bracket, double track, 150 ft., 9-point suspension for a high speed trolley with equally satisfactory results.

Later developments have brought about the 150 ft., 11-point suspension, the standard spacing of the hangers for this class of work being 13.6 ft. This construction has a very level contact wire and will give good results.

All of the foregoing constructions have been erected on ordinary wood or tubular iron poles.

A recent installation of 200 ft., 4-point construction with rectangular lattice iron poles for wheel collection has been built. (Fig. 4.) In this installation the distance between the wires was increased to 32 in., the same stress being retained in the messenger and contact wires as in the ordinary standard construction, making only a slight increase in cost per mile of material.

In order to give maximum flexibility to the contact wire, the loop form of hanger has been developed, having an average weight of 8 oz. (Fig. 5.) The stem of this hanger is formed into a long loop at the upper end, so that the contact wire is free to rise from the upward pressure of the collector without lifting the weight of the messenger cable. On 11-point construction several hangers on either side of the collector will be in action at one time. This hanger is intended for spans of 150 ft. or under, but it can be used on the 240 to 300 ft. spans by using two messenger cables, one directly over the other. The main messenger cable then supports the auxiliary messenger for one-third the distance from the main messenger support, and the contact wire is suspended from the auxiliary messengers with hangers spaced the same distance apart as

Fig. 4. Four Point Suspension

for single messenger construction. No appreciable wear from the action of these hangers can be detected on either the steel or copper messenger cable. Another advantage of this arrangement in operation is that slack or stretch in the contact wire can be compensated for without the necessity of readjusting the hangers.

Pull-Off and Curve Work

This is the most difficult and expensive part of catenary construction, as the necessity of holding two wires in position does not permit any saving in poles and fixtures, and the labor required is several times that of tangent work for a given distance. The ordinary bridle pull-off construction (Fig. 6) fulfills all the requirements and has some flexibility, and is generally accepted as standard. To obtain good results on curve work the supporting poles should be located on the outside of the track and pull-offs installed so as to maintain the contact wire within 4 to 6 inches of the center of the track. The longer the bridles can be made the greater the flexibility that can be obtained, and on high speed curves of large radius installed in this manner good operation has been the result. Several installations have used steady braces (Fig. 7) consisting of a long cylindrical wooden body and a clamping car for clamping to the supporting brackets.

For pantograph operation this arrangement

Fig 5 Loop Hanger

is satisfactory, but a considerable reduction in the pole spacing on curves is necessary. Where wheel collectors are used, frequent renewals have to be made, owing to the breaking of the wooden bodies by trolley poles slipping the wire. The point of greatest rigidity in the contact wire lies directly underneath the messenger support and the addition of the weight and tension of the steady brace at this point forms a hard spot.

Anchorages

Recent changes in the method of anchoring the line have resulted in flexibility at this point.

The former method of clamping a rigid hanger between the messenger and the contact wire is now replaced by an arrangement of separate anchor clamps. The messenger clamp is located at a point 10 ft. from the bracket and the contact wire clamp at a point 25 ft. from the bracket. The bracket to which the anchor wires are fastened is in turn anchored to adjacent poles.

Catenary construction on ordinary city electric railways having frequent turnouts and small radius curves should be avoided wherever possible, as local conditions are usually such that the line can not be put up and held with the required tension, owing to the difficulty of locating supports strong enough to hold the strains.

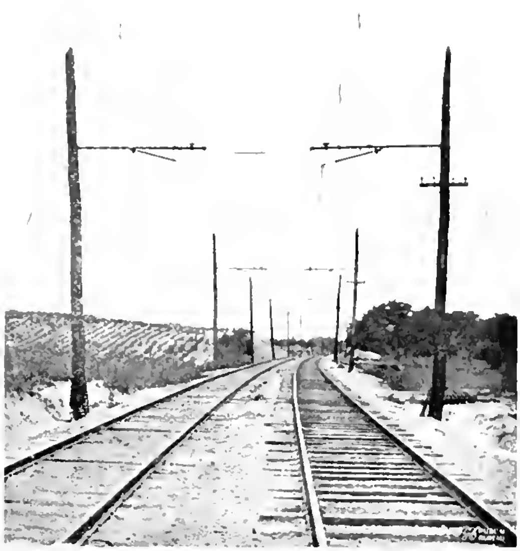


Fig. 7. Catenary Construction Showing the Use of Steady Braces

Fig 6 Pull-Off Construction

NOTES ON ELECTRIC LIGHTING

Part II

By Caryl D. Haskins
Manager Lighting Department, General Electric Company

In the first part of this article we decided that our generating apparatus should be three equal units, turbine-driven. We shall not consider the design of the machines—that is a text book matter.

Let us now consider for a moment some of the other apparatus in our station beside the generating units.

The switchboard, for example, is of vital importance to the good or poor operation of the central station. It is only the layout of the switchboard that we are going to discuss; a consideration of its units would carry us too far. First, we must have the one great essential, a panel for the generator one which will control the generator in all its functions. Generally, there should be one panel for each generator. A generator panel, of course, must be provided with an ammeter, a voltmeter, and an indicating wattmeter. For the sake of economy, a single voltmeter may, in some instances, serve for several generators, and when so used may be placed at one end of the switchboard. Personally, I feel that the provision of a voltmeter on each panel is better practice. The indicating wattmeter is an important instrument on the switchboards of today, since almost every circuit in a generating station is running at a more or less variable power factor. The average switchboard should have certain other instruments, which may be termed minor instruments, as for example a synchronism indicator, which may take either the form of an actual instrument or consist of merely a pair of synchronizing lamps; or a frequency indicator, giving upon a scale, such as that of a voltmeter, the *frequency* of the machine, which means the *speed* of the machine. The latter is a very useful device especially in water power stations, where the speed of the prime mover may be variable. A power factor indicator, though less common, is very valuable, since it saves the comparison of volts times amperes with the reading of the indicating wattmeter; and finally we may find it desirable to use the recording or "curve drawing" instruments for giving us permanent records of voltage or current fluctuations, etc.

Fig. 1. Generator Side

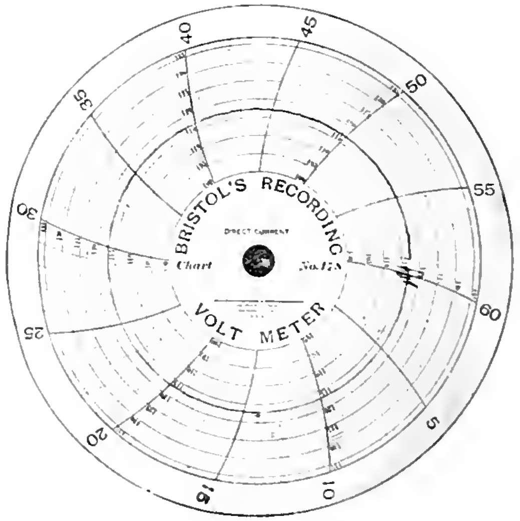


Fig. 2. Regulator Side

We must, of course, have one or more exciter panels in our switchboard for the control of the exciter sets.

Up to this point we have omitted a discussion of single-phase, two-phase and three-phase generation, and here again I must refer you to your text books. The analytical consideration of two versus three-phase service takes one into highly technical questions. Single-phase service is obsolete except for lighting circuits, while three-phase service is becoming daily more universal. Let us then decide arbitrarily that our lighting feeders are to be single-phase and our power feeders three-phase.

It is the practice in many stations to serve power through lighting feeders, but this practice has a grave disadvantage in that the power load often fluctuates severely, and sudden fluctuations in voltage are detrimental to good lighting. Today it is customary in good practice to install a feeder regulator in connection with each lighting feeder, that is, a regulator which will maintain the voltage of that feeder at normal. To show the value of this practice, I have brought these charts (Figs. 1 and 2) showing the variations in voltage on a circuit not equipped with a regulator, and the voltage regulator on the same circuit when equipped with a regulator. The general use of automatic feeder regulators is relatively a new thing; so new, in fact, that five or six years ago only about one station in five or six had them in service. Today, however, there is a large and growing demand for these regulators in central station work, for it is obviously desirable that every central station should have a uniform voltage at the lamps. The rate of installation of feeder regulators during the last four years has increased roughly about 400 per cent. In the old days we used to have voltage regulation of a crude kind by means of hand regulators. Today we have a piece of practically stationary apparatus which depreciates very slowly, and which may be regarded as automatic. Regulators are controlled through relays in a dozen different ways. Power circuits as a rule, do not require close regulation; they do not suffer serious consequences, as do lighting circuits, from voltage fluctuations.

My first experience in connection with the operation of a central station was about twenty-two years ago. The voltage at which the current was transmitted was not high—2400 volts direct current—but in those days we considered it very high. The switches installed were of the ordinary knife blade type and, of course, when we pulled them, we got a heavy arc. We therefore had a notice prepared, which was posted in a conspicuous place near the switch, and read as follows: "The operator will take the paddle in his hand and strike, etc., etc."

The paddle consisted of a good sized wooden handle into which was set a piece of 2-inch belting, and with this instrument we "struck out" the arc as we pulled the switch.

Today, of course, the practice is to break the arc under oil, in what are known as "oil switches." As its name indicates, the oil switch is so designed that when opened the arc which takes place is submerged in oil of a suitable character, thus securing promptly sure, and safe disruption. It is probably one of the most essential and highly developed pieces of apparatus in use today in connection with high tension generating systems. One of our leading scientists has compared the work performed by certain large existing oil switches under short circuit operation, with stopping the Empire State Express in fifty feet when traveling at the rate of a mile a minute, and to my mind this is an excellent way of expressing the "safety buffer" capacity of these devices. Potentials up to 110,000 volts are being handled with oil switches, and I know of certain oil switches that are now being designed and that will shortly be under construction, which will open circuits operating at 140,000 volts. Those of you who have had some experience in connection with high potentials in your work here will appreciate what it means to solve the problem of merely bringing in and out the circuits to such a switch.

Returning to the question of voltage regulation, I have already impressed upon you that it is of great importance that the voltage of the feeders for lighting purposes shall remain uniform. In this respect, alternating current has an enormous advantage over direct current. It will be readily understood that fluctuations in the consumption of energy at the ends of the feeders must, of necessity, result in a material change of "drop" over the entire circuit. It is therefore necessary that the applied voltage at the generating station should respond very readily to this fluctuating demand, in order that the actual voltage applied may remain substantially constant. In no minor feature is alternating current at a greater advantage over direct current than in this connection.

The regulation of direct current systems is, of necessity, accomplished by means of boosters, that is, motor-generator sets or storage batteries, or by rheostatic control. The booster, of course, means moving apparatus, substantially a motor driving a dynamo, its function being commonly to raise the voltage. Generally speaking, this method is undesirable for small plants.

The use of storage batteries for this purpose has troublesome disadvantages except on very large systems, where it becomes desirable. Rheostatic control, however, is worse than either. The use of rheostats serves to reduce the voltage only, with heavy loss of energy. Even for small plants, this method of regulating the voltage is generally condemned. There are but few rheostatic control systems in operation in this country today in central stations, even old ones. In many of the larger direct current stations voltage control is accomplished by means of buses of different voltages, that is, a bus of high voltage, one of low voltage, and another of intermediate voltage. I know of one large city in this country having five buses for this purpose. It does not require an expert to appreciate how complicated such an arrangement renders the switching system. Comparing rheostatic with inductive voltage control on a system of similar size, we find results about as follows:

	Watts Loss	
	Rheostat	Regulator
Full Load	0	335
¾ Load	1300	265
½ Load	2750	215
¼ Load	687	185
No Load	0	175

The induction regulator is, practically speaking, a stationary piece of apparatus; that is, it has no parts with considerable movements, and is so designed that energy is inductively impressed on the outgoing lines in plus or minus direction, as the conditions of regulation may require. This action is controlled automatically or by hand, as may be best or preferred, in such a manner as to raise or lower the voltage of the outgoing lines. The structure being practically stationary, the regulator is subject to but little depreciation and is therefore very much to be preferred to boosters, quite apart from the question of efficiency. Hand control, of course, is by observation on the part of the operator, while automatic control is accomplished by means of a motor, operated through a relay controlled by a contact making voltmeter.

Substations will be dealt with more fully in a later paper. We may say a few words today, however, regarding the various classes of substations.

We may classify substations thus:

(*a*) The static substation, which is by far the most common form. It may consist of one transformer, or a bank of transformers, and its function is to step the voltage up or down, as the case may be, to meet conditions.

(*b*) Motor-generator substations, where the change in voltage (more commonly a change from alternating current to direct current service) is accomplished by means of a motor driving a generator.

(*c*) Rotary substations, in which the rotary converter takes the place of the motor-generator set, performing the same functions.

Dense districts make direct current distribution desirable, and where this system is desirable, the motor-generator rotary is employed to translate the current from alternating to direct.

In comparing 100 kw. units we find that the average efficiency of the rotary at one-half load is about 80 per cent, and that of the motor-generator set about 76 per cent. At full load the efficiency of the motor-generator is 81 per cent, and that of the rotary converter, 87 per cent. Generally speaking, therefore, the advantage is with the rotary. The rotary, however, is a somewhat more delicate piece of apparatus. There are today probably about eight motor-generator sets in use for lighting service to every rotary, but the improvements in rotaries have been rapid of late and the ratio is fast changing in favor of the rotary.

In considering translating devices we must not forget the mercury arc rectifier, a comparatively new device, but one which has already done much for the art in connection with series arc lighting. It chances that at least one of the preferred arc lighting systems of today calls for direct current—direct current from central stations which have no direct current apparatus. The mercury arc rectifier solves the difficulty for such stations in a particularly simple and economical way.

Stated briefly, with the elimination of all complexities, the mercury arc rectifier consists of a vacuum tube with inleading and outleading terminals, containing mercury within it in such a manner as to permit of the starting of an arc (not in vacuum really, but through mercury vapor) between one pocket of mercury and another. Such an arc is peculiar physically, in that it permits, when once established, of the passage of electric current through it ***in one direction but not in the other.*** We may define the theory of the rectifier thus:

Mercury vapor, under ordinary conditions, is a non-conductor, that is, if mercury be placed in a test tube and submitted to the Bunsen flame, the vapors thrown off are highly non-conductive. If this same mercury vapor is "ionized," that is, if each atom of mercury vapor receives a definite electric charge (like a Leyden jar), and if these charged atoms are moving under the influence of the potential, then the vapor immediately becomes a conductor, but in one direction only. We can not state why this is so, but can only accept it as a physical axiom of recent discovery.

The functionings of the mercury arc rectifier are not, to many people, easy of immediate comprehension, but a German engineer, who was in this country last year, expressed the matter most clearly when he said, "It's yoost like getting a feash hook in your fingker."

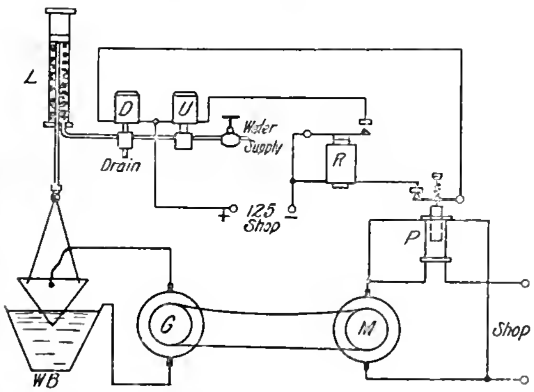
We have now taken a cursory glance at some of the essential features of the generating station. In the next paper I shall deal with the distribution and translation of the current, particularly with relation to pole lines and their construction, the conductors, insulators, and the governing conditions of voltage for various applications and distances; in short we shall deal with the questions of detail involved in getting the current from the generators to the point of use.

AUTOMATIC LOAD REGULATION BY MEANS OF WATER-BOX CONTROL

By Harold V. Green

The Testing Department of the General Electric Company recently made an endurance test upon a motor of special construction, the instructions calling for continuous daily operation under full load for a number of months. To conduct the test properly, it was necessary to devise some sort of automatic load control. A description of the mechanism employed is given below.

The motor was belted to a shop generator, this generator in turn being loaded on a water-box equipped with the usual water-box control. Because of the large field current taken by the generator, and also because of the unsatisfactory operation of a water-box with a fixed setting of the blade, the TD type



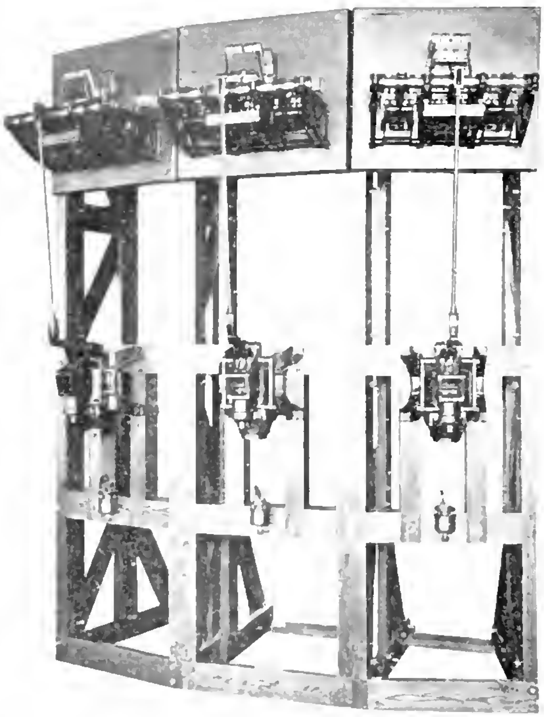
of voltage regulator was not applicable. It therefore became necessary to construct a regulator that would act upon the water-box blade through the medium of its remote electrical control. To fulfill this requirement a special regulator was devised which employed the use of the hunting regulator principle; the range of variation being kept so small as not to be appreciable. This regulator is shown in the accompanying diagram. A contact-making wattmeter, *P*, was placed in the motor circuit, and was so adjusted as to open its contacts at full load. The hydraulic lift, *L*, from which the water-box blade was suspended, was controlled through the electro-magnetic valves *U* and *D*; *U* admitting water to the under side of the piston and *D* draining it. With all switches closed and the wiring arranged as shown in diagram, the valve *D* was in its open position and the water-box blade would descend by gravity. When full load on the motor was attained, contacts on *P* would open, thereby opening the circuit through the relay *R* which, in turn, would close the upside of the water-box control. Thereupon the water-box blade would ascend until its motion was arrested by the closing of the contacts on relay *P*, when the blade would again begin its downward travel and the cycle would be repeated. To prevent too rapid a cycle of operation the supply of water to the hydraulic lift was throttled at the inlet valve.

When properly adjusted this regulator was able to hold a load on the motor within one-half of one per cent. Observations of the behavior of the water-box blade showed that there was a movement of the blade up or down of about one-sixth of an inch, at intervals of approximately one minute, depending upon the stability of the shop voltage.

A LARGE ALTERNATING CURRENT CIRCUIT BREAKER INSTALLATION

By D. S. Morgan

The construction of a circuit breaker for use on heavy alternating current circuits presents a somewhat difficult problem to the designing electrical engineer. The distribution of the current uniformly throughout the various parts of the breaker and the avoidance of skin effect, energy losses in heating, etc., are the factors with which he has to deal.

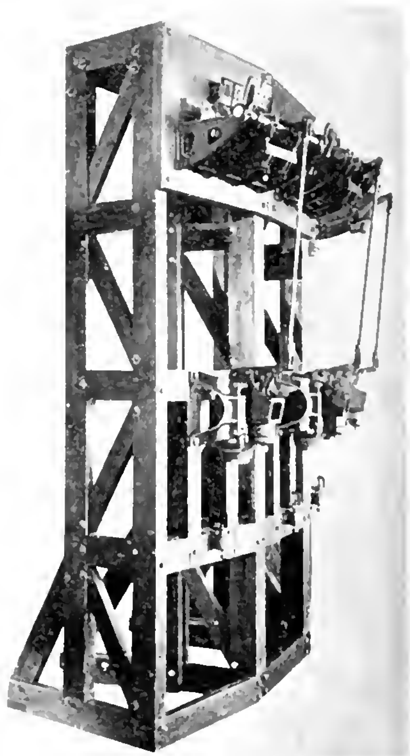


12,000 Ampere A.C. Circuit Breaker

The largest alternating current circuit breaker yet built is installed in the Worsted Mills of the American Woolen Company at Lawrence, Mass., and protects a 600 volt, 40 cycle turbine alternator. The breaker is a triple-pole solenoid-operated, Type C, Form K-2 breaker, and was built by the General Electric Company. It has a current carrying capacity of 12,000 amperes and will carry this current continuously without overheating.

If a circuit breaker for use on heavy alternating current circuits of 6000 amperes and over were built on the lines of usual direct current construction it would not satisfactorily perform its work, and would in service heat to a dangerous degree. To avoid this, special construction must be employed.

In the design of the circuit breaker in question, a large amount of radiating surface was provided and also an arrangement was made for the uniform distribution of the current in the various parts by subdividing the contact brushes and the studs of each pole into six sections, each insulated from the others. Each pole of the circuit breaker is operated by a separate solenoid mechanism so connected that the entire triple-pole breaker is controlled by a single control switch on the switchboard panel. The open and closed positions of the breaker are indicated by signal lamps located at the controlling switch.



12,000 Ampere A.C. Breaker. Side View

To obviate the necessity of opening an arc at the control switch, the circuit of the closing coils is opened on control relays located near the circuit breakers, the trip coils being opened by auxiliary switches operated by the breaker itself. The breaker is made automatic by the use of current transformers and relays. The circuit breaker, solenoids and control relays are mounted on specially designed hard wood supporting framework made to conform to the perimeter of the turbine to which the framework is secured. (See illustrations.)

Operation

The breaker has now been in operation for several months and according to reports received lately is operating satisfactorily. This, however, is not more than was expected, because before shipment, after being well tried out for purposes of adjustment and to discover any weak points in construction, the breaker was subjected to thorough mechanical endurance tests under conditions much more severe than it could possibly be expected to encounter in actual service.

THE TURBINE

By Harriet Monroe

Look at her—there she sits upon her throne
As ladylike and quiet as a nun!
But if you cross her—whew! her thunderbolts
Will shake the earth! She's proud as any queen,
The beauty—knows her royal business too,
To light the world, and does it night by night
When her gay lord, the sun, gives up his job.
I am her slave; I wake and watch and run
From dark till dawn beside her. All the while
She hums there softly, purring with delight
Because men bring the riches of the earth
To feed her yearning fires. I do her will
And dare not disobey, for her right hand
Is power, her left is terror, and her anger
Is havoc. Look—if I but lay a wire
Across the terminals of yonder switch
She'll burst her windings, rip her casings off,
And shriek till envious Hell shoots up its flames,
Shattering her very throne. And all her people,
The laboring, trampling, dreaming crowds out there—
Fools and the wise who look to her for light—
Will walk in darkness through the liquid night,
Submerged.
Sometimes I wonder why she stoops
To be my friend—oh, yes, who talks to me
And sings away my loneliness; my friend,
Though I am trivial and she sublime.
Hard-hearted?—No, tender and pitiful,
As all the great are. Every arrogant grief
She comforts quietly, and all my joys
Dance to her measures through the tolerant night.
She talks to me, tells me her troubles too,
Just as I tell her mine. Perhaps she feels
An ache deep down—that agonizing stab
Of grit grating her bearings; then her voice
Changes its tune, it wails and calls to me
To soothe her anguish, and I run, her slave,
Probe like a surgeon and relieve the pain.
But there are moments—hush!—when my turn comes,
Times when her slave commands, becomes her master,
Conquering her he serves. For she's a woman,
Gets bored there on her throne, tired of herself,
Tingles with power that turns to wantonness.
Suddenly something's wrong—she laughs at me,
Bedevils the frail wires with some mad caress
That thrills blind space, calls down ten thousand lightnings
To shatter her world and set her spirit free.

Then with this puny hand, swift as her threat,
Must I beat back the chaos, hold in leash
Destructive furies, rescue her—even her—
From the fierce rashness of her truant mood,
And make me lord of far and near a moment,
Startling the mystery. Last night I did it—
Alone here with my hand upon her heart
I faced the mounting fiends and whipped them down;
And never a wink from the long file of lamps
Betrayed her to the world.
So there she sits,
Mounted on all the ages, at the peak
Of time. The first man dreamed of light, and dug
The sodden ignorance away, and cursed
The darkness; young primeval races dragged
Foundation stones, and piled into the void
Rage and desire; the Greek mounted and sang
Promethean songs and light a signal fire;
The Roman bent his iron will to forge
Deep furnaces; slow epochs riveted
With hope and secret chambers; till at last
We, you and I, this living age of ours,
A new-winged Mercury, out of the skies
Filch the wild spirit of light, and chain him there
To do her will forever.
Look, my friend,
Behold a sign! What is this crystal sphere—
This little bulb of glass I lightly lift,
This iridescent bubble a child might blow
Out of its brazen pipe to hold the sun—
What strange toy is it? In my hand it lies
Cold and inert, its puny artery—
That curling cobweb film—ashen and dead.
But see—a twist or two—let it but touch
The hem, far trailing, of my lady's robe,
And lo, the burning life-blood of the stars
Leaps to its heart, that glows against the dark,
Kindling the world.
Even so I touch her garment,
Her servant through the quiet night. Even thus
I lay my hand upon the Pleiades
And feel their throb of fire. Grandly she gives
To me unworthy; woman inscrutable,
Scatters her splendors through my darkness, leads me
Far out into the workshop of the worlds.
There I can feel those infinite energies
Our little earth just gnaws at through the ether,
And see the light our sunshine hides. Out there
Close to the heart of life I am at peace.

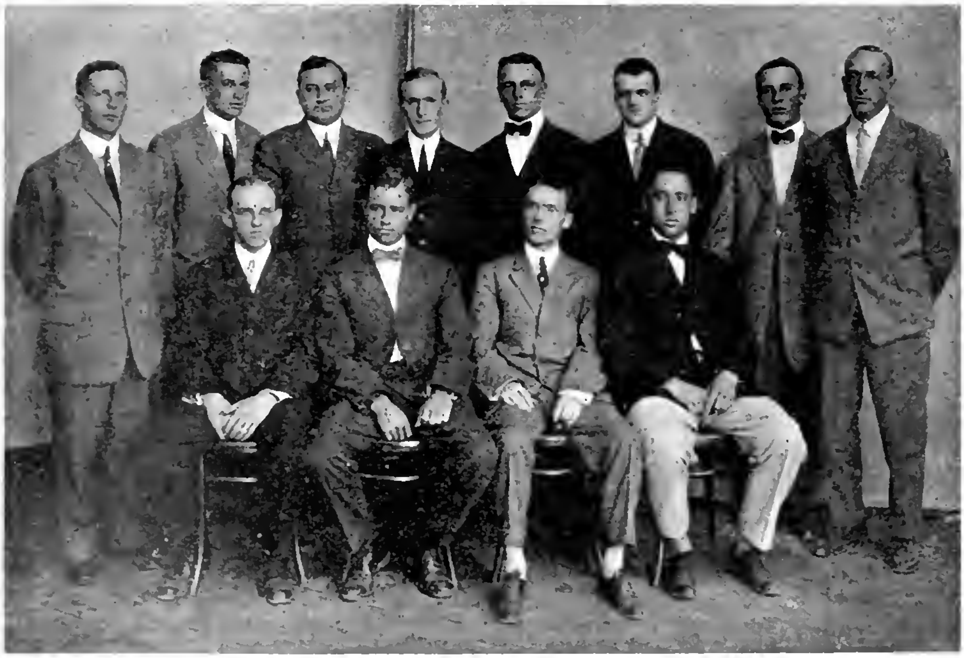
The Atlantic Monthly

FIRST ANNUAL MEETING OF SWITCHBOARD SPECIALISTS

The switchboard specialist is the logical result of the need for the services of trained experts to deal with the control and distribution of the large amounts of electrical energy and the high voltages that are now being constantly developed.

In laying out a large station, particularly, great precautions must be taken to secure the proper switching equipment. The energy must be safely and economically controlled. The system must have proper flexibility and must be simple in arrangement so that no confusion will arise in operation. The switchboard must be so designed that extensions can be made without unnecessary expense or liability of shut-down and at the same time without danger to the workmen. In other words there must be at the command of the customer an expert who is so conversant with all conditions of switchboard practice in its various manifestations, that he is able to recommend in every instance the best equipment available, due consideration being given to all the essential points in the installation. But for the switchboard specialist in the field to be able to acquaint the customer with the best apparatus that can be supplied to fill his needs, it is necessary for the specialist to be fully informed concerning new developments in his line.

This can best be accomplished by bringing together at certain intervals the entire selling and designing forces of the manufacturing concern, with the purpose of giving a thorough consideration to all points both commercial and engineering that have developed since the previous meeting. The result will be two-fold: 1st, to acquaint the specialist with the recent developments in switchboard work; and, 2nd, to enable the designing engineer to become acquainted with the problems of switchboard engineering that have been encountered by the switchboard specialists during the last year, the new needs that have arisen, and the behavior of apparatus in actual service.



Switchboard Specialists in Attendance at First Annual Meeting

With these ends in view, the switchboard specialists of the General Electric Company held their first annual convention during the week commencing August 29th. The first four days of the week were spent in Schenectady, and on Friday and Saturday the conference was continued at Lynn.

In order to derive as much benefit as possible and to economize time, a comprehensive programme, laid out in advance, was rigorously adhered to, and the entire switchboard situation was gone into thoroughly. Shop trips to inspect apparatus were taken each day after the conclusion of the subjects scheduled for discussion.

The free interchange of ideas which took place at the convention must result in a decided help to all concerned, but especially to the customer since the better acquainted a salesman is with the appliance he sells, the more the benefits that accrue to the customer who follows his recommendations.

The accompanying illustration shows the specialists in attendance; they are, sitting left to right, C. C. Adams, T. S. Knight, C. M. Parker, F. W. Paterson: Standing, left to right, A. B. Lawrence, W. H. Heinz, Saul Lavine, G. A. Elder, H. H. Bodge, E. A. Harriss, F. E. Hause, H. H. Gardiner.

Specialists are located in offices of the General Electric Company at Boston, Chicago, New York, Pittsburgh, Philadelphia, San Francisco.

NOTES

During the months of July, August and September the following student engineers entered the Testing Department of the General Electric Company.

Albergotti, W. McA., Clemson College
Allen, H. E., University of Colorado
Ames, M. P., University of Vermont
Anderson, C. B., Purdue University
Anderson, J., Lehigh University
Andrews, H. L., Clemson College
Bacon, H. R., Sheffield Scientific School
Bahm, J. B., Louisiana State University
Bailey, E. H., University of Illinois
Balmson, G. F. R., Lehigh University
Becker, W. J., Union College
Beebe, L. H., Pennsylvania State College
Beekman, R. A., University of Missouri
Berg, A. L., University of Colorado
Bergland, W. S., Princeton University
Bell, H. A., Ohio State University
Bell, W. R., Worcester Polytechnic Institute
Benford, F. A., University of Michigan
Bennett, C. S., University of Kentucky
Bird, D. M., University of Nevada
Bird, Howard, Sheffield Scientific School (Yale)
Binns, C. A., Leland Stanford University
Bonnett, L. B., Syracuse University
Boos, H. C., Cornell University
Bossinger, H. C., Cornell University
Bower, G. W., Pennsylvania State College
Brockman, T. H., Tulane University
Bronson, J. T., Syracuse University
Brooks, G. W., Pratt Institute
Brown, H. D., Cornell University
Byerts, W. E., University of Nebraska
Camp, W. E., Oklahoma A. & M. College
Cann, L. B., Delaware College
Card, B. A., University of Kansas
Chadbourne, V. R., University of Maine
Chapman, F. W., Clemson College
Charest, J. G., Union College
Cheshire, J., Vanderbilt University
Clenn, E., University of Colorado
Cole, K. E. N., University of Arkansas
Corlette, L. H., Iowa State College
Corwin, H. G., Clarkson School of Technology
Cramer, H. P., Leland Stanford University
Crane, D. R., University of California
Crawford, H. V., University of Arkansas
Cumming, G. B., University of California
Curtis, L. F., Tufts College
Davis, A., Georgia School of Technology
Dennis, A. R., Union College
De Toledo, P. F., Union College
Deuel, H. R., University of Montana
Dickerson, A. F., A. & M. College of Texas
Dillinger, G. A., Union College
Doyle, E. D., University of Illinois
Dull, A. W., Purdue University
Edgell, W. T., Jr., La Fayette College
Edmonds, W. E., University of Kansas
Edwards, E. B., University of Michigan
Eliason, W. L., Delaware College
Farber, E., University of Kansas
Farrar, J. L., Lehigh University
Faulds, N. M., Oklahoma A. & M. College
Force, H. H., Ohio State University
Fosterling, C. W., Georgia School of Technology
Foust, C. A., Lehigh University
Fraukenfield, M. W., Virginia Polytechnic Institute
Fulmer, T., Clemson College
Gardner, G. N., Harvard University
Garza, J. I., University of Illinois
Gates, H. C., University of Michigan
Gifford, E. E., Syracuse University
Gill, J. H., University of Texas
Gill, M. F., University of Texas
Gold, R. G., Worcester Polytechnic Institute
Goldberg, W., Case School of Applied Science
Goodrich, G. P., University of Maine
Graeff, W. K., Pennsylvania State College
Grover, H. H., Union College
Hall, C. A., University of Maine
Hallock, H. F., University of Michigan
Hamman, A. M., Columbia University
Hansel, D. R., University of Pennsylvania
Harrison, E. M., Purdue University
Haspel, E., Tulane University
Hawkins, H. B., Virginia Polytechnic Institute
Heissler, L. J., Clarkson School of Technology
Henry, H. W., Rose Polytechnic Institute
Happerlen, J. A., University of Nebraska
Hoel, R. W., Pratt Institute
Hord, T. A., Jr., University of Texas
Horn, A. F. E., Delaware College
Horn, Max, University of Pennsylvania
Hoskins, H. A., W. Virginia University
Huston, C. B., University of Nebraska

Ingram, H. L., A. & M. College of Texas
Jeter, G. G., University of Illinois
Johnson, F. B., Iowa State College
Johnson, P., University of Nebraska
Jones, C. E., Georgia School of Technology
Jones, L., University of Colorado
Jump, G. H., Syracuse University
Keese, F. D., Syracuse University
Kelley, S. D., Union College
Keppel, W. M., Cornell University
Keyes, W. R., University of California
Kimball, W. G., Sheffield Scientific School
Kirkman, J., Cornell University
Knapp, L. H., Purdue University
Kriegsman, A. E., Union College
Lane, W. G., Iowa State College
Lapp, H. D., University of Michigan
Leavitt, J. H., Tufts College
Lewis, William, Lehigh University
Mack, E. D., University of Nevada
Madison, H. J. Rose Polytechnic Institute
McCarthy, E. T., Cornell University
McClintock, Paul, Tufts College
Mercer, J. M., Iowa State College
Metcalfe, V. E., University of Colorado
Miller, A. G., University of Missouri
Mills, G. P., University of Kentucky
Moore, D. H., N. Dakota Argicultural College
Moreland, C. M., University of Arkansas
Morris, G. S., University of Kansas
Myer, W. M., Pratt Institute
Neilson, W. B., Jr., Union College
Nixdorff, S. P., Cornell University
Noble, J. A., Iowa State College
Nuti, C. B., University of Wisconsin
O'Connell, W. T., Worcester Polytechnic Institute
Odell, I. N., Purdue University
Orbison, T. E., Cornell University
Owen, A. S., Cornell University
Paine, R. A., Virginia Polytechnic Institute
Parker, F. T., Leland Stanford Institute
Paul, W. E., Union College
Peabody, G. A., Rhode Island State College
Phelps, S. L., Purdue University
Phillips, W. R., N. C. College of A. & M. A.
Pierce, L. G., University of Illinois
Plankinton, J., Oregon Argicultural School
Plenge, H. D., Clemson College
Poindexter, P. W., Rose Polytechnic Institute
Ponsler, R. L., University of Kansas
Proctor, W. R., Purdue University
Propst, H. M., Oregon Agricultural College
Rank, F. A., University of Colorado
Rankin, H. McC., University of Michigan
Riggs, L. W., Cornell University
Rhode, W. C., University of Wisconsin
Rolnick, S., Ohio State University
Rose, T. D., University of North Carolina
Rusher, M. A., Cornell University
Sage, W. C., Purdue University
Schaller, W. F., University of Illinois
Schmidt, F. L. A., Case School of Applied Science
Shuler, E. H., Clemson College
Sears, R. P., Union College
Seymour, E. R., Case School of Applied Science
Shanklin, S., University of Kentucky
Shelby, J. B., University of Kentucky
Sherman, A. H., Union College
Shirley, A. A., Purdue University
Shirley, O. E., University of Illinois
Slutter, N. W., Union College
Smith, D. F., University of Nebraska
Smith, R. P., Harvard University
Snyder, T. I., Purdue University
So Relle, A. W., University of Michigan
Spurck, R. M., University of Illinois
Stafford, R. W., Colorado University
Stephens, L. T., Pennsylvania State College
Stilwell, E. D., University of Wisconsin
Storm, S. B., Tulane University
Stump, J. H., Rose Polytechnic Institute
Summers, J. A., Pennsylvania State College
Swope, R. B., Lehigh University
Sykes, C. S., University of Vermont
Taylor, A. L. R., University of Utah
Taylor, B. W., Ohio State University
Taylow, C. W., Tufts College
Thomas, E. E., Purdue University
Thomas, R. B., University of Kansas
Thornberg, C. E., University of Nebraska
Townsend, C. P., Clemson College
Tozier, E. S., Rutgers College
Treene, W. H., Cornell University
Twogood, E. N., University of California
Varderzee, G. W., University of Wisconsin
Van Meter, M. E., Iowa State College
Venn, J. G., Worcester Polytechnic Institute
Vivian, W. T., University of Nebraska
Wall, R., Leland Stanford University
Wanner, R. W., Pennsylvania State College
Ward, C. Q., Kansas State Agricultural College
Washburn, F. J., University of Vermont
Weber, E. R., University of Colorado
Webster, G. A., University of Maine
West, G. S., Tulane University
Wettengel, F. J., Iowa State College
Wheatlake, B. C. J., University of Illinois
Wheeler, R. H., Rhode Island State College
Whicker, M. N., Purdue University
Whitmore, P. J., Union College
Whyte, A. C., Stevens Institute of Technology
Williams, W. W., University of Cincinnati
Wilson, A., Cornell University
Wilson, J. E., University of Pennsylvania
Wilson, L. H., Clarkson School of Technology
Winne, H. A., Syracuse University
Winter, F. H., University of Kansas
Wood, H. J., Georgia School of Technology
Wolf, A. F., Tulane University
Zwiebel, O. J., Worcester Polytechnic Institute

GENERAL ELECTRIC REVIEW

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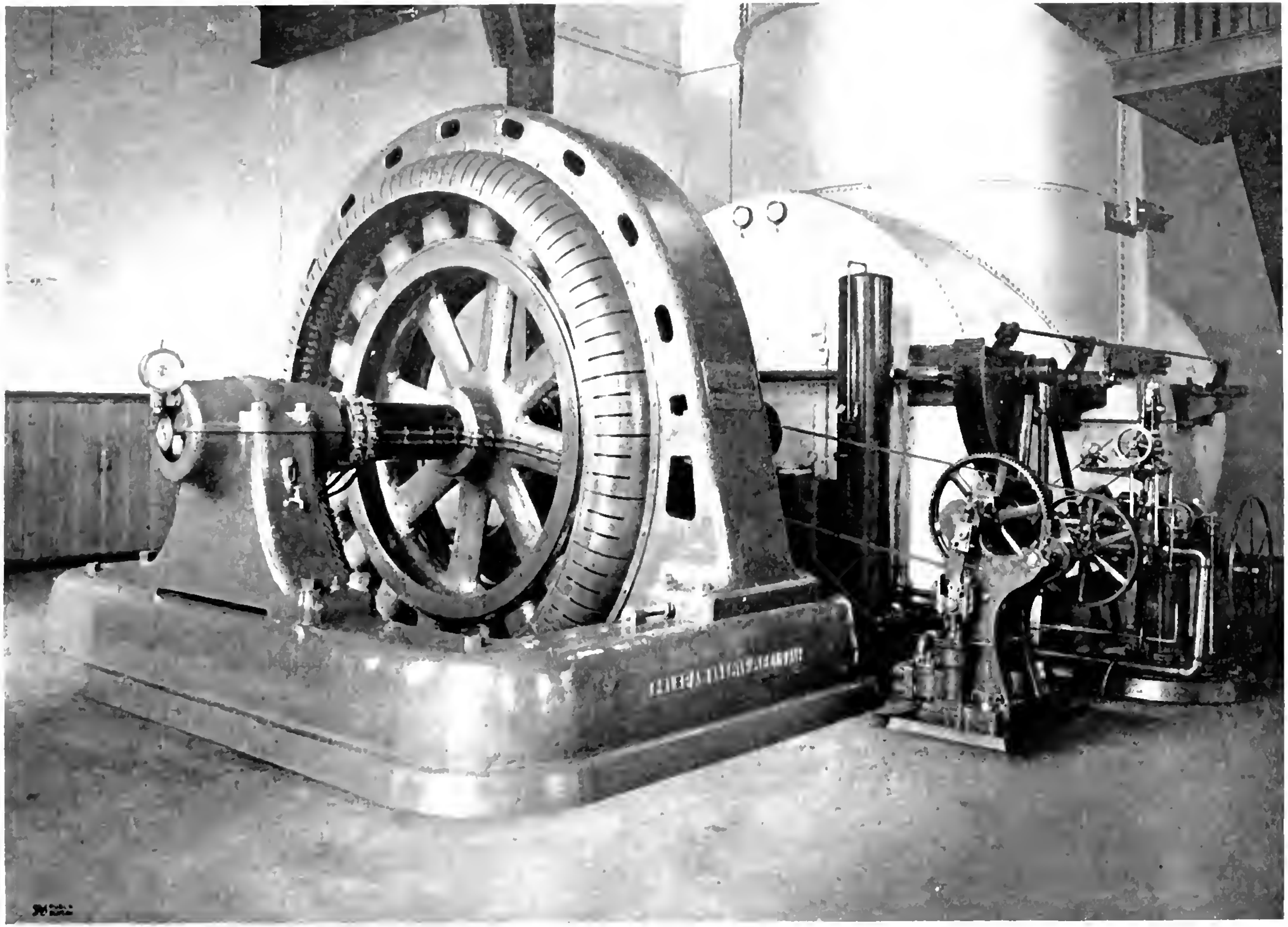


2000 Kw., 6600 Volt, 3-Phase Generator, Waterwheel-Driven, Moreau Power House

(See Page 569)

GENERAL ELECTRIC REVIEW

ELECTRICITY ON THE BALTIMORE AND OHIO

On another page of this issue we print an article by Mr. S. T. Dodd covering briefly the various types of electric locomotives used in the Baltimore and Ohio tunnel, and including a quite complete description of the latest type which has been installed during the present year.

A study of the electrification on the Baltimore and Ohio Railroad is in fact a review of the development of heavy electric traction in the United States, and to be properly understood the various steps must be considered in the light of contemporary history. The Baltimore belt line tunnel was designed to avoid the delays to traffic that were encountered at the city of Baltimore and was constructed at a time when electric traction had reached a state of development that made it possible to design the tunnel with the object in view of operating it electrically. As a consequence electric installation was not delayed, as it has been in other instances, by the conservatism and disinclination to make a change that is found in the case of an already established steam installation. The success in the preceding years of several more or less experimental heavy railway installations, had established the feasibility of heavy electric traction. The light high-speed railway motor of the eighties, with its double reduction high-speed gearing, had given place to the slow-speed multipolar iron clad motor of 1890, with its single reduction gearing. The success of this single reduction motor as compared with the double reduction type had naturally raised a number of very strong advocates for carrying the elimination of gears to its logical limit and producing a motor that should be absolutely free from gearing; their belief being that such a machine would be the ideal motor for heavy service. The adaptation of such a gearless motor to the speeds of the Baltimore and Ohio tunnel entailed some difficulties, such as the use of a large number of poles, a large diameter of driving wheels, and the connection of two motors permanently in series; but the work of a number of inventors and designers had proved the possibility of designing a gearless motor in spite of these difficulties and the six-pole gearless motor was therefore considered and adopted for this pioneer installation.

A different type of locomotive was selected for this second installation ten years later, as the locomotive was required wholly for freight service. Power economy combined with the high tractive effort required in freight service means slow speed, and economical motor design for a slow-speed locomotive means a geared motor. The decision as between geared and gearless motors for a locomotive of a certain speed seems to depend on principles of which the following is a general statement:

The peripheral armature speed of a well designed motor is fixed within fairly definite limits. When the normal linear speed of the locomotive is comparable with this peripheral armature speed it points to the conclusion that a motor can be economically designed with a speed of rotation approximating that of the axle, and indicates the possibility that a gearless design will be economical. As an illustration, the New York Central and the New York, New Haven and Hartford installations, where operating speeds of fifty to sixty miles per hour are required, are alike in one single feature, namely, the employment of gearless motors, thus indicating that for speeds of fifty to sixty miles per hour a gearless design is advisable.

When locomotive speeds and peripheral armature speeds are not comparable, as for example, in the case of a freight locomotive, we may conclude that an economical motor design requires a reduction of speed between the armature and axle, and this condition therefore indicates the necessity of a geared motor. These principles seem to have determined the design of the Baltimore and Ohio locomotives of 1903.

It is interesting to note that the new type of locomotive is also a geared design, although it is proposed for passenger as well as freight service and is designed for speeds approximately the same as those of the gearless locomotive of 1893. These facts seem to indicate that for the Baltimore and Ohio conditions of speed and train weight, the geared motor offers the most satisfactory solution.

Incidentally the improvement in mechanical design and workmanship is an important item in effecting this decision between geared and gearless motors. As an example the satisfactory installation of twin gearing may be noted. This makes possible the use of a high power geared motor where a gearless motor might have been more satisfactory if the choice had rested between the gearless motor upon one hand, and the ordinary type of single geared motor with overhung gearing upon the other.

The new locomotives embody a number of interesting features, the details of which are described in Mr. Dodd's article.

COMPENSATORS

Compensators—or auto-transformers as they are sometimes called—may, under certain conditions, be used to considerable advantage in place of transformers.

Their relative desirability depends upon a number of conditions, the size, cost and efficiency on the one hand, and absence of insulation between the load and the supply circuit on the other. If the difference in voltage between the two circuits is slight, the decrease in size, cost and losses due to the use of a compensator is great, and the absence of insulation usually of little importance. If, on the contrary, the difference in voltage is great, the size and therefore the cost and losses of the compensator approach those of a transformer capable of doing the same work, and the necessity of insulation between load and supply circuit assumes greater importance; so that a transformer would be more desirable.

In reaching a decision it is necessary to determine first the relative size of the compensator and the transformer which will have the required output. The method of rating compensators is therefore important.

The article by Mr. W. W. Lewis, which begins in this issue, treats of the advantage resulting from the use of compensators instead of transformers, and of the method of rating the former. This article is deserving of careful consideration because, while the method of rating compensators is very simple, it is not as well understood, perhaps, as it should be.

Many questions have arisen as to how a compensator which, for example, will transform 10 kv-a. from 100 up to 110 volts, can be rated 1.1 kv-a. The matter becomes clear when it is remembered that a 10 kv-a. transformer consists of 10 kv-a. of primary winding and 10 kv-a. of secondary winding interlinked by a magnetic circuit. In a transformer, there would, therefore, be a total of 20 kv-a. of winding for 10 kv-a. of output, and we may say that the rating of a transformer is equivalent to one-half of the total volt amperes of winding. The standard practice of rating compensators on the basis of one-half the total kv-a. of winding contained therein is, therefore, perfectly logical, and, since, the compensator mentioned above requires a total of 2.2 kv-a. of winding, it should be rated 1.1 kv-a. although its actual output would be 10 kv-a.

THE DEVELOPMENT OF PROTECTIVE DEVICES FOR HIGH TENSION CIRCUITS

The growing demand for electrical power, in many cases at places far remote from a point of economical generation, has resulted in the construction of long transmission lines and the transmission of energy at ever increasing voltages. The difficulties of utilizing large amounts of electrical power transmitted for long distances at high voltages would make such developments impracticable for commercial use had it not been for the design and introduction of reliable switching, measuring, and protective devices for safely and conveniently controlling this power.

A description of the appliances for accomplishing this purpose is of particular interest at this time, as they are being introduced extensively and have proved so successful that most transmission developments for some time to come may be expected to follow similar lines.

The article in this issue of the Review by Mr. P. G. Langley traces the development of the devices designed to protect electrical circuits and explains under what circumstances the apparatus now available should be used.

D. S. Morgan.

ELECTRIC LOCOMOTIVES FOR THE BALTIMORE AND OHIO RAILROAD COMPANY

By S. T. Dodd

The belt line of the Baltimore and Ohio Railroad is of interest to students of electrical development because the first electric locomotives ever used for heavy trunk line service were installed on this line.

In 1893, municipal requirements, as well as considerations of safety and convenience, demanded the use of some type of motive power other than steam locomotives for the operation of the tunnel through the city of Baltimore. As a consequence, a contract was entered into with the General Electric Company for supplying electric locomotives capable of handling passenger service.

It is difficult to appreciate today the courage that was required to make this decision at that period in the history of electric development. Only seven or eight years had elapsed since the electric railway motor had emerged from the experimental stage and had first been applied to the operation of actual street railway cars. The modern system of electric traction and modern types of electric motors and equipment were absolutely unknown. The decision, therefore, to use electric locomotives, and the construction of these locomotives themselves, mark an important epoch in the history of electricity.

The locomotives furnished for this first installation were of the gearless type, weighing ninety-six tons each. Each unit consisted of two four-wheel sections coupled permanently together, each section being equipped with two motors of the type known as the AXB70 and carrying a portion of the cab, mounted upon it. The characteristic feature of the motor was that it was gearless. It was built concentric with the axle and transmitted its power directly to the driving wheels. In this respect these original Baltimore and Ohio locomotives were prototypes of the heavy electric locomotives built since 1907 for passenger service on the roads entering New York City. In order to bring the locomotive speed down to tunnel requirements the motors were designed with six poles, and two motors were connected permanently in series.

It will be realized that a number of new problems presented themselves in this pioneer installation and that a number of new features had to be incorporated; but the success of the installation can be seen from the fact that the original locomotives are running today and doing satisfactory service in hauling passenger trains. The locomotives had a capacity of 28,000 pounds tractive effort at a speed of sixteen to twenty miles per hour, corresponding to approximately 1200 horse-power.

About ten years later, the extension of the service and its increased requirements demanded additional locomotives, and it was decided to adopt a type of locomotive particularly suitable for freight service.

The freight locomotives of 1903 are the heaviest electric locomotives in operation today. Each locomotive weighs 160 tons and consists of two 80-ton units coupled together and capable of being operated by one engineer. Each half unit is equipped with four motors geared to the axles. A geared drive was adopted in this case in order to obtain the heavy tractive effort and the slow speeds required for freight service. A complete 160 ton unit is capable of exerting a maximum tractive effort of 80,000 pounds at starting, and a tractive effort of 70,000 pounds at a speed of eight and one-half miles per hour, which corresponds to an output of 1600 horse-power. In daily service, one such locomotive takes trains weighing up to 1800 tons through the tunnel and over maximum grades as high as 1½ per cent. To compare the capacity of this locomotive with that of steam locomotives of standard type, it may be noted that, in the absence of the electric locomotive, three steam locomotives weighing with their tenders 370 tons are assigned to this duty and have difficulty in pulling trains of this weight over the track.

During the present year the service on the belt line has demanded a still further addition to the locomotive equipment and two additional locomotives have been put in service, which are illustrated and described in this article. The locomotives were designed and equipped by the General Electric Company, while the mechanical parts were furnished by the American Locomotive Company. A general view of the complete locomotive is shown in Fig. 1. This type of locomotive is similar to the type built by the same manufacturers for the Detroit River Tunnel Company, but differs from it in details and is the first of this design to be used on the Baltimore and Ohio. It is worthy of study as a good example of the latest type of electric locomotive for heavy service. The cab resembles in general the type which has been widely used for switching locomotives on interurban electric railroads and possesses many of the features of convenience which have contributed so largely to the success of this design. The trucks and running gear are of a heavy locomotive type suitable for the severe duty demanded in trunk line service. The running gear is articulated and consists of two four-wheeled trucks connected through a massive hinge which allows the two trucks to support and guide one another without interfering with the lateral flexibility required for taking curves with a long wheel-base. The framing is massive in appearance and the sections are heavier than actually required for mechanical strength on account of the necessity of obtaining ample weight for tractive effort. Side frames consist of steel castings, five inches thick, bolted together through steel end frames and bolster castings of a box girder pattern. Draft gear and buffers are carried on the outer end frames. Wheels are steel tired, fifty inches in diameter, with the motor gears mounted directly on extensions of the wheel hubs. Journal boxes are of cast steel, carried in pedestal jaws between shoes nine inches wide, and have journal bearings 7½ by 14 inches. The weight of the locomotive is carried on the boxes through semi-elliptic journal box springs equalized together so as to obtain the most uniform distribution of weight that is possible over groups of springs. It is well known that the advantage of

Fig. 1. Latest Type of Baltimore and Ohio Locomotive

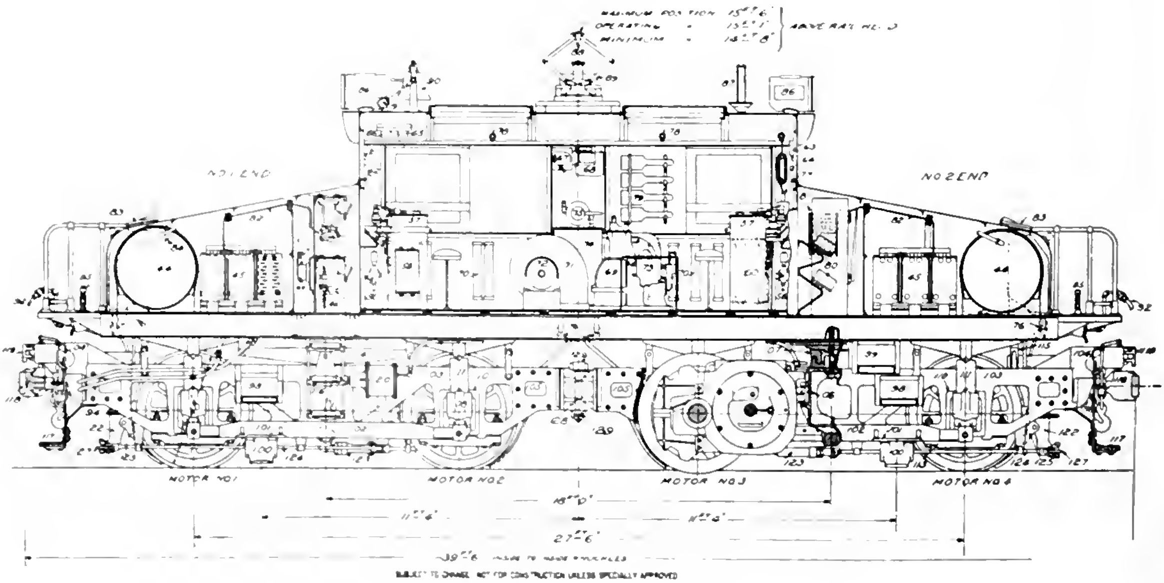


Fig. 2. Arrangement of Apparatus

this construction is that it concentrates the principal hauling and buffing strains in the trucks themselves and relieves the platform and cab of all stresses except those due to their own weight and that of the control and operating apparatus mounted on them.

The principle embodied in this type of locomotive construction is not new, but is one, the success of which has been demonstrated through its practical application to steam locomotives for a number of years. The Mallet compound locomotive, the heaviest type of freight steam locomotive in use, resembles the new Baltimore and Ohio electric type in that it has a wheel-base made in two halves and hinged together, taking the hauling stresses directly through this hinge. The remarkable success of this type of steam locomotive, its low flange wear, and its adoption by a number of important railroads for pusher service on their heaviest grade divisions, may be considered as proof of its suitability for heavy service.

The cab platform is 38 feet, 6 inches in length overall, and is carried upon side bearings on the two trucks and upon two center pins, one of which has a slight longitudinal sliding motion in order to accommodate the variation in center pin distance due to curving.

The platform is built up of 10 inch longitudinal sills 34 feet 1 inch in length and riveted to 10 inch ends sills. Body bolsters are built up of 1 inch by 12 inch plates to which are riveted the center pin castings referred to above. A cover plate below the two center sills forms, with the floor above, an enclosed air space which serves for delivering air to the motors from the blower located in the center of the main cab. The whole platform is braced and squared by heavy floor plates extending the whole width of the platform and rivetted to side sills and end sills.

The cab consists of a main operating section located in the center of the platform and sloping auxiliary end sections extending towards the ends of the locomotive. While the trucks and running gear of the locomotive transmit the principal mechanical stresses and are therefore of interest from the standpoint of mechanical design, the cab is of more interest from an electrical standpoint. Several interior illustrations are therefore presented, which show the detailed study that has been expended on the location and arrangement of apparatus and wiring.

Fig. 2 shows the arrangement of the principal pieces of apparatus. The auxiliary cabs are six feet in width and contain parts

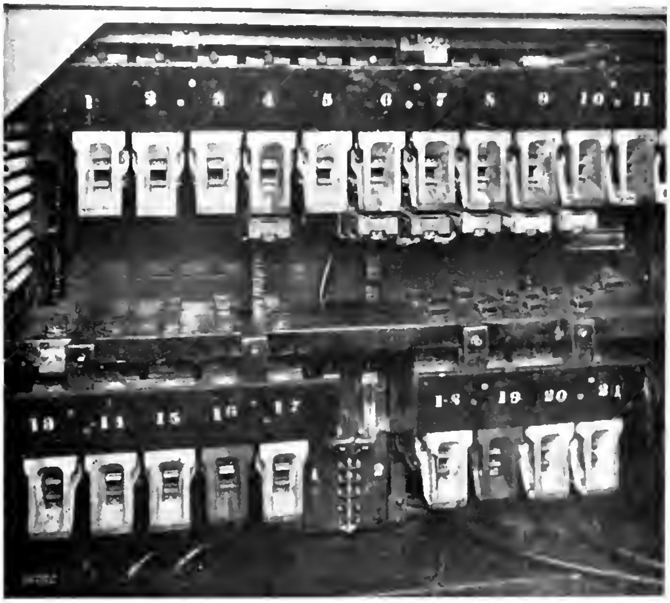


Fig. 3. Bank of Contactors

of the apparatus which are not subject to inspection and repairs. In the outer end of this cab is located the main air reservoir and sand boxes for sanding the leading wheels, and next to these, on the floor of the cab, are placed the rheostats. Perforated side sheets allow a circulation of air through and around these rheostats for ventilation, the upper part of the sheets being hinged and held with spring-locked buttons so as to permit convenient access for inspection of rheostats and wiring. The end cab is held to the platform and main cab by means of bolts, and for major repairs these can be removed and the end cab separated from the locomotive, thus giving access to all the apparatus contained in it.

The contactors are located in the auxiliary cab but stand in a bank facing the main cab, from which access to them for cleaning and inspection can be obtained. Fig. 3 is a view of this bank of contactors, taken from the floor of the main cab. During operation these contactors are enclosed by asbestos-lined folding doors which shut them away from the main operating cab, as shown in several of the succeeding views.

The space on either side of the auxiliary

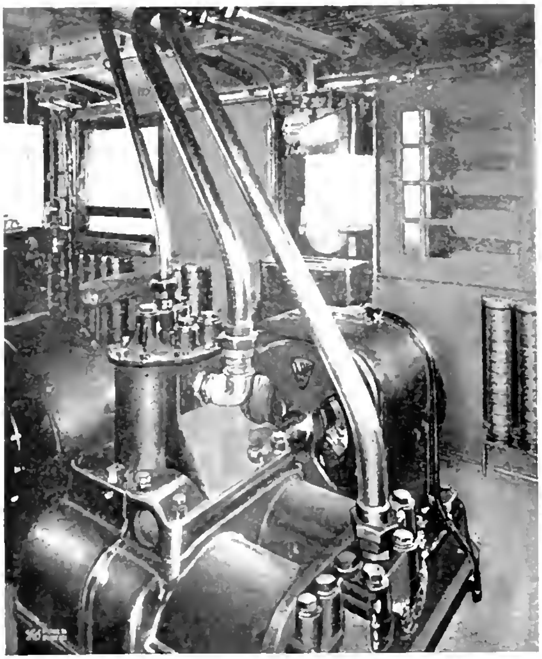


Fig. 4. Interior of Cab Showing Motor-Driven Air Compressor

cab is devoted to a platform running from the main cab to the ends of the locomotive, permitting on one side access from the main cab to the coupler, and on the other side an uninterrupted view for the operating engineer.

Turning now to the main operating cab, it will be noted from the illustrations that apparatus is arranged and wired so as to offer a maximum of accessibility combined with a maximum economy of space. All wiring is in conduit, and the interior of the cab presents a neat and workmanlike appearance, even the bell and whistle ropes being drawn through pipes for protection and to conform in appearance with the rest of the piping and wiring. The central piece of apparatus in the cab is the air compressor. This is a CP26 compound compressor, motor-driven, with a capacity of 100 cubic feet piston displacement per minute when pumping against 130 lbs., reservoir pressure. Experience has demonstrated that the center of the main cab is the most desirable point for locating the compressor. Although it does not require an excessive amount of care, the various items which may require attention, such as valves, piston rings, brushes, etc., are naturally on different sides of the compressor. It must therefore be accessible from every side and consequently the center of the cab has been chosen for its location, rather than a less prominent place. Figs. 4 and 5 show the compressor and the piping leading to it. In passing from the low pressure to the high pressure cylinder, the air is carried through a two inch pipe to the roof of the cab and then through about 35 feet of pipe lying on the roof which provides a radiating surface to reduce the temperature of the air before it enters the high pressure cylinders. A similar length of radiating pipe is inserted between the high pressure cylinder and the main reservoir for the same purpose. The compressor is controlled by an electro-pneumatic governor mounted on the "A" side of the cab as shown in Fig. 4 and arranged for maintaining the reservoir pressure between the limits of 120 and 130 pounds.

Beside the compressor is placed a fan for

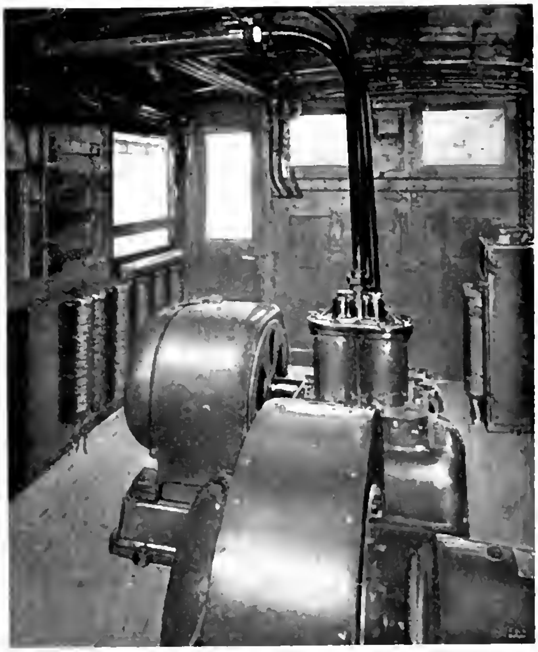


Fig. 5. Motor-Driven Air Compressor and Blower

forced ventilation of the motors, which delivers air into the enclosed space or distributing chamber between the center channels, as above described. From this distributing chamber the air is carried through branch pipes to the motors.

Against the side walls of the cab, as shown in Fig. 4, are mounted racks for paddles and flags, and electric coil heaters for maintaining the proper temperature of the cab.

Sand boxes for sanding the track in front of the rear truck of the locomotive are also placed in the middle of the side walls and are operated from the engineer's position simultaneously with the forward sand boxes in the auxiliary cabs.

Figs. 6 and 7 show the apparatus for direct control of the locomotive, located at the engineer's window. This is in duplicate at the opposite ends of the cab, and consists of the master controller, air brake valves, air gauges, and ammeters. The handles for bell and whistle ropes, the switches for headlights, and valves for sanders are also within convenient reach. Fig. 7 shows in detail the arrangement of this apparatus and also the uninterrupted view of track and right-of-way which is obtainable from the operator's seat.

It will be noted that one of the great advantages of this design of locomotive is that the engineer's window is about twelve feet back from the front end of the locomotive, an arrangement which affords a protection in case of collision and buffing accidents. In spite of this distance, the design of the sloping end cab and the open side platform in front of the engineer gives him a view which is practically as comprehensive as if he were located in the more dangerous situation at the front end of the locomotive.

The motor equipment consists of four GE209 motors. Each motor is furnished with twin gearing, a pinion being mounted on each end of the armature shaft and a corresponding gear on each driving wheel. Precautions are taken in the design and mounting of this gearing to ensure absolute alignment of the corresponding teeth of each pair of gears and pinions. With such precautions this type of gearing maintains accurately the alignment of armature shaft and axle, reduces the strains of gear teeth to a minimum, and has been demonstrated to give absolutely satisfactory results in service.

The motor is a 600 volt commutating pole machine, the equipment of four motors being

Fig. 6. Control Apparatus

capable of exerting a tractive effort up to the slipping point of the wheels of the locomotive which, at a coefficient of adhesion of 25 per cent, is equivalent to a tractive effort of 46,000 lbs. at a speed of fourteen miles per hour.

To obtain some idea of the power of these new locomotives, they may be compared with the heaviest types of steam passenger locomotives. The new Baltimore and Ohio electric locomotives weigh ninety tons on drivers. The weight on drivers of the Pacific type of steam locomotives, which is the type used for heavy passenger service, very rarely exceeds seventy-five tons. A weight of ninety to one hundred tons on drivers is only obtained on freight locomotives of the Consolidation and Mikado types. The weight on drivers, which determines the maximum pulling power of the electric locomotives, is therefore comparable with the heaviest types of steam locomotives for freight service.

In the steam locomotive, however, on account of boiler limitations, it is impossible to carry the maximum tractive effort at speeds higher than eight or ten miles per hour, while the electric locomotive will

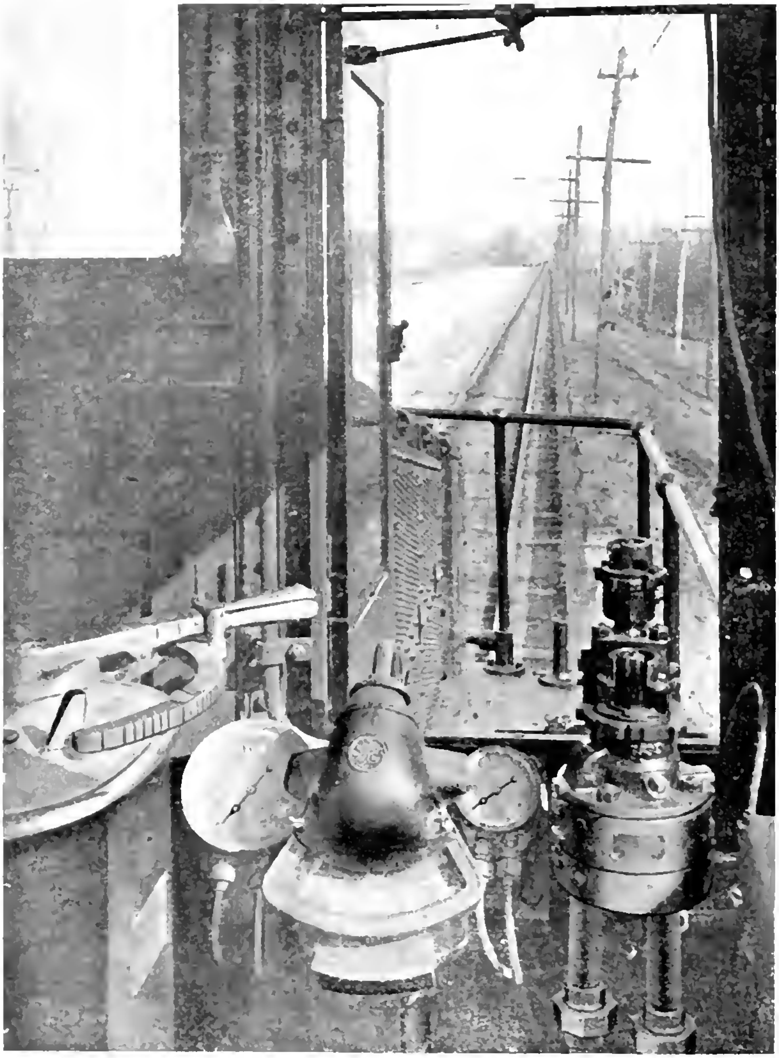


Fig. 7. Control Apparatus and View of Track from Engineer's Seat

develop its maximum tractive effort at a speed of fourteen miles per hour. This tractive effort of 46,000 pounds, at a speed of fourteen miles per hour, corresponds to an output of 1700 horse power.

The electric locomotive, furthermore, is more flexible and has a greater power than indicated by these figures. By means of the multiple unit control, which is a feature of these locomotives, two of these 90-ton units can be coupled together and operated by one engineer in the forward cab. All the motors are controlled simultaneously by one operating handle, and therefore one engineer has under his control a maximum capacity of 3400 horse-power, or a maximum tractive effort of 90,000 pounds developed by one 180-ton locomotive.

It might be noted that 180 tons represents approximately the weight of a single large steam locomotive and its tender, and that in the steam locomotive only half this weight is on drivers, while in the electric locomotive the whole 180 tons is on drivers and is capable of being applied for developing tractive effort.

With a light passenger train, a single 90-ton electric locomotive will develop speeds of twenty-five to thirty-five miles per hour on the level. From the facts here cited, it is evident that the Baltimore and Ohio railroad has in its new locomotive an engine which is suitable for either freight or passenger service and is capable of handling the heaviest freight trains over the tunnel grades or the highest speed passenger trains at the greatest speed consistent with its tunnel service.

The following table gives the principal dimensions of the new locomotive:

Number of motors	4
Gear ratio	3.25
Number of driving wheels	8
Diameter of driving wheels	50 in.
Total wheel base	27 ft., 6 in.
Rigid wheel base	9 ft., 6 in.
Length inside knuckles	39 ft., 6 in.
Length of main cab	15 ft., 6 in.
Length of cab overall	33 ft., 6 in.
Total weight	184,000 lbs.
Tractive effort at 25 per cent co eff.	46,000 lbs.
Speed at maximum tractive effort	14 m.p.h

COMPENSATORS

Part I

By W. W. Lewis

The primary and secondary coils of a transformer may be connected in series between two supply mains and load taken from the secondary alone, or the primary alone may be placed across the supply mains and load taken from the primary and secondary in series. Such an arrangement of the transformer coils is commonly called a compensator, and the function of the arrangement is simply to boost or lower the supply voltage. When it is desired to effect only a slight change in voltage, when both voltages are low, or when it is permissible to have the secondary circuit directly connected to the primary, compensators may frequently be used to advantage. In such cases considerable economy will result, as compensators are usually smaller and more efficient than the corresponding transformers.

A simple example will serve to illustrate this. Fig. 1 shows diagrammatically the transformation of 100 kw. of power from 1000 to 500 volts by means of a 100 kw. transformer, and Fig. 2 by means of a compensator of

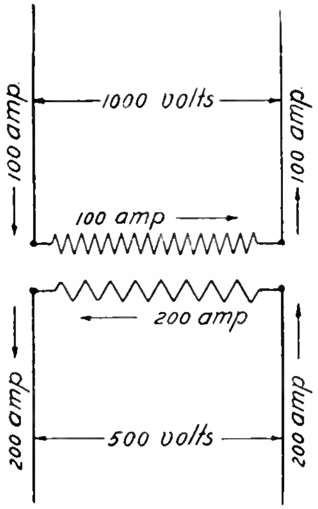


Fig. 1

one-half the capacity. Only a portion of the power output of the compensator is transformed from one coil to the other through the medium of the flux induced in the core. The remainder of the output is taken directly from the supply circuit by means of the series connection. While the output of the compensator in Fig. 2 is 100 kw., it is only necessary to transform one-half that amount and a 50 kw. compensator is sufficient. It

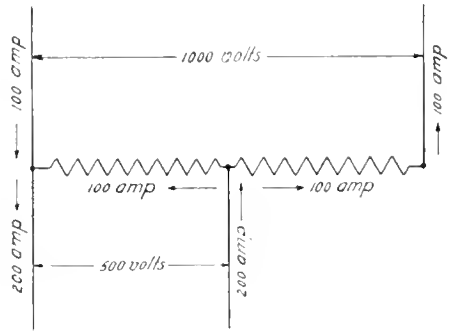


Fig. 2

is apparent that the total number of turns has been reduced one-third and that the ampere capacity of the secondary has been reduced one-half. The saving in space on account of the less amount of copper allows a corresponding saving in iron, and the net result is lower first cost, less copper and iron loss, less IR drop, and improved efficiency and regulation.

Consider the general case of the transformation of a given amount of power ei (Figs. 3 and 4), neglecting losses and exciting currents. In Fig. 3 let

e = primary voltage
i = primary current
e_2 = secondary voltage
i_2 = secondary current
r = transformer rating

Then

$$ei = e_2 i_2 = r$$

But ei is evidently the rating of the primary coil and $e_2 i_2$ the rating of the secondary coil, so that the rating of the transformer is the same as the rating of either coil; or we may consider the transformer rating to be one-half the sum of the primary and secondary coil ratings, or

$$r = \frac{ei + e_2 i_2}{2}$$

Fig. 4 represents a compensator to transform the same power ei.

Let

e = impressed voltage
i = corresponding line current
e_2 = secondary voltage
i_2 = secondary current
r_1 = compensator rating

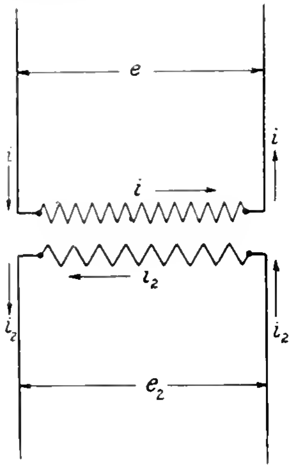


Fig. 3

In usual terms the primary of the compensator is the coil ac (Fig. 4), across which the high tension voltage is impressed, and the secondary the coil ab, from which the load is taken. In design, however, it is convenient to consider the winding as consisting of a secondary ab and a primary bc. The primary voltage is $(e-e_2)$ and the primary current is i.

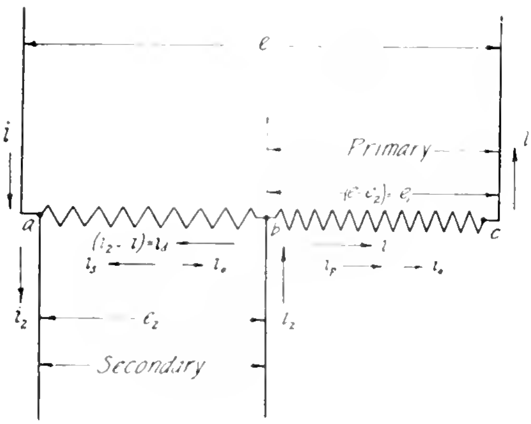


Fig. 4

The secondary winding ab is traversed by both the primary and secondary currents, and as these are practically opposite in phase, the resultant current carried by ab is (i_2-i).

Then the rating of the primary coil is $(e-e_2)\ i$, and of the secondary coil $e_2\ (i_2-i)$. Obviously

$$(e-e_2)\ i = e_2\ (i_2-i) = r_1$$

Or, as before, we may consider the rating as one-half the sum of the primary and secondary coil ratings, or

$$r_1 = \frac{(e-e_2)\ i + e_2\ (i_2-i)}{2}$$

In general, we may say that the compensator rating is one-half the sum of the ratings of the individual sections of the winding. The advantage in this conception of the rating will become apparent later when the problem is complicated by taps. Now to transform the power ei, we have a compensator of rating $(e-e_2)\ i$, or a transformer rated ei; that is, the ratio of compensator rating to transformer is

$$\frac{(e-e_2)\ i}{ei} = \frac{(e-e_2)\times 100}{e} \text{ per cent}$$

Then if

$e_2 = 1/10\ e$, comp. will be rated 90 per cent of corresponding trans.
$1/4\ e$, comp. will be rated 75 per cent of corresponding trans.
$1/2\ e$, comp. will be rated 50 per cent of corresponding trans.
$3/4\ e$, comp. will be rated 25 per cent of corresponding trans.
$9/10\ e$, comp. will be rated 10 per cent of corresponding trans.
e, comp. will be rated 0 per cent of corresponding trans.

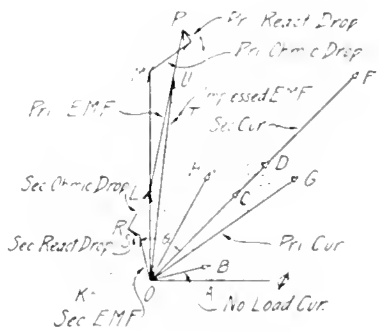
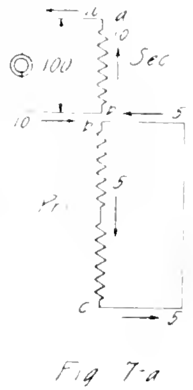


Fig. 5

From what has preceded it may be seen that the nearer the two voltages are alike, the smaller is the compensator that is necessary to transform a given amount of power. Since the primary and secondary windings are connected, the occurrence of a ground on the high voltage line will subject the insulation on the secondary to the strain of the high tension voltage. This prohibits the use of compensators when complete insulation between primary and secondary is necessary. For these reasons (with certain exceptions, such as in railway work) compensators should be used only when the actual difference between the impressed and delivered voltages is slight, or when both voltages are low.



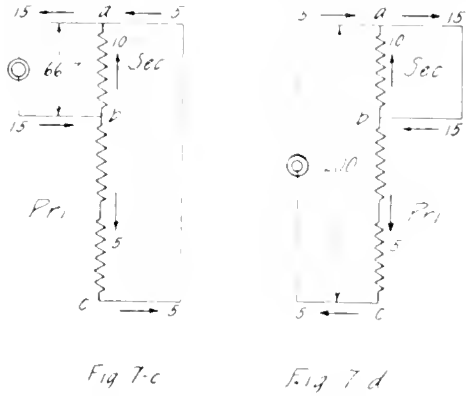
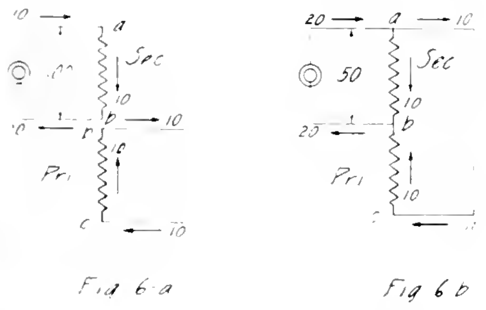


Fig. 7

The transformation by compensator may be represented vectorially as in Fig. 5. Using the same notation as in Fig. 4, Fig. 5 may be explained as follows:

At no load the only current flowing is the exciting current $OB = i_e$, composed of a wattless component OA and an energy component AB. OL and LM represent voltages equal and opposite to the secondary and primary induced voltages and in quadrature with the flux ϕ, and may be designated e'_2 and e'_1. Now load the secondary. The secondary current may be represented by $OD = i_s$. There is a corresponding current in the primary equal to i_s times the ratio of secondary to primary turns, which may be represented by $OC = i_p$. The total primary current is equal to $i_p + i_e$, represented by OG $(= i)$ in the parallelogram $OCGB$. The secondary line current is the sum of i_p and i_s, represented by the line OF $(= i_2)$.



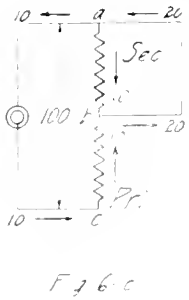


Fig. 6

The current in the secondary coil is equal to $(i_s - i_e) = (i_2 - i) = i_d$, represented by OH in parallelogram $OKHD$. The load current or secondary current, $i_2 = i_p + i_s$, may also be found by adding together the primary current i and the current in the secondary coil, i_d, or $OG + OH$ in the parallelogram $OFHG$. The secondary terminal e.m.f., $OS = e_2$, is found by subtracting from OL the secondary ohmic drop LR and the secondary reactive drop RS, parallel and perpendicular respectively to OH. The primary terminal voltage is found by adding to LM the primary ohmic drop MN and the primary reactive drop NP, parallel and perpendicular respectively to OG, which gives $LP = e_1$. The total impressed voltage, e, is the vector sum of LP and OS $(= OU)$ in the parallelogram $OSUT$. The power factor is represented by the cosine of the angle θ between the vectors OS and OC.

As previously stated, in all matters of design the compensator is considered as consisting of two separate windings, a primary bc and a secondary ab (Fig. 1), and it is treated in the same manner as a transformer with similar windings. To illustrate, consider the case of compensator impedance and assume that all the impedance is due to reactance.

Fig. 6a shows a 1:1 transformer and Fig. 6b a 1:2 compensator having the same number of turns and carrying the same currents in the windings. To get an idea of the impedance of the transformer, short-circuit the primary windings and apply enough voltage to the secondary to force rated current through both windings. Assuming the normal voltage of the secondary to be 1000, if 100 volts are required to send rated current of 10 amperes through the windings, the reactance drop (neglecting drop due to ohmic resistance) is 10 per cent. With the compensator, however, only 50 volts are necessary

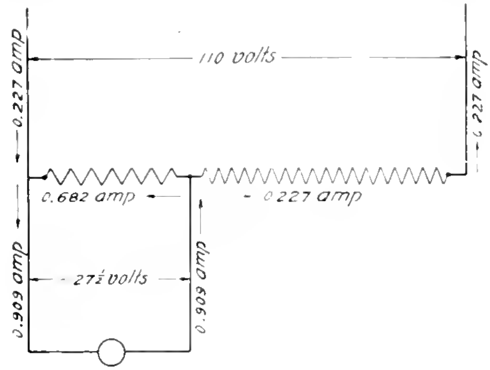


Fig. 8

to force the same current through the windings; i.e., the reactance drop is 5 per cent.

This difference may be accounted for as follows: In the case of the transformer (Fig. 6a) the 10 amperes flowing through the primary winding produce a certain reactive drop, and an e.m.f. must be applied to the winding equal and opposite to this drop. This e.m.f., e, is induced by a flux produced by the secondary, which flux, being common to both windings, induces at the same time voltage across the secondary. Across the primary we then have an induced voltage e, neutralized by a reactive drop e, giving a resultant = O. Across the secondary we have the voltage e necessary to force 10 amperes through the leakage reactance of the secondary, and a voltage e induced by the flux required to energize the primary, a total of $2e (= 100$ volts). The voltage e necessary to send 10 amperes through either winding is 50.

In the case of the compensator the primary winding is connected directly across the generator and is in parallel with the secondary. Fifty volts is necessary to send 10 amperes through the secondary and the same 50 volts will send 10 amperes through the primary, since the windings are in parallel. The result is a reactance drop of 50 volts, or 5 per cent as against 10 per cent for the transformer. The generator volt-amperes are, however, in each case the same.

Let Fig. 6c represent the same compensator stepping down with a 2:1 ratio; the normal voltage of the total winding being 2000. To force 10 amperes through the primary bc we need as before 50 volts and also 50 volts to force 10 amperes through ab. As the secondary ab is short-circuited, the voltage applied to it by the generator is zero; therefore the 50 volts necessary to force current through ab are induced by the ampere-turns of bc. This, together with the 50 volts necessary to force 10 amperes through bc, gives 100 volts across bc and zero volts across ab. The reactance voltage is as before, $\frac{100}{2000} = 5$ per cent, the volt-amperes being the same as in Fig. 6a and Fig. 6b.

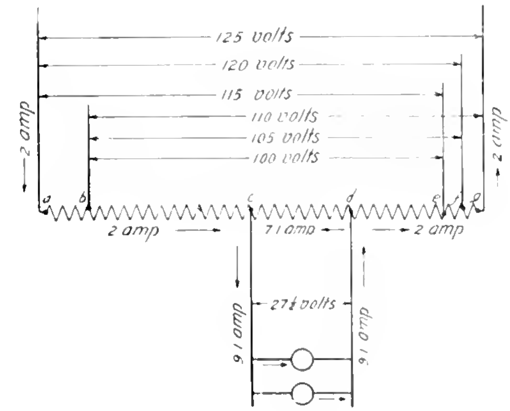


Fig. 9. Single Circuit, 250 Watt House Compensator

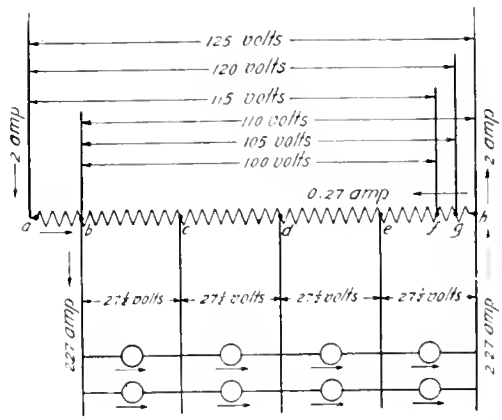


Fig. 10. Four Circuit, 250 Watt House Compensator

For a ratio of transformation of say 1:3, we find by the same reasoning a compensator reactance drop of $6\frac{2}{3}$ per cent as against 10 per cent for a transformer with corresponding windings and currents, as represented in Fig.

7. In general, if the ratio of transformation of a compensator is $m{:}n$, the reactive drop will be $\frac{n-m}{n}$ of the drop required for a transformer with the same windings and current capacity.

The General Electric Company manufactures special and standard compensators for various uses, and the most important of these will now be taken up in more or less detail and an attempt made to explain their connections and the manner of calculating their rating.

House Compensators

These are for the operation of low voltage tungsten lamps in multiple, one compensator taking care of a whole house. Compensators for 250 and 500 watts output are built for operation on 100–125 volts, with one and four secondary circuits, and a similar line of compensators for operation on 200–250 volts. A 1100 watt, eight-circuit compensator for 200–250 volts is also built. Four taps are brought out of the primary to take care of variations in primary voltage. These compensators are classified as follows: LC 60-0.216–100 105 110 115 120 125–$27\frac{1}{2}$ volts. Figs. 9 and 10 show the connections for 250-watt house compensators of one and four circuits respectively. The manner of figuring the kilowatt rating of these will be explained in detail. In Fig. 9, with 250 watts input and 125 volts impressed, 2 amperes will flow in

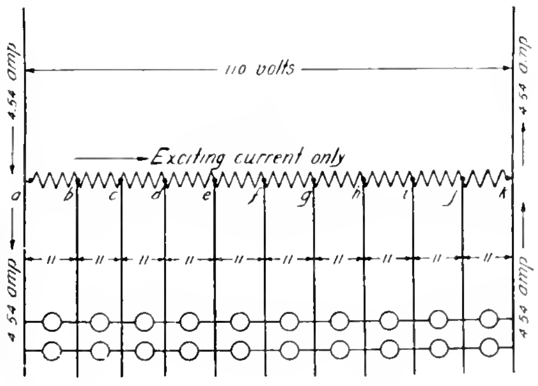


Fig. 11. 500 Watt Sign Compensator

the primary line; at the same time 9.1 amperes at $27\frac{1}{2}$ volts will be drawn from the secondary. Then 2 amperes will flow in the sections *ac* and *dg*, and (9.1 − 2, = 7.1 amperes in the section *cd*.

The following tabulation show the conditions with various impressed voltages:

Impressed Volts	Section	Amperes	Volts
125	*ac* + *dg*	2.00	$97\frac{1}{2}$
	cd	7.10	$27\frac{1}{2}$
120	*ac* + *df*	2.08	$92\frac{1}{2}$
	cd	7.02	$27\frac{1}{2}$
115	*ac* + *de*	2.17	$87\frac{1}{2}$
	cd	6.93	$27\frac{1}{2}$
110	*bc* + *dg*	2.27	$82\frac{1}{2}$
	cd	6.83	$27\frac{1}{2}$
105	*bc* + *df*	2.38	$77\frac{1}{2}$
	cd	6.72	$27\frac{1}{2}$
100	*bc* + *de*	2.50	$72\frac{1}{2}$
	cd	6.60	$27\frac{1}{2}$

An inspection of this tabulation will show the maximum current carried by each section under any condition, and it is evident that such maximum current must be provided for in winding the compensator. The maximum

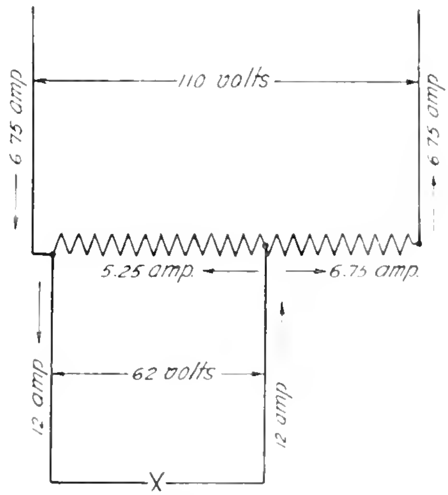


Fig. 12 Multiple Flame Arc Compensator

current in each section times the respective voltage gives the following:

Section	Current	Volts	Watts
ab	2.17	15	32.6
bc + *de*	2.50	$72\frac{1}{2}$	181.3
ef	2.38	5	11.9
fg	2.27	5	11.4
cd	7.10	$27\frac{1}{2}$	195.2
			432.4

The rating of a compensator for the above service is $\frac{432.4}{2}$ equals 0.216 kw. As the current values (except in section cd) are nearly

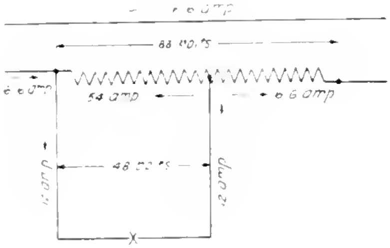


Fig. 13. Series Flame Arc Compensators

alike, the primary section, $ac+dg$, would be wound throughout for 2.5 amperes and the secondary section, cd, for 7.1 amperes.

The problem presented in Fig. 10 is very similar to that of Fig. 9, with the further complication that from one to four circuits may be in use at one time, the output at any time being proportional to the number of circuits in use. An investigation shows the following maximum conditions for each section:

Section	Amperes	Volts	Watts
ab	2.17	15	32.55
bf	1.87	100	187.00
fh	2.27	10	22.70
			242.25

This gives a rating of $\frac{242.25}{2}$ = 0.121 kw., or about 56 per cent of the rating of the one circuit compensator with the same output.

It is evident that the rating thus obtained gives no indication of the output or performance of the compensator. It does, however, afford a basis of comparison as to size, cost and losses with a transformer of similar rating or another compensator.

Sign Compensators

As indicated by the name, these compensators are for use in supplying power to signs lighted by low candle-power, low voltage tungsten lamps. Three sizes are made at the present time, all ten circuit secondary, 60 cycles, suitable for operating at 50 to 140 cycles and 100 to 130 volts.

Let Fig. 11 represent a sign lighting compensator, 500 watts output, 110 volts impressed, with the secondary divided into ten circuits of 11 volts each and each circuit good for 50 watts output. The following table is the calculation of the rating.

No. Circuits Loaded	Total Watts Output	Pri. Cur.	Cur. in Loaded Sec.	VOLTAGES Pri.	VOLTAGES Sec.
1	50	.454	4.09	99	11
2	100	.91	3.63	88	22
3	150	1.36	3.18	77	33
4	200	1.82	2.72	66	44
5	250	2.27	2.27	55	55
6	300	2.72	1.82	44	66
7	350	3.18	1.36	33	77
8	400	3.64	0.90	22	88
9	450	4.09	0.45	11	99

By inspection it will be seen that the maximum current flowing in the loaded secondary coil at any time is 4.09 amperes with one circuit loaded, and in the primary coil 4.09 amperes with nine circuits loaded. When all ten circuits are loaded, we have the condition shown in Fig. 11, viz., 4.54 amperes in both primary and secondary lines and exciting current only in the coils. As the single loaded circuit might be any one of the ten, all the coils must be designed to carry the maximum current of 4.09 amperes. The rating of the compensator will then be:

$$\frac{(4.09\times 99)+(4.09\times 11)}{2}=\frac{450}{2}=0.225 \text{ kw.}$$

Arc Lamp Compensators

Various compensators are manufactured for the different kinds of arc lamps. Those

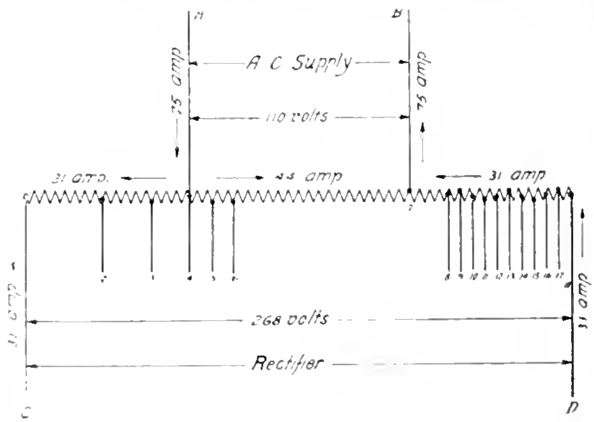


Fig. 14. Mercury Arc Rectifier Compensator

for flame arc lamps will be considered as typical. They are of two styles, one for series and one for multiple operation. The multiple compensators are for operation on 110, 220, 440 and 550 volt mains, all giving 12 amperes, 62 volts on the secondary. The series compensators are for operation on 6.6 and 7.5 ampere constant current circuits, giving 12 amperes, 48 volts on the secondary. Figs. 12 and 13 give the connections. The calculation of the rating is evident.

Mercury Arc Rectifier Compensators

The purpose of these is to step up the alternating current supply voltage to a voltage suitable for the rectifier. Fig. 14 shows a compensator RRC–60–5.5–330/110, designed for regulating the voltage and current of rectifiers operating at 50 amperes, 120 volts direct current. With 110 volts impressed, a range of voltage from 120 to 340 may be obtained in various steps. Rough regulation is secured by means of one blade of a double-handled dial switch, which allows line *A* to be shifted to any part of the winding from tap 1 to 6, line *B* being fixed to tap 7. Fine regulation is secured by shifting line *D* from tap 8 to 18 by means of the other blade of the dial switch, line *C* being fixed to tap 1. The rating of this particular compensator is figured roughly on the basis of 8.3 kw. output at 330 volts.

Starting Compensators

Standard starting compensators are made for two-phase and three-phase, Form K, squirrel-cage induction motors, with voltages of 110, 220, 440, 550 and 2200 and frequencies of 25, 40 and 60 cycles, in sizes from 5 to 200 h.p. The use of starting compensators greatly reduces the starting orque but prevents a large rush of current, which would cause disturbances on other parts of the power system. For motors smaller than 5 kw. no starting compensators are used. The compensators for motors of from 5 to 18 h.p. are provided with 40, 60 and 80 per cent starting taps and designed for respective line currents

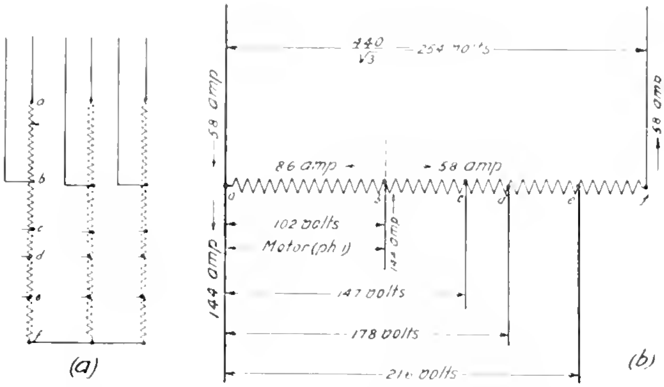


Fig. 16. Starting Compensator for 50 H P. Form K Induction Motor

of 16, 36 and 65 per cent of the starting current that the motor would require without compensator. For larger motors taps are provided for potentials of 40, 58, 70 and 85 per cent of the line voltage, and for respective currents equal to 16, 34, 50 and 72 per cent of the current required to start without compensator. The proper starting voltage is found by trial and permanent connection made to that tap. The compensators are rated arbitrarily: thus CR152 for use with induction motor 1Q8 poles, 15 h.p., 900 r.p.m., 110 volts, Form K.

In designing these compensators the motor efficiency is assumed to be about 75 per cent, and the starting current without the compensator about $5\frac{1}{2}\times$ (full load current). The calculations are then made, using the proportions of currents mentioned above for different taps. This would give a compensator designed for continuous load. As starting compensators are only intended for one minute service, the current density in the coils is greatly increased above the usual densities; in other words a greatly reduced size of copper is provided, and the size of the compensators is correspondingly reduced.

Figs. 15 and 16 show compensators for two- and three-phase motors respectively, and the following tables will make clear the calculation.

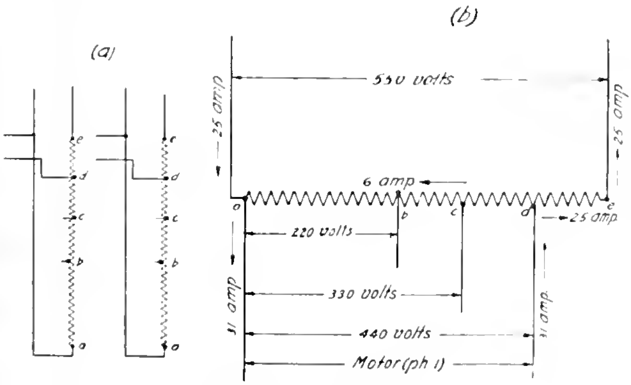


Fig. 15. Starting Compensator for $7\frac{1}{2}$ H P Form K Induction Motor

CR131 starting compensator for 110/50/720/440 volt motor.

Tap	Tap Volt. in Per Cent	Tap Volt. Motor	Tap Volt. Per Leg.	Starting Current	Current Primary	Current Loaded Coil
1	40	176	102	144	58	86
2	58	255	147	210	122	88
3	70	308	178	257	180	77
4	85	374	216	304	259	45

Conditions to be provided for:

Section	Maximum Current	Voltage	Actual Design Amp. 1 Min.
ab	86	102	88
bc	88	45	88
cd	122	31	180
de	180	38	180
ef	259	38	259

For starting synchronous motors and rotary converters special compensators are built. Automatic starting compensators do not differ from the above as far as the compensator feature is concerned.

(To be Continued)

THE PROMISE OF ELECTRIFIED AGRICULTURE*

By Edmund P. Edwards

The central station industry of the United States is today devoting its entire energy, with relatively few exceptions, to serving the needs of our urban population. This is the field which has offered the greatest return for the least investment of time and capital, in that the communities served occupy a restricted area and represent concentrated wealth.

The term "has offered" is used advisedly if the data of eminent statisticians is to be relied upon and their prophesies given weight, for this data shows that a new era has dawned in this country and that in the last few years an unparalled economic revolution has started and is gaining tremendous impetus. For want of a better name we may call this revolution "scientific agriculture."

Electricity is destined to play one of the most important parts, if not *the* most important part, in this movement, and I venture to predict that the time is not far distant when station operators will consider the agricultural field as equaling in fertility the present limited "served areas."

Europe has been forced to a realization of this and is far ahead of America today in the development of agriculture and the application of electricity to its needs. This realization has been forced upon Europe because of the necessity for intensive farming. Results have been achieved more quickly and with less expenditure of effort because of the relative denseness of the population as compared with that of America, and because the average area of the European farm is much smaller than the average area of the American farm.

As an instance of German development, we are told that in 1902, thirty-five towns near Hanover having a total population of thirty-five thousand including outlying districts were using about two thousand horsepower in motors for agricultural purposes.

The same necessity for intensive farming is rapidly approaching in this country as is evidenced in many ways, notably the falling off in our export of food stuffs.

Our principal product is corn, of which we exported 10.3 per cent in 1900. This dropped to 1.11 per cent in 1909 in the face of an increase in production equaling 32 per cent. Exports of wheat amounted to 34 per cent in 1900 and to 17.19 per cent in 1909 in the face of an increase in production equaling 41 per cent.

Shall we wait until we are a debtor instead of a creditor nation before we take steps to apply a remedy which is in our own hands and which has been successfully applied by European countries? The solution of this problem must be undertaken intelligently and it can only be solved by a close and systematic study of conditions as they exist today and the results of this study applied to local conditions as the needs of each separate community dictate.

It is the purpose of this paper to present the problem as a whole for the consideration of those best qualified to attack it along

* Paper read at the Twenty-sixth Annual Meeting of the Association of Edison Illuminating Companies, Thousand Islands, N. Y., September 6, 7 and 8, 1910

broad lines. No endeavor will be made here to deal in great detail with the innumerable ramifications of the subject. If the possibilities as a whole, which I believe to exist, are made apparent to the readers of this paper, my immediate purpose is served and it only remains for those who are guiding the central station industry to work out in detail each individual problem or prospect looking to the utilization of electricity, for if we stop with a general treatment of the subject but little benefit will accrue. While the farmer of today is immeasurably better equipped to study the problem of agriculture from a scientific standpoint, he is not so much interested in the general phase of the situation as should be the vender of electricity and the manufacturer of agricultural implements and machinery. Furthermore, the farmer has very little time to devote to the abstract problem. Consequently it develops upon the manufacturer and the central station industry to propagate data in its simplest and most attractive form, setting forth clearly to the farmer the advantages that will be derived by him from the installation of labor saving electrically-operated devices.

Certainly the best way to launch such a campaign will be through the co-operation of the operating companies and the manufacturers, using a competent personnel thoroughly trained to point out the mutual advantage that can be derived by the farmer, the central station operator, and the manufacturer.

General Statistics

The land area of the United States comprises 1,903,461,760 acres. Of this area 44.1 per cent is devoted to farming. The total population in 1909 was estimated to be 88,262,446. Of this population about 62,000,000, or 70 per cent live in the rural districts. The remaining 26,000,000 constitutes our urban population. As of today, then, our central stations are serving only 30 per cent of our population. There are approximately 7100 public service corporations distributing electricity today, having a total installed capacity of approximately 5,000,000 kilowatts or a per capita installation of .19 kilowatts per urban inhabitant.

Let us assume that our efforts result in the installation of 0.1 kw. per capita in the rural districts, only one-nineteenth of that devoted to the needs of urban communities. This would mean an increase of approximately 620,000 kw. or 12.4 per cent.

If we can reach but a small percentage of the rural population the outlet for current and electrical apparatus will be enormously increased. Is this increase worth going after? Can it be accomplished? The following figures indicate that it is worth while and can be accomplished.

The wealth production of farms in 1899 was $1,717,000,000. In 1909 it was $8,760,000,000. An increase of 87 per cent in ten years as against an increase in population of 20 per cent. By far the greatest increase has been made in the last three years, which goes to show the strides that agriculture is making. Contrast these figures with the combined production of gold and silver, amounting in 1909 to $127,242,300 which is only 5.35 per cent of the combined value of the corn and wheat crop for that year.

Again, of the total of 29,073,233 people engaged in gainful pursuits in 1900, 10,381,765 were engaged in agriculture and kindred occupations. Still there is a continual complaint because of the shortage in agricultural labor.

The number of horses and mules in the United States in 1910 is estimated at 29,163,000, 89 per cent of these being utilized in agriculture. Is it not reasonable to assume that many of them can be superseded or their efforts augmented by mechanical contrivances? The increase in value of mules and horses warrants the belief that it is possible to do both.

The man with a single plow twelve inches wide must walk 5,280 miles in turning the sod of a field one mile square and three horses are usually required. This plowing must be done in a limited time. Let us assume ninety days.

As the average amount that can be plowed in one day by one man is about two acres, it would require 105 horses and 35 men to plow that one square mile.

In 1900 there were 838,591,744 acres in farms. To plow this land it would therefore require approximately 4,650,000 men and 13,850,000 horses, and this covers only one operation. Add to this the operations of discing, harrowing, seeding and cultivating and some realization will be had of the possibilities presented for the application of mechanical devices and power to operate them. This problem has already been attacked by the manufacturers of steam and gasolene traction engines and great progress has been made. European countries, however, recognize the simplicity and economic value of electricity as applied to plowing and they have developed electric plows which are thoroughly commercial.

Is not all this a clear indication that electrical energy is utilized in our rural districts to a much smaller extent than in our urban districts, whereas the need for electrification is as great if not greater?

Irrigation

Irrigation is destined to become one of the most important, if not the most important, economic factor of this country. Water, where and when you want it, will act as a governor regulating the stability of the national machine.

Elections, the value of securities, and in fact nearly every thing of importance, hinges on the condition of crops. This in turn hinges largely on weather conditions and the natural supply of water. Uniformity in the production of crops is therefore basically necessary and irrigation will help to bring this about

The development of irrigation in this country in the past few years has made great strides. It has increased land value enormously. It should prove one of the greatest sources of revenue to the central station when applied to truck gardens alone. The character of the load is ideal, coming as it does in the summer months and at the time of low peak.

The combined population of Greater New York, Chicago, Philadelphia and Boston is over 9,500,000 and these cities cover an area of six hundred and ninety square miles. They are all surrounded by truck gardens. Assuming that the central station reaches out for a radius of ten miles, the territory covered will comprise 764,800 acres. Assuming that six thousand gallons of water per acre per day is required for irrigation, a load approximately one and one-fourth million kilowatt hours per day of twenty-four hours will result. Assume that this load lasts for thirty days, totaling approximately 40,000,000 kilowatt hours, at 10 cents per kilowatt hour; this will yield a revenue of $4,000,000. Discount this as liberally as you please, the proposition is still immensely attractive. Certain central stations have already made extensive inroads into this practically undeveloped field. Others are slowly following their example.

NOTABLE INSTALLATIONS

The activities of the Mount Whitney Power & Electric Co. in Tulare and Kern Counties, Calif., are particularly worthy of note and are dealt with in great detail by Mr. John C. Hayes in a paper read before the American Institute of Electrical Engineers, April, 1910. Surface water versus pumped water, rates, cost, etc. are discussed.

This company at the present time is irrigating about 18,000 acres using a connected load for this purpose of nearly 4000 kilowatts out of a total capacity of about 6000 kilowatts.

The Rochester Railway & Light Company has also done much in this field, having installed sixteen pumping plants on farms adjacent to Rochester.

The North Shore Electric Co., of Chicago, is inaugurating a similar campaign.

Electric Stimulation of Vegetable Growth

It is surprising to note the number of experiments that have been made, the calibre of the men conducting them, and the results which have been obtained along the line of electric stimulation of plant life. Among these men are Prof. Lemstrom of Helsingfors University, Finland; Sir Oliver Lodge, England; Prof. Daniel Berthelot, France; Ex. Judge T. H. Williams of Brooklyn, and Warren H. Rawson of Boston.

The European practice most in vogue is electrostatic in nature. A network of wire is supported over the fields at a height of from fifteen to seventeen feet. A rectified current having a potential of 100,000 volts is used. The net work is positively charged and the negative conductor grounded.

In Sir Oliver Lodge's experiments a two horse-power oil engine was used, the primary current being furnished by a three ampere, 220 volt generator stepped up through an induction coil. Nineteen and one-half acres were treated in this manner for ninety days, current being actually used for three hundred and twenty-two hours during the early summer months and in the early morning hours. It was shown that both the quality and the quantity of the yield was materially bettered through this treatment and the growth greatly accelerated, wheat showing an increase in quantity of 45 per cent, corn 35 to 40 per cent, potatoes 20 per cent, beets 26 per cent, strawberries 50 per cent to 128 per cent, and barley 39 per cent. Practically the same results were noted on a twenty-four acre field in Germany.

The theory is advanced that the flow of sap is stimulated and the nitrogen of the air freed and made available as a fertilizing agent.

It is impossible to predicate the extent to which such methods of cultivation may be utilized, but possibilities seem to exist, for we are told by the Department of Agriculture that 6394 tests on corn, 3227 tests on wheat, and 1483 tests on oats, show an average dollars and cents loss relative to the increase in yield where chemical fertilizers are used.

This does not mean, of course, that the use of chemical fertilizers for grain crops is ill advised or unnecessary. On the contrary their use is essential in order to replenish an exhausted soil.

Lodge's experiments show that it cost approximately $2.00 per acre (operating cost) to achieve the results noted. The average cost per acre where commercial fertilizers are used is $7.14 per acre.

If it were possible to apply this system to any appreciable part of our grain area, it can readily be seen that the food problem would be largely solved for some time to come. Even if it is not possible to reach out into our corn fields, it may not only be possible but practical to stimulate the growth of our truck products.

The lead of Europe is being followed to some extent in this country and the results obtained abroad have been duplicated here. Judge Williams has a farm at East Northport, L. I., where the Lodge system is used. Mr. Rawson has a farm at Arlington, Mass., where the electrostatic method is being tried out. In the very near future we will know more about this subject and be in a better position to determine whether or not these principles can be utilized to practical advantage.

Other methods have been used for the stimulation of plant life by electricity, such as the electrolytic effect of buried plates connected by copper conductors and electrically charged, the utilization of atmospheric electricity, etc.

Electric Appliances on the Farm

Many electrically-operated machines and devices are now on the market. The list is being added to rapidly. The following tabulation will give some idea of the development along these lines:

DEVICE	HORSE-POWER REQUIRED
Cream separator	½ to 4
Milking machine	3 to 5
Grindstone	½
Bottle washer	½
Water pump	1 to 10
Shredder	10 to 15
Silage grinder	10 to 20
Feed grinder	5 to 10
Threshing	10 to 20
Wood saw	3 to 5
Corn sheller	1 to 4
Hay press	1 to 25
Refrigerating	½ to 25

Taking the lower capacity we get a total of 50 h.p. installed. Suppose that each of the 5,737,372 farms had a connected load of 50 h.p. The manufacturer would be called upon to furnish 286,869,600 h.p. in motors with a corresponding capacity in generators, and the central station operator would find an inexhaustible outlet for power.

Heating and cooking devices, fans, etc., which we may term luxuries, would follow the installation of what we may call economic necessities.

Many farms throughout the country are today installing electrically-operated machines. The number of farms so electrified, are of course, a negligible percentage of the total, but there is a healthy if gradual increase going on.

Hearts' Delight farm at West Chasey, N. Y., operated by Mr. M. H. Miner, is a striking example of what can be accomplished through the use of electrical devices and machinery. This farm has been fully written up of late and it is unnecessary to give a detailed account of the installation.

There are many similar installations operating on a small scale and the avidity with which the press of the country seeks and disseminates information bearing on these installations is a very good indication of the interest that the community at large takes in the subject. Scarcely a day passes when no mention is made in the papers of the country of electrical applications on the farm. This newspaper campaign will serve a valuable purpose in preparing the ground for a more analytical and practical treatment of the subject.

In conclusion, it must be borne in mind that the figures used in this paper are only intended to be illustrative. They are not intended as an accurate guide to what we may expect from the promise of electrified agriculture.

BEECHNUT PACKING COMPANY

By W. D. Bearce

Fig. 1. Top Floor of Peanut Butter Factory Showing Three Motor-Driven Blowers

Recent pure food agitation with the resulting legislation has been particularly effective in securing the use of clean materials and methods for canning and preserving the many food products which are every year turned out by our canning factories. Probably no one thing could induce a greater increase in the consumption of canned meats, fruits, vegetables, etc., than the conviction by the consumer that absolutely sanitary methods and pure materials are being used in the handling and preparation of the raw materials. Following this line of argument, the Beechnut Packing Company with their modern plant at Canajoharie, N. Y., are endeavoring to impress the consumer with the unquestionable superiority of their methods and for this reason the factory throughout the year is open for inspection to all visitors.

One of the most important factors in the maintenance of hygienic surroundings, as is well exemplified in this factory, is the use of individual motor drive wherever possible. While in this particular case the primary consideration in the installation of motor drive is the feature of cleanliness further advantages are also gained, such as economy of power, increased production, etc.

Located on the Erie canal some forty miles east of Utica, the factory is in the midst of a fertile farming country; furthermore, in this section of New York state, hydro-electric power is comparatively cheap and plentiful, and no generating plant need be maintained. The power for this factory is purchased from the Montgomery Light & Power Company, a local distributing agent, at 2300 volts, 60 cycles. It is generated at the East Creek power station eleven miles distant, whence it is transmitted to Canajoharie at 15,000 volts and stepped down at the local substation. The East Creek power station has a rated capacity of 1000 kw.; this is now being added to by a new station of 6000 kw. capacity located at Tribes Hill, about three miles from the present plant.

Fig. 2. Hoppers for Cooling Roasted Peanuts

A day load of this character is particularly desirable for a central station, and it is therefore possible to offer hydro-electric power at a rate below the cost of steam power. In the event of breakdown, the factory can make use of its own generating plant, which has a rated capacity of 80 kw. However, as the average load at the factory is about 200 horse-power, this plant can supply only about one-half the power required.

The several illustrations accompanying this article show the variety of operations which employ electric drive to advantage. The two larger departments, the peanut butter factory and the sliced meat department, are unusually good examples of the improved conditions attending the use of individual drive.

A short description of the methods employed in handling the materials will enable the reader to more easily understand the work which is required of these motors.

Three floors are devoted to the manufacture of peanut butter. On the top floor (Fig. 1) raw shelled peanuts are received in 250 pound bags and stored until used. On this floor also are located the peanut roasters and three blower motors, the latter forming part of the blower system. The peanuts are first placed in the motor-driven roasters and after being

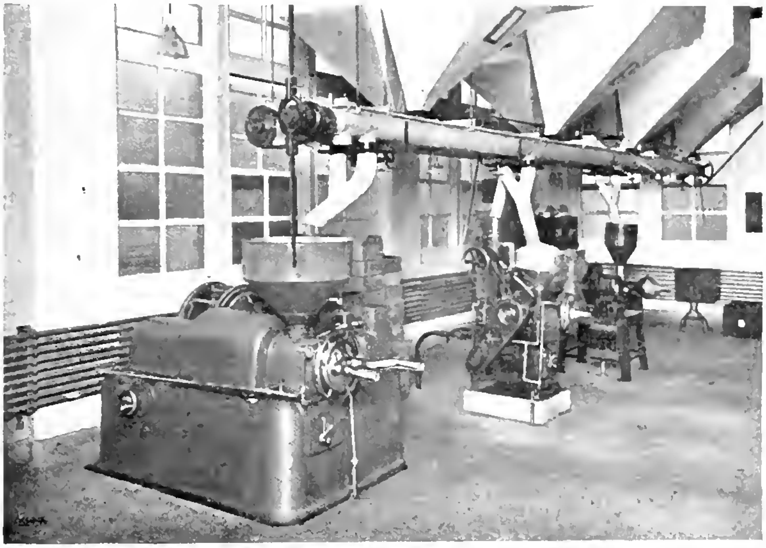


Fig. 3. Motor-Driven Peanut Butter Machines

Fig. 4. Filling Glasses with Peanut Butter

properly cooked are taken out into large hoppers to cool. (Fig. 2). From these hoppers, which are three in number, they pass to the next floor by gravity and are delivered to the so-called blanching machines, which remove the brown skin from the peanut and split it in halves. The process also breaks out the germ or heart, which part is afterwards discarded.

From the blanching machines the peanuts pass through a winnowing process to the floor below, during which the brown skins, germs, and any other foreign matter is blown out. On this floor they pass through a further cleaning process and are again raised to the top floor by an air blast of just sufficient force to lift one-half of the peanut. In this way any stones or heavy material which may have escaped the winnowing process is taken out. Returning to the third floor, the peanuts are dropped onto the moving belt of the sorting machines, where the operatives sort out any defective peanuts or foreign material. The product is now ready for the peanut butter machines and drops into the hoppers on the second floor. (Fig. 3).

On this floor are located three peanut butter machines, each direct connected to a Form K induction motor. The largest machine, which is driven by a 15 h.p. motor, has a capacity of five tons per day. The two smaller machines are driven by 3 h.p. motors and have a capacity of about 1500 pounds per day. It is interesting to note that two

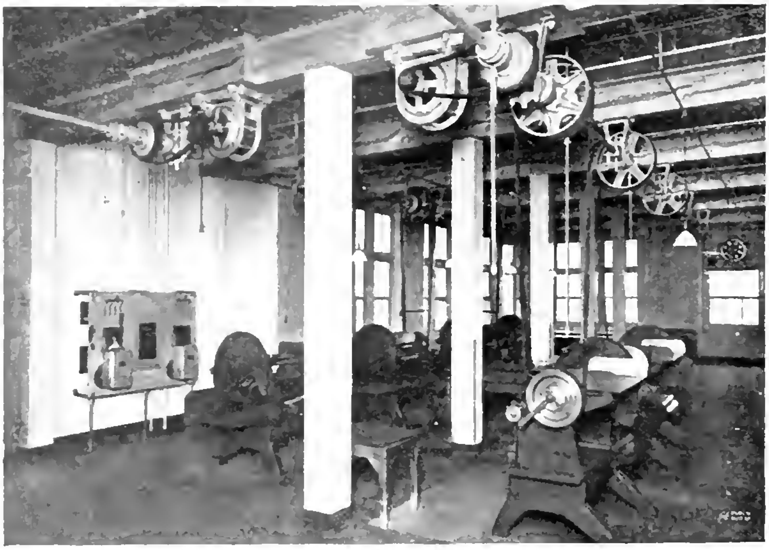


Fig. 5. Machines for Slicing Bacon and Dried Beef Operated from Line Shaft

varieties of peanuts are used, the so-called Virginia peanut and the Spanish peanut. By mixing these in proper quantities the required amount of oil is obtained from the latter variety. In the illustration (Fig. 4) the operatives may be seen filling the glasses directly from the spouts, at a rate of fifty-eight per minute. In this department it is evident that belts, shafting and shaft hangers would afford opportunities for the accumulation of dirt and dust, whereas by the use of the direct connected motor, the room can be kept clean and sanitary.

The White Packing Room

The white packing room, so called on account of its white enameled finish, is used entirely for preparing and packing the sliced dried beef and sliced bacon. Special machinery, the cutting knives of which revolve at 500 revolutions per minute, is employed for slicing the meats. Fig. 5 shows a corner of this room in which two 10 h.p. motors, suspended from the ceiling, are used to drive the several slicing machines. It will be noted that the machine on the extreme left is equipped for individual drive. This equipment is more clearly shown in Fig. 6. The two motors now used for driving the line shaft are soon to be replaced by individual motors mounted on each machine. A considerable saving can be effected in this way, as on many occasions either the raw material is not promptly delivered or else the sliced meat is not required for packing and only two or possibly three of the machines need be operated. In Fig. 5 the starting apparatus for each motor consisting of switches and compensators mounted on standard panel, may also be seen.

In another part of this room the glass jars are thoroughly wiped out by motor-driven cleaners similar to the one shown in Fig. 7. A $1\frac{1}{3}$ h.p. motor carries the two wipers while a 2 h.p. motor collects all dust and carries it from the room. Several of these outfits are being set up to replace belt-driven machines.

Among the many other purposes for which electrical energy is employed, is the driving of ventilating fans, vacuum pumps, labelling machines, belt conveyors and elevators. The conveyors are driven by an induction motor and raise the empty jars to

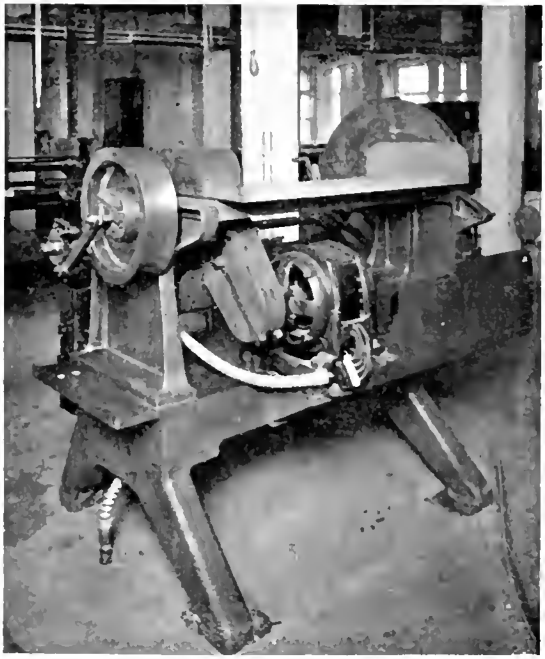


Fig. 6. Slicing Machine Individually Driven by Small Induction Motor

the fourth floor, the force of gravity carrying the boxes down the inclined rolls (Fig. 8).

In the bean department, which is located on the third floor of the main building, the machinery is driven by a 10 h.p. motor, chain belted to the line shaft. The machinery in this department consists of sorting machines similar to those used in the peanut department, and filling and sealing machines.

The cap-room, so called, is on the first floor adjoining the boiler room. In this department the metal covers are punched out and shaped in large punch presses. The rubber washers are cut on special machines, and threads are pressed into the screw top covers. Several special grinders are also required for sharpening the knives of the slicing machines. This entire room is operated by the 10 h.p. motor shown in Fig. 9.

The power, as before mentioned, is supplied at 2300 volts, 2-phase, 60 cycles. From this potential it is stepped down to 220 volts for driving the motors. In order to supply the incandescent lamps with 110 volts, a neutral wire is tapped in on the transformer winding and the various circuits are balanced on the two phases. Almost all the incandescent lamps, which are well shown in several of the illustrations, are tungsten, using Holophane reflectors. There are in all one hundred and sixty 100 watt lamps and fifty 60 watt lamps of this type.

The total number of motors in actual service is eighty-three, totaling 250 h.p.

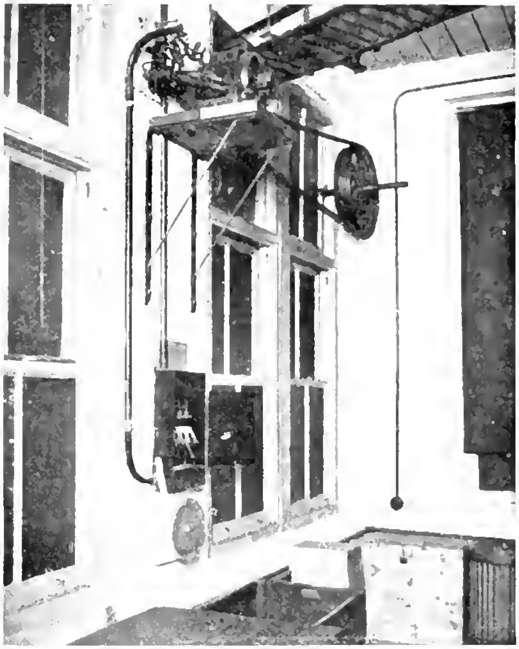


Fig. 8. Induction Motor for Operating Conveyor; Rolls for Carrying Boxes by Gravity From Fourth Floor

Current at 220 volts is supplied from six 25 kw. General Electric transformers. During the past year this plant turned out 7,500,000 packages of product and employed about 350 persons.

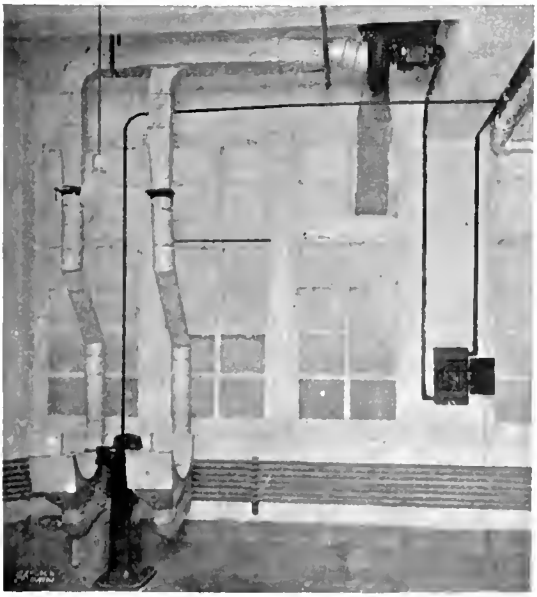


Fig. 7. Motor-Operated Cleaners for Glass Jars

Fig. 9. Special Grinders for Sharpening Knives of Slicing Machines. Group Driven From 10 H.P. Motor

INSTALLATION OF LOW PRESSURE TURBINE, BETTENDORF AXLE COMPANY, DAVENPORT, IOWA.

By P. Bendixen, Master Mechanic

About two years ago the Bettendorf Axle Company, of Davenport, Iowa, were considering an addition to their electrical equipment due to the growth of the plant, and made a thorough investigation of the various prime movers suitable for the purpose. Taking into consideration the heating of the shops in winter and the fact that the old power plant was running non-condensing, all factors pointed to the low pressure or exhaust turbine as the most suitable power unit to install, from the standpoint of reliability, simplicity, economy and maintenance.

The power equipment at that time consisted of two 100 kw. direct connected high speed tandem compound engine-driven units, a number of hydraulic pumps, and an air compressor exhausting into one header, making an ideal arrangement for connection to an exhaust turbine. Having made a study of various turbine plants, the company decided to install a 500 kw. horizontal Curtis turbine. This turbine was put in operation in September, 1909, and has been in service for about fourteen hours per day since. It supplies all electrical power required by the plant, which at present amounts to 250 kw. average load; this power being used mostly for the operation of cranes, the lighting of shops, and for lifting magnets. When machinery now under construction is completed and installed, the load will be increased to about double. The main steam supply is derived from the exhaust of the hydraulic pumps, but, owing to the fact that these pumps are subject to interrupted service due to breakdowns on the system, other means of supplying steam had to be provided and a connection was therefore made from the exhaust header to the high pressure steam pipe through a 4 inch by 8 inch Foster pressure-reducing valve. By means of this connection the required amount of steam to keep the turbine in operation is secured. This arrangement works very satisfactorily, as the valve operates within a range of one-half pound drop in pressure. The average back pressure is about three pounds, and to take care of an excessive back pressure, the exhaust header is provided with a 12 inch relief valve set to operate at five pounds pressure. All steam to the turbine passes through an 18 inch two stage separator, which separates all oil and moisture from the steam. A 3150 foot Worthington condenser is installed, the condensed steam being returned to the boiler feed water heater.

While no figures are available to substantiate a statement as to the exact performance of the turbine, it is thought possible, when running with 28 inch vacuum, to recover 75 per cent of the energy delivered to the pumps, compressors, and reciprocating engines. In cool weather it has been possible to run for weeks with a vacuum of from 29 to 29½ inches, this, of course, making quite a difference in the steam consumption. In order to maintain a good vacuum, it has been found necessary to pipe the steam seal in which the carbon packing rings are located with high pressure steam to insure against any leakage of air around the shaft. The amount of steam required for this purpose can best be found by experiment, and when once adjusted requires very little attention.

Before putting the turbine in service it was run for a few days under various loads, the generator being loaded on a water box. It was found that sufficient exhaust steam was available to furnish 425 kw. continuously, and as much as 575 kw. for short periods. Six boilers of about 120 h.p. each were in service at that time. The results of the test would indicate that 75 to 80 per cent of the energy delivered to the engines and auxiliaries was recovered.

The governing of the turbine is very good, as with a load fluctuation of about 500 amperes the variation in potential does not exceed two or three volts. The lighting load consists of enclosed arc, flame arc, mercury vapor and incandescent lamps, all of which show up very much better when operated by the turbine than when the engine-driven units carry the load. This improved performance is owing to the better regulation of the turbine.

In operating the turbine, a practice is made of drawing a few buckets of oil from the tank every two weeks and adding the same amount of fresh oil; this seems to keep the oil in good condition. No trouble has been experienced in keeping the bearings cool, this being accomplished by means of circulating water. In order to maintain a uniform flow, the water is taken direct from the mains and passed through a reducing valve which takes care of any fluctuation in pressure in the main supply.

The emergency governor is tested regularly once a week; it has never failed to respond to increase in speed, invariably tripping the stop valve on the turbine.

It is found that the attention required by a turbine generator of the size here installed is not as much as that demanded by one of the engine-driven units. Good results are got without the use of a receiver generator between the units and the turbine, as the reducing valve makes up for any deficiency in the steam supply, which might be due, as stated before, to the stoppage of one of the engines or pumps. With this arrangement a sufficient supply of steam (direct from the boilers if necessary), is always assured, thus making the installation fully as reliable as the high pressure engine or turbine, and much more economical than either of these when running non-condensing.

The longest continuous run so far made with this turbine has been five days and nights. No shut-downs, due to trouble of any kind with the turbine, have occurred since the turbine was first put in operation, and this company can conscientiously recommend the installation of a low pressure turbine in any place where a sufficient supply of exhaust steam is available for its operation.

THE DEVELOPMENT OF PROTECTIVE DEVICES FOR HIGH TENSION CIRCUITS

By P. G. Langley

The past decade has witnessed a growth of electrical development which far surpasses

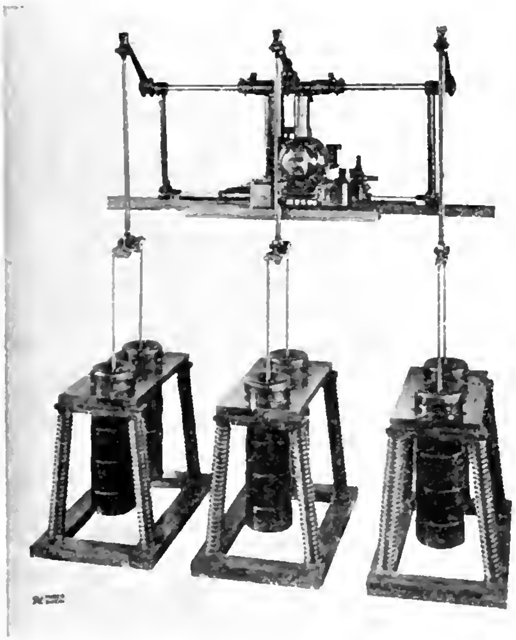


Fig. 1. 60,000 Volt High Capacity Oil Switch

the progress made in any other industrial line. It was shown at an early date that the simplest, safest, most efficient, and therefore the cheapest method of utilizing power, was to be found in the use of electricity as the converting agent.

Electricity is most economically generated near a natural source of power, whether of water, gas or coal origin. This fact has led to the development of many power possibilities, some of them remote from localities where there was a demand for power. Those close to centers of demand were first developed, and as the distances over which power was to be transmitted were small, few serious difficulties were encountered in the early days. As the nearer sources of energy were gradually developed and the demand for power increased, the utilization of the more remote powers was undertaken. Then arose engineering problems which forced the development of apparatus capable of handling the high voltages necessary for economical transmission over long distances. One of the first important steps toward high voltage transmission was made about eight years ago by the Washington Water Power Company. This company, in order to supply power to the mines of Washington and Idaho over transmission lines about one hundred and fifty long miles, decided to use 60,000 volts. This development proved so successful that it was speedily followed by others, and by rapid rises in voltage, until 110,000 volts is now not unusual and a rise to 140,000 volts has been proposed.

To meet these conditions of operation it has been necessary to develop switching, measuring, and protective equipments along

Fig. 2. Expulsion Type Combined Fuse and Disconnecting Switch

radically new lines. High voltage developments are necessarily expensive, and to effect economy, large powers must be employed; so that in addition to taking care of high potential strains, it has been necessary to produce equipments capable of withstanding the explosive effect of interrupting the flow of large amounts of energy.

The first high voltage switches were designed along the lines of the then existing switches for lower voltages, the spacing and insulation being increased in proportion to the voltage. These switches (Fig. 1) consisted of contacts working in separate enclosing chambers, partly filled with oil, in which the arc was finally broken. For each live wire two breaks in series and consequently two chambers were employed, each pair of chambers being installed in an isolating, fireproof compartment. The chambers were later improved by the addition of baffle plates and expansion compartments, which prevented disruption of the oil, splashing of oil out of the pots, and allowed space for the safe expansion of gases formed by arcs.

To increase the rupturing power, these switches are provided with explosion chambers surrounding the contacts, these chambers confining the oil and forcing it at high pressure between the contacts at the point where the arc is ruptured. The explosion chambers are entirely submerged in a larger volume of oil and any oil forced out by the expansion of gases is immediately and automatically replaced. These switches are usually electrically operated and located at some distance from the point of control, but they have also been designed for hand operation. They are limited to systems of not over 60,000 volts.

Such switches are suitable for large power installations and are expensive. To meet the condition where a small amount of power was to be tapped from a transmission line some simpler protective device had to be provided. This problem was solved by the introduction of the expulsion type fuse (Fig. 2.)

This fuse, which is mounted in a suitable holder that acts as a disconnecting switch for the circuit, allows of opening the charging current of a line or the magnetizing current of a transformer. When this is done the fuse holder is disconnected from the circuit so that a fuse can be easily and safely removed or replaced.

These fuses under proper conditions furnish excellent protection for lines and apparatus, since, due to their property of generating a

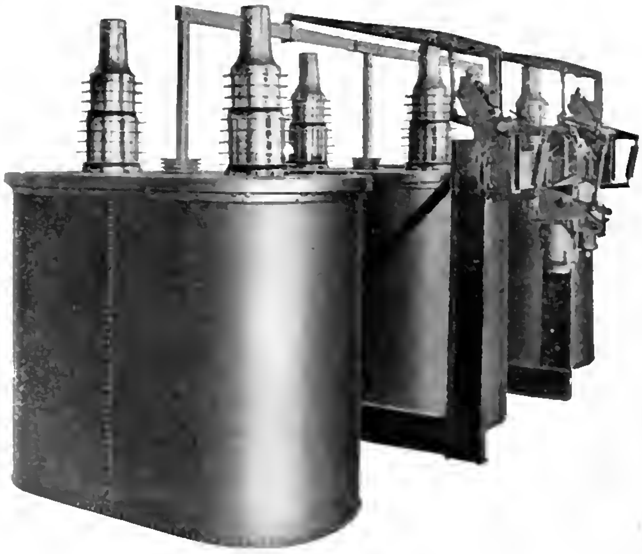


Fig. 3. Moderate Capacity High Voltage Oil Switch

high pressure at the rupturing point of the fuse, and their quick action, the circuit is opened with little if any more disturbance than when an oil switch is used.

There are a number of engineering features which should be carefully considered before deciding upon the use of fuses. Fuses should not be used:

1. When the current to be ruptured exceeds the rating of the fuse, or when the capacity of the system exceeds the rupturing capacity of the fuse.

2. Where the arc formed by the blowing fuse is objectionable.

3. Where short interruptions of service, due to the time necessary to replace fuses, is an objection.

4. Where overloads or short circuits are frequent, and circuits should be opened selectively after a time limit. In such cases, oil switches should be recommended.

To meet the demand for a reliable oil switch of moderate capacity that could be installed at a less cost than the larger switch a new type has been designed. In this switch each pole, which consists of two breaks in series, is assembled in a separate iron tank of large dimensions. The three poles necessary for a three-phase circuit are operated as a unit by one mechanism, either by means of a hand-operated lever, by air, or by solenoids electrically operated from the control board. (Fig. 3.)

Fig. 4. High Capacity High Voltage Oil Switch

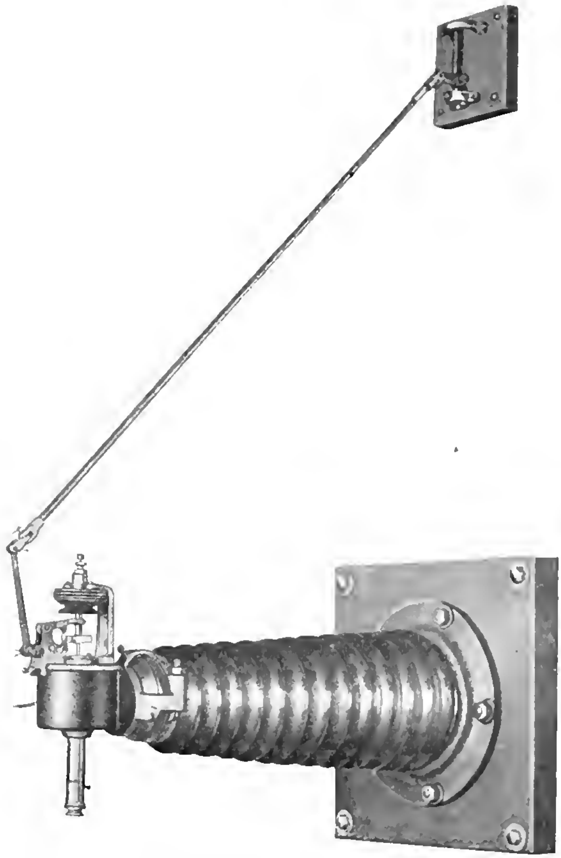


Fig. 5. High Voltage Series Relay

This switch does not require isolating cells for the oil tanks, these being simply set up on the station floor. The spacing of contacts and size of tanks are varied according to voltage, the limit of which is 110,000 volts.

High capacity oil switches which are capable of handling the largest powers yet developed, at any voltage considered up to the present time, have been designed along the lines of the one last mentioned. In order to provide the necessary insulation between live parts, spacings and break distances have been increased. The oil tanks are larger and contain a greater volume of oil. (Fig. 4.)

These switches, being top connected, admit of a very simple and flexible station layout. Since all wiring is overhead, station buildings do not require basements, and therefore can be constructed more cheaply than when bottom connected switches are used. The absence of cell work and barriers, also tends to greatly reduce the cost of installation.

In order to provide automatic protection for apparatus under abnormal conditions of

Fig. 6. High Voltage Series Transformer

overload or short circuit, two schemes are now in general use. The first and oldest employs series transformers, the primaries of which are connected in the high voltage circuit to be protected. The secondary winding, suitably insulated from the primary, is connected either direct or through suitable relays to the coil that acts upon the tripping mechanism of the switch controlling the circuit. The second uses relays, thoroughly insulated from the ground, the solenoids of which are connected directly in the main circuit. These relays operate the tripping mechanism of the switch either direct by means of insulating rods, or by means of an auxiliary source of power and a trip coil on the switch mechanism. They are designed only as single-pole units, one of which is connected in each live wire, and are not suitable for conditions which require the bringing together of two high voltage circuits in one unit.

Where wattmeters or watthour meters are required, series transformers are necessary and can be used to operate protective devices in addition to carrying the instrument load.

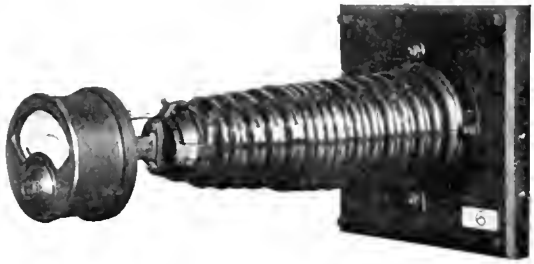


Fig. 7. Series Ammeter for High Voltage Circuit

By mounting a standard ammeter on a suitable insulator to prevent leakage to ground, a very satisfactory indicating device has been developed for use on high voltage circuits (Fig. 7). These instruments are connected directly in the main circuits and should be so mounted that accidental contact with them by the station attendant is impossible. These instruments are used in those installations which lend themselves to the use of series relays, and together they form a very compact and cheap equipment.

Disconnecting switches of various forms are in general use on high voltage circuits.

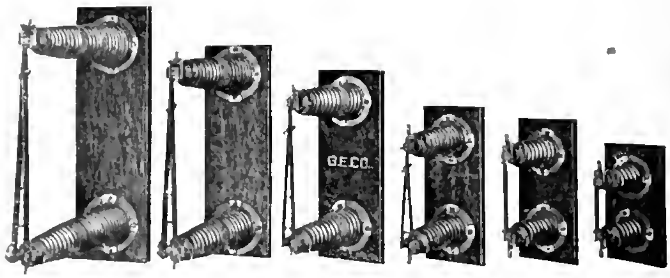


Fig. 8. Knife Blade Disconnecting Switch

These, as a rule, are not intended to open a power circuit, but can be depended upon to open the magnetizing current of a transformer or the charging current of a line. The well known knife-blade type is widely used, the spacing and break distances being in proportion to the voltage. These switches are invaluable for isolating stations or apparatus at times when it is necessary to make repairs or do other work which would otherwise require shutting down the entire system.

Fig. 9. High Voltage Outdoor Disc Switch

Switches capable of opening a moderate amount of power have been perfected for outdoor use (Fig. 9). These are mounted on poles or tower structures and may be operated from the ground by means of suitable mechanism. The final breaking of the arc is accomplished on metal horns which, bending upward and outward, allow the arc to follow its natural course upward and to rupture itself at the ends of the horns.

Fig. 10. High Voltage Strain Insulator

The most difficult problem in high voltage development has been to produce suitable insulation for the lines on which the success of any power transmission scheme depends. Exposed to all weather conditions, traversing long stretches of exposed country, and compelled to make numerous bends and to follow the natural grades, it has been necessary to produce insulators to meet any and all service conditions.

With the old style pin insulator construction, line voltages were limited to about 60,000 volts, owing to the great weight of the insulators for higher voltages and the great cost of towers, which had to be erected at close intervals.

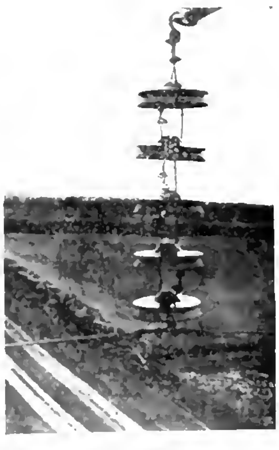


Fig. 11. High Voltage Suspension Insulator

Higher voltage transmission has been made possible by the introduction of a comparatively new insulator, known as the link type (Figs. 10 and 11). These are made in two forms, one called the suspension type and the other the strain type. Each complete insulator consists of a number of porcelain units joined together by suitable links, the number of units in series being varied in proportion to the line voltage. By the use of these insulators it has been possible to greatly increase the distances between supports, and to reduce the cost of lines to a practical basis.

THE CURTIS TURBINE*

Part II

By Charles B. Burleigh

Referring again to the 25 kilowatt turbine, we will now take up the consideration of the buckets and wheels, but we must first determine our bucket speed and wheel diameter. It should be clearly understood, however, that the values deduced and given in this article are simply to exemplify the interrelation of the steam velocity, bucket speed, wheel diameter, etc., and are not intended to be taken as the actual values that exist in these turbines. In our example, our steam conditions are fixed by an expansion from 150 pounds gauge (the pressure that we have assumed) to atmospheric pressure, resulting in a steam velocity of 2950 feet per second. To be safe let us allow 10 per cent velocity loss and select 2655 feet per second as the available velocity.

We can not select a single wheel, as it would necessitate a wheel velocity of $\frac{2655}{2} = 1327$ feet per second, and a two wheel abstraction would require a wheel velocity of $\frac{2655}{4} = 664$ feet per second. This latter would do, but we feel that a machine of somewhat less diameter and slower shaft speed would be more practical. Let us therefore try a three-wheel type, which will give us $\frac{2655}{6} = 442.5$ feet per second as bucket speed.

This is a very desirable peripheral speed and one that is well within the limit of safety.

Now let us see how we may best utilize this 442.5 feet per second bucket speed, which represents the speed of our wheel peripheries to which the buckets are secured, the wheels being securely keyed to the shaft upon which we must rely for our results.

It will at once become evident that the speed of this shaft will be wholly dependent on the radius of the circle through which the buckets move at the foregoing specified speed. To obtain a desirable shaft speed, therefore, we must determine on a proper wheel diameter.

In arriving at a decision regarding these features of design, we have considerable latitude as there are two variables, our wheel diameter and our rotative speed. We can therefore take advantage of this fact by selecting a rotative speed which permits of the most satisfactory design of generator.

On carefully considering the 25 kilowatt generator we find that a shaft speed of 3600 revolutions per minute readily lends itself to the best design.

Now let us consider the effect of a shaft speed of 3600 revolutions and a bucket speed of 442.5 feet per second on our wheel diameter.

A disc one foot in diameter revolving at a speed of 3600 revolutions per minute will have a circumferential speed of $3600 \times 3.1416 = 11309.76$ feet per minute.

The diameter of the wheel, to the periphery of which the buckets are to be secured, must bear the same ratio to one foot that 11309.76 feet bear to $442.5 \times 60 = 26550$ feet (our bucket speed per minute) or $\frac{26550}{11309.76} = 2.347$ feet = 28 inches as the diameter of our wheels including our buckets.

In arriving at our bucket speed we determined to adopt the three-wheel design. We can, however, modify this decision somewhat with decided advantage to our design.

Instead of using three separate and distinct wheels we may secure three rows of buckets to the periphery of one wheel, so arranging them that the steam will pass through and actuate the three rows in the same manner as though each row was supported by its own individual wheel; by so doing we are enabled to reduce the weight of the rotor and produce one which can not under any conditions distort or run out of alignment, and at the same time reduce the steam friction losses to a minimum as well as economize length parallel to the shaft.

The buckets should be the next item for our consideration.

At one time the Curtis turbine buckets were cut by special machinery, in some cases from the periphery of the wheel of steel casting, in others in the outer circumference of a ring of steel casting the outer diameter of which corresponded to the diameter of the wheel to which it was ultimately to be secured.

Some eight or more years of experience however, has developed the fact that under certain wet steam conditions, slight steam wear has become apparent; it was therefore decided some years ago to use compositions

* The calculations in this article are theoretical and disregard friction, losses due to angle of nozzles, etc., etc.—*Editor*

for all buckets. The buckets are dovetailed in corresponding slots machined into the peripheries of the steel wheel or wheels, the other ends of the buckets being secured to a shrouding by riveting over bosses which are provided on the ends of the buckets.

This results in a bucket construction practically impervious to the action of any quality of steam and one well insured against mechanical injury. Its staunch characteristics are evidenced by the satisfactory operation of over two million horse-power capacity of these machines in commercial service, their installation extending over a period of some eight years.

A row of intermediate or redirecting buckets secured to the shell of the machine is installed between each two rows of moving buckets. These intermediates are exact counterparts of the moving buckets, but their curvature is in the opposite direction from that of the moving buckets.

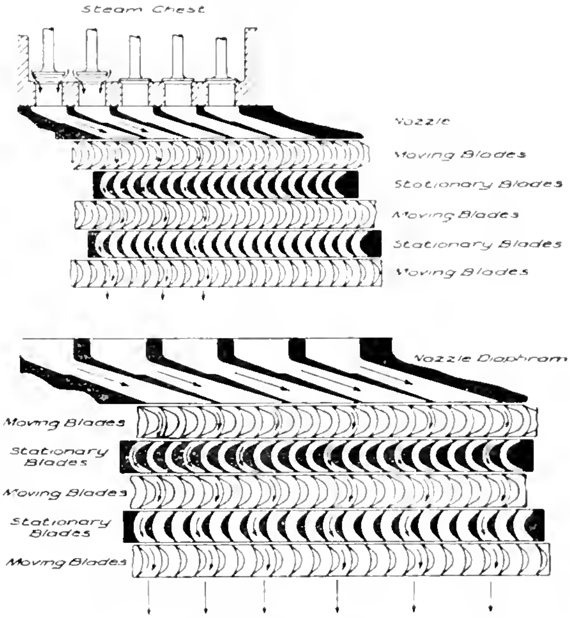
Like the moving buckets, these intermediates are securely shrouded, and as their only province is to redirect the steam delivered to them by the preceding row of moving buckets and deliver it in its original direction to the succeeding row of moving buckets, they only extend around that part of the periphery of the machine covered by the steam belt, which, as previously stated in the machine under discussion, is only about one-sixth of its periphery; the remainder of the periphery is left entirely open.

The following diagram will enable me to call to your notice perhaps more clearly some of the characteristics in connection with the bucket shape and the steam action on them.

At the upper left-hand corner several expanding nozzles are represented, designed to deliver the steam to the buckets, expanding it in its passage through the nozzle from 150 pounds to atmospheric pressure, thereby imparting to it the stated available velocity of 2655 feet per second.

It will be noticed that the angle of delivery or direction given by the nozzle to the steam, corresponds closely to the arc of the buckets, the first row of which the steam will easily enter without shock, excessive friction or sharp angular deflection.

In the case of the machine under consideration, the steam, on entering this row of buckets at a speed of 2655 feet per second, will give up energy to the buckets and lose velocity equal to twice the bucket velocity (twice 442.5 feet per second), actuating the buckets toward the right in proportion to the energy imparted. The steam following the path provided by the curvature of the buckets will leave them in the reverse direction at a speed of 2655 minus twice the



Arrangement of Expanding Nozzles and Movable and Stationary Buckets

bucket speed or $2655 - 885 = 1770$ feet per second.

The steam is next delivered to the first row of intermediates or redirecting buckets, secured to the shell of the machine and incapable of motion, and following the path provided by the curvature of these intermediates, is delivered to the second set of moving buckets with its original direction restored and without diminution of its velocity of 1770 feet per second.

You will notice that here again the direction given the steam by the intermediates permits of its easy unobstructed entrance to the moving buckets; these being secured to the same wheel as the first set must of necessity move at the same speed (442.5 feet). Here again the steam gives up energy to this row of buckets in proportion to twice the bucket velocity and leaves them at a speed of 1770 minus 885, or 885 feet per second. This second row of moving buckets delivers the steam to the second row of intermediates, which in turn delivers it to the third and last row of moving buckets at a speed of 885 feet per second. These buckets moving at the same speed as the others (442.5 feet or one-half the speed of the steam) abstract the remainder of the steam's velocity. Thus the steam has given up all its energy to the moving member.

One or two features of bucket design may be of interest. You will notice that the path provided for the steam is a gradual curve, presenting no sharp or sudden changes of direction, and that the path gradually increases in area as the velocity is being abstracted from the steam in its travel.

You will also notice that viewed in cross sections the distance between the center of the buckets is less than between the tips. The reason for this is that with steam traveling at a high velocity, on making the turn at the bucket center, it would be subjected to a compression, which, if this area were equal at all points, would result in effecting a partial vacuum on the front center of each bucket. As a result, eddy currents would develop in the steam and a portion would change its direction of flow, be drawn into this vacuum and run back into the incoming jet, thus impairing the efficiency. Thus, while the expansion of the steam is in no way dependent on the area between buckets (for which reason inequalities at this point are of less vital importance than in other types of turbines), it is still a matter worthy of very careful design to porportion this area exactly in accordance with the compression and still not contract the area to the extent of introducing friction, which would be so objectionable.

The short staunch bucket design with all buckets positively secured and prevented from changing position with relation to each other, is a prominent factor in the success of these machines.

It will be noticed by reference to the diagram, that since the finished buckets are narrower than the supporting material and the shrouding, they are absolutely protected from coming in contact with anything other than the actuating medium.

A description of the shell of this machine I have purposely left for the last, as in the single stage machine at least, this portion would be entirely unnecessary but for three comparatively unimportant functions:

1st. It serves as a convenient support for the intermediates and steam chest.

2d. It confines the exhaust steam and enables us to dispose of it conveniently.

3d. It prevents, to a certain extent, heat radiation and keeps drafts of air from distortint the steam flow through the buckets.

If it were not for these three relatively unimportant duties it might be omitted entirely, since the steam is expanded to atmospheric pressure before being delivered to the interior of the machine, and atmospheric pressure prevails throughout every part of the machine enclosed by the shell, the same pressure would exist if the shell were not present. I mention this to show more clearly that there is no necessity for packed joints or fine clearances in any direction in order to maintain designed efficiency.

This condition exists of course only in the Curtis turbine of the single pressure step or stage, non-condensing type, and would not apply to a multi-stage or single-stage condensing unit. The shell, therefore, of the unit under consideration is a simple cast iron casing designed to be easy of access and to conveniently and rigidly support the steam chest and intermediates to which they are securely bolted.

The foregoing, while referring more specifically to the twenty-five kilowatt horizontal non-condensing unit, is substantially descriptive—with the modifications with regard to pressure stages and velocity stages of the entire line of both horizontal and vertical turbines of the Curtis type.

While the efficiency was an item of extreme importance in the design of the Curtis turbine, reliability and simplicity were of paramount importance.

The appreciation of the limitations of the gas engine, the steam engine and the reaction turbine resulted in the development of a steam turbine with characteristics closely resembling the hydraulic turbine. This steam turbine is as simple and reliable as the hydraulic turbine, more efficient than the steam engine, and compares very favorably with the gas engine in this particular when all items which represent the expense of operation are considered.

The simplicity of the Curtis turbine is beyond dispute, as in this particular it is almost identical with the hydraulic turbine, which previous to the development of this type of steam turbine, stood alone as the simplest power producing prime mover.

As compared with the reciprocating steam or the explosive type of engine, the omission of cylinders, pistons, piston-rods, wrist-pins, cross-heads, guides, connecting-rods, cranks and crank-pins, as well as flywheels, offer sufficient excuse for the existence of the steam turbine; to say nothing of the fine adjustments necessary, due to the fact that, with the exception of the flywheel, sliding metallic contact exists between these parts during operation.

So much for the simplicity of the turbine. As regards its efficiency, it is superior to the reciprocating engine, especially after a period of service, for unlike the engine, which loses efficiency after service, the turbine does not deteriorate in this respect, even after long continued operation; a fact which is substantiated by the statement of Professor N. C. Carpenter, Professor of Steam Engineering, Cornell University, in his discussion of Mr. Orrok's paper (mentioned below). Professor Carpenter said that upon testing a 75 kw. Curtis turbine that had been in service some 7000 hours, the results were not materially different from those obtained on a new machine of the same capacity and design.

For an extended discussion of the relative efficiencies of the turbine and reciprocating engines, the reader is referred to the article by Mr. Richard H. Rice, which appeared in the April, 1909, issue of the REVIEW. A comparison of the efficiencies of the small Curtis turbine and turbines of other types is to be found in the paper by Mr. George A. Orrok, which appeared in the "Tansactions of the American Society of Mechanical Engineers," May, 1909. The deduction to be drawn from the paper of this unprejudiced author, is that the Curtis turbine, in point of efficiency, is so superior as to be in a class by itself.

COMMERCIAL ELECTRICAL TESTING

PART XIV

BY E. F. COLLINS

TRANSFORMERS—(Cont'd)

Efficiency Tests

The efficiency of a transformer is the ratio of its net power output to its gross power input, the output being delivered to a non-inductive circuit. The power input includes the output together with the losses, which are as follows: (1) The core loss, which is determined by the core loss test at rated frequency and voltage, and (2) the I^2R loss of the primary and the secondary calculated from their resistances. As the losses in the transformer are affected by temperature and the wave form of the e.m.f., the efficiency can be accurately specified only by reference to some definite temperature, such as 25° C., and by stating whether the e.m.f. wave is sinusoidal or otherwise. The formula for efficiency may be written:

Per cent efficiency

$$= \frac{\text{output}}{\text{output} + \text{core loss} + I^2R \text{ loss}}$$

Regulation Tests

In transformers the regulation is the ratio of the rise of secondary terminal voltage from full load to no load (at constant primary impressed terminal voltage) to the secondary full load voltage. Regulation may be determined by loading the transformers and observing the rise in secondary voltage when the load is thrown off. This method is not satisfactory on account of the expense of making the test and the small difference between no load and full load secondary voltages. Much greater reliance can be placed on results calculated from separate measurements of reactance drop, resistance and magnetizing current, than on actual measurement of regulation. The following method is used by the General Electric Company:

Let IR = total resistance drop in the transformer expressed in per cent of rated secondary voltage.

IX = reactance drop similarly expressed.

P = proportion of energy current in load, or the power factor of the load. Non-inductive load, $P = 1$.

W = wattless factor of primary current. (With non-inductive load, W = magnetizing current expressed as a decimal fraction of full load current; with inductive load, W = wattless component of load plus magnetizing current.)

Secondary full load voltage = 100 per cent.

Secondary no load voltage = E.

For non-inductive load

$$E = \sqrt{(100 + IR + W\,IX)^2 + (IX)^2}$$

For inductive load

$$E = \sqrt{(100 + PIR + WIX)^2 + (PIX - WIR)^2}$$

In each of these equations, the last expression within brackets represents the drop "in quadrature."

The reactance drop expressed in per cent

$$IX = \sqrt{(\text{per cent impedance drop})^2 - (IR)^2}$$

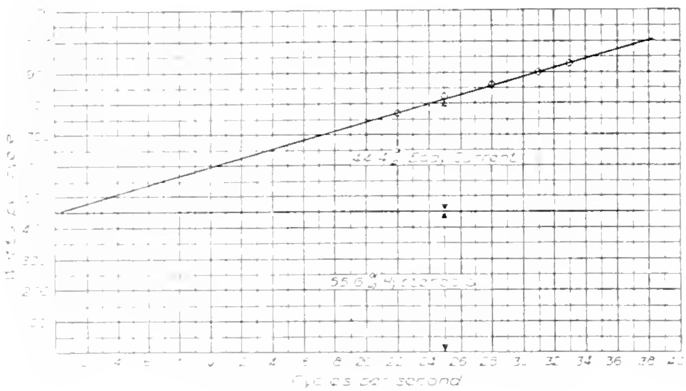


Fig. 63. Separation Curve

The magnetizing current

$$= \sqrt{(\text{exciting current})^2 - \left(\frac{\text{core loss}}{\text{voltage}}\right)^2}$$

Special Engineering Tests

The separation of the core loss from copper loss may be considered as a special test on constant potential transformers. The core loss of a transformer consists of hysteresis and eddy current losses. The hysteresis loss is that due to cyclic reversals of the magnetism of the core, its value depending on the quality of the iron, and in a given transformer varies directly as the frequency and as the 1.6 power of the magnetic density. Eddy current loss is due to electric currents flowing in the iron, and varies with the conductivity of the iron, the thickness of the laminations, and the square of the frequency.

The method for separating the losses is as follows: Since the hysteresis loss varies directly as the frequency and the eddy current loss as the square of the frequency, by maintaining a given density in the core and varying the frequency, data can be obtained from which a separation curve can be plotted. The voltage to be applied varies directly with the frequency at which it is applied; thus 100 volts at 60 cycles becomes 200 volts at 120 cycles. Plotting watts per cycle as ordinates and cycles per second as abscissæ, curves similar to those shown in Fig. 63 are obtained. At least four points should be taken to determine the curve. By comparing the losses at normal frequency and density, the quality of the iron and the insulation between laminations can be deduced.

The eddy current loss in the copper conductors of a transformer may be separated from the ohmic loss in the following manner: The ohmic loss is independent of frequency, while the eddy current loss varies with the square of the frequency. Hold the current constant and take readings of watts, volts and speed while varying the frequency. Plot watts loss as ordinates and cycles per second as abscissæ, and project the curve back to the zero line. At zero frequency, the total loss will represent the true ohmic loss or I^2R. (See Fig. 64.)

In very exceptional cases, short circuit tests are taken on transformers to determine their behavior in case they are accidentally short circuited in service. This test is obtained by connecting one winding of the transformer to the power source, which should be of four or five times the capacity of the transformer, and short circuiting the other windings. The tendency of the ends of the coils to flare

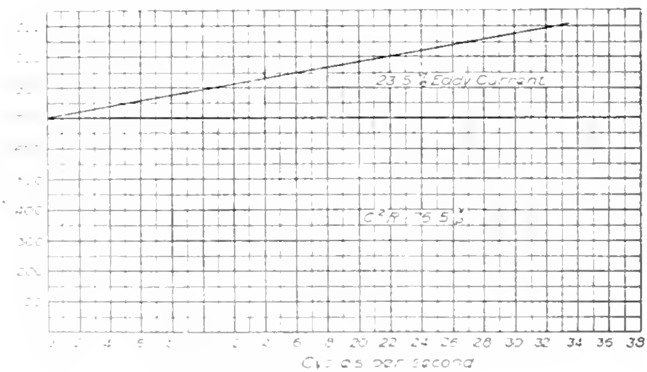


Fig. 64. Separation Curve

out due to the excessive magnetic repulsion is the important point in this test. The test should be short, as the current is from 15 to 30 times normal.

SERIES TRANSFORMERS

Series transformers designed to supply current for operating meters and relays are generally tested in groups of ten to twenty at a time. The tests made are: Cold resistance on the secondary winding (one out of every five), polarity, ratio, heat run and insulation. To test the insulation between layers, the transformers are run for one minute at full load primary current with the secondary open. The primary and secondary windings must be carefully distinguished. In series transformers the winding that is to be connected in series with the circuit is called the primary, and the primary leads are nearly always brought out through much larger bushings than the secondary leads.

Cold Resistance

When several transformers are tested at the same time, a measurement of cold resistance on the secondaries need only be taken on about one-fifth of the transformers in the group. The primary resistance is too low to be measured accurately, and this test is usually omitted. The same precautions must be observed on these transformers as on large transformers.

Polarity

Polarity should be carefully taken. If the polarity is not correct, trouble will be experienced in making connections for polyphase meter circuits.

Ratio

Instead of actually determining the ratio, the transformers are checked with a standard. The one selected as standard must be sent to the standardizing laboratory to be care-

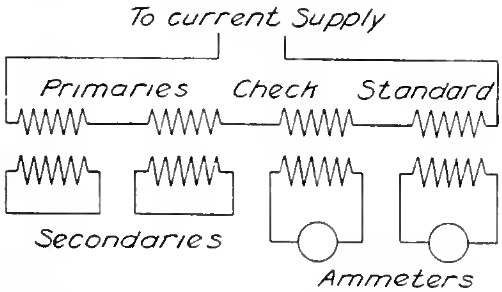


Fig. 65. Connections for Ratio in Series Transformer

fully checked for ratio at proper load and frequency. Having selected one of the group as a standard, connect the primaries of all the transformers in series. Short circuit all the secondaries as shown in Fig. 65; then connect the ammeter to the secondaries of the standard and check the transformer. This connection must be made with lamp cord or other suitable wire, and must be sufficiently long to allow the ammeter to be at least ten feet from the primary circuit in order to avoid the effects of stray field. Check the reading of the ammeter connected to the standard by means of another ammeter, bring the current up to normal and note the reading of the check ammeter. Now transfer the ammeter on the standard to another transformer and bring the current up to the reading previously noted or the check ammeter. When correct, read the ammeter on the transformer in test; if this reading agrees with the reading when the ammeter was on the standard the ratio is correct. Proceed in this manner until all the transformers have been checked with the standard.

New check readings are often necessary, due to unequal heating of meters and lines. Ratios should check within one per cent. Keep all secondaries short circuited except those to which the meters are connected. A few transformers of this type are built with two sets of windings; these should be tested as though they were two separate transformers.

Heat Run

On a new design of transformer a heat run should be made at normal primary current with the secondary short circuited until constant temperature is reached. Temperature rise by resistance should be taken hourly on one transformer out of every five, and thermometer temperatures on each one. When constant temperatures are reached, the transformer should run for two hours at the thirty minute load, which will be found stamped on the name plate. On transformers that are duplicates of some that have been previously built, a two hour heat run at the thirty minute load is sufficient. Measure hot resistances on one out of five and take thermometer temperatures on all. They should then be run for one minute at the thirty minute load with the secondary open to test the insulation between turns and between layers. This corresponds to the double potential test on other transformers

The high potential test may be taken on several transformers at the same time. See that all secondaries and cases are properly connected together. Series transformers used in connection with potential regulators have the same characteristics as constant potential transformers and are tested as such.

(To be Continued)

NOTES ON ELECTRIC LIGHTING

Part III

By Caryl D. Haskins

Manager Lighting Department, General Electric Company

We have now reached the third stage in our electric lighting problem—we must distribute our product. Not many years ago the distribution of electric current was the simplest, least technical, and least considered branch of the work of the central station engineer. This is no longer true. The problems of distribution—the opportunities for saving or loss in a good or bad system and the possibilities of increased dividends by a betterment of distribution—have been sharply accentuated.

The problems involved in distribution are many and, as a class, belong in a large measure to those which are often best solved by men who have come up from the bottom. The direct current system of distribution was, of course, the earliest phase of the situation and the simplest. Superficially, direct current distribution involved no technical questions; it was the lineman's problem. Soon, however, direct current practice tended toward underground work and became less simple.

Direct current service went underground first because it was early found to be suited to dense territories only—territories which did not lend themselves well to overhead wiring. To be sure, ten years ago many if not all large cities had a very high percentage of overhead wiring, but fire safety and estheticism speedily combined to put the wires under the surface. Incidentally, the telephone and telegraph wires were forced underground at about the same time.

The national decision that dense city wiring had to go underground brought the engineer face to face with new and serious wiring problems—mechanical as well as electrical problems, very difficult to solve in the light of the then existing knowledge. Much of the early history of underground practice was a history of mishaps, but rapid improvement in the art and a close study of its difficulties by a large number of men, many of whom made a specialty of this particular phase of the situation, largely overcame many of the problems. This underground work developed a new class of electrical engineers—engineers who of necessity possessed a precise knowledge of advanced chemistry.

The Edison three-wire system is the basis of all important current distributions for lighting, but long before this system was introduced, the so-called "Edison ring" system had been developed. The "ring" system effected no material saving in copper, but made a decided improvement in regulation. This was, perhaps, the earliest and simplest form of the multiple feeder system, in which the current might feed in either direction, according to the character of the load. The Edison three-wire system was the first to go underground in long sections, and the first satisfactory form of underground conductor was the so-called "Edison tube;" probably you are all familiar with it. It consisted of iron pipe within which the conductors were placed, solidly surrounded by a non-conducting compound. This compound changed with the advance of the art, but the construction used was too satisfactory to be speedily altered. The joining of the pipe was naturally a difficult matter and in the earlier days the joints were liable to failure and breakdown—a difficulty which yielded only to improvements resulting from experience.

One of the greatest difficulties in early underground work, a difficulty which occurred on lighting systems but to an even greater extent on railway circuits, was that of electrolysis. Dealing as we were in the earlier days with direct current, the grounding of circuits and the consequent tendency of current to go "crosslots" caused deterioration and ultimate breaking up of gas and water pipes by electric decomposition. This was at one time a very serious and alarming situation in many of our larger cities. Today we are practically free from this difficulty as a result of better insulation and construction. I specifically remember in one of our larger cities, not so very many years ago, a difference of potential of fifteen volts between gas and water pipes in the same cellar, a phenomenon of "homeless" current. I recall also an instance of a dishonest but ingenious person who operated a fractional horse-power motor between water and gas pipes. Some one paid for the current he used, but it was not he.

As I have already stated, the greater part of the troubles caused by electrolysis was due, not to electric lighting service, but rather to street railway service; in fact, it was owing to poor bonding of the rails, in consequence of which the rail current, with no low resistance return path, split up into devious crosslot paths through pipes and water.

Good modern practice tends toward underground service for both direct current and alternating current, through lead covered cable. This is the standard construction today for underground work. There is little need of going into the construction of lead covered cable; you are all familiar with it and know its many advantages. It stands well against disintegration, it is proof against constant immersion in water, and a tight "wiped" joint is easily and quickly made. Remember that the Romans could wipe a joint quite as well as we do today. For all these reasons and many more, leaded cables stand out practically ideal for most if not all underground service. Great lengths of leaded cable are today put down in open trenches, it being only necessary to place it far enough underground to insure adequate mechanical protection. The wiring in Central Park, New York City, which was very nearly completed when winter set in last year and to which approximately 1500 street lamps had been connected, is all underground, the cable being simply laid in trenches and given no further protection than the soil above it.

For street work, conduit has numerous advantages. With this construction it is customary to put down enough ducts to care for the requirements of years to come; the conductors being drawn in as more circuits are needed. In working with lead covered cable, it is feasible and usual today to trench and lay sufficient cable to take care of present needs, but repeated trenching for cable additions is both costly and inexpedient. Cable laying through manholes and conduit has been brought to a highly perfected state and a gang of five or six men will lay a surprising amount of cable in one day. As you probably know, the work has been commonly done by means of a drawing-in wire laid with the conduit. Lately there is a tendency to do away with this wire and most of the cable laying in certain large cities is done by sending a weasel (with a string) through the conduits after an imaginary rat. This is good practice; one may even say good engineering.

In the earlier days lines were run out, each independent of the other. In some of the larger cities we used to hear of the "Front street line," the "Smith street line," the "Market street line," etc. Each was entirely independent; today both alternating and direct current systems commonly have all lines and feeders tied together. They are, however, sectionalized and can be broken apart whenever occasion demands it. The average modern system stands as one big meshwork, with the net result that regulation is easy as compared with the early practice of separate lines, each with its separate load conditions.

Before going further, I have one more word to say about electrolysis. Electrolysis, quite aside from the waste of current, is very destructive of underground piping, with the result that this property of gas and water companies was, at some points in some cities, seriously impaired in a brief time. Serious accidents, directly attributable to electrolysis of gas and water pipes, occurred on several occasions. I recall one very serious accident in one of our large cities some years ago where electrolysis opened a gas pipe and a heavy leak followed. The leaking gas had pocketed in a large recess in some structural work and was ignited by a spark. A terrific explosion resulted; two street cars were blown up and five or six people killed or injured. Electrolysis is, in fact, replete with danger if proper engineering steps are lacking to safeguard against it.

Alternating as well as direct current lines must, of course, go underground in the very dense sections of large cities, for exactly the same reasons as those already given. In some cases even the transformers for stepping the voltage down to the requirements of house to house service are likewise placed underground in manholes. This practice is likely to grow more common with city growth. It is already common practice among the lighting systems of Europe, and is rapidly becoming so in the United States.

Alternating current is generally distributed on secondary circuits at about the same potential as direct current, and the wiring in dense districts is also tied together in a meshwork. It is common practice to bank transformers at the most efficient center of distribution, according to the distribution of the load. In good practice, the operating company of alternating current meshworks maintains curve drawing meters on the system, for the purpose of keeping a record of the voltage fluctuations under various conditions of load. The distribution of transformers and the arrangement of the secondary meshwork can and should be accurately determined from these records, and altered from time to time to suit the progressive change of conditions.

Recording voltmeters distributed over the secondary system indicate just what the voltage fluctuations are, and the transformers can be moved from center to center to maintain a balanced condition for the average load.

It must be borne in mind that long distance alternating current lines, and even short distance overhead lines, are liable to much disarrangement due to lightning discharges and other static disturbances. No such difficulty obtains, to any appreciable degree at least, in underground service. Where underground and overhead alternating current lines are in series with each other, this difficulty does occur and is probably somewhat accentuated. Where underground cable is brought into a central power station, as is common in large towns, the static charge, due either to the static induction of the system itself or to occasional static charges from atmospherical disturbances, makes necessary the installation of devices for the protection of apparatus and appliances within the power house. Today, almost all incoming cables in power houses are provided with "bell ends" on the lead jacket to safeguard both the cable itself and the station equipment from static discharge which otherwise might establish, and indeed often has established a breakdown "short" on the system.

Probably ninety-five per cent of the wiring that is employed in this country today for lighting and power purposes transmits energy in the form of alternating current. This alternating current line work varies all the way from lines of two or three No. 6 wires in the extreme rural districts, to the cables borne on the enormous steel tower constructions of the great long distance transmissions. The rural lines interest because it is through such lines that we are to take light and power to those 15,000,000 people already referred to.

The cost of these lines is an important controlling factor in the extension problem and varies enormously in different sections of the country and under different physical conditions. I know of lines well built lines, thirty foot poles (perhaps a little too short), forty-five poles to the mile (which is fair rural spacing) where the construction has been carried out, exclusive of the wiring, for \$450 to \$500 per mile. Such lines carry relatively low alternating current potentials, up to say 6600 volts. Above 6600 volts the cost goes up rather rapidly because of the cost of insulation. There exist, however, other somewhat similar lines carrying no more energy, but built in outlying territories under entirely different conditions at very a much higher cost; a cost which would be prohibitive for other than the suburban sections of large cities. In our larger cities, the cost of such work is probably about \$1500 to \$1800 per mile. There can be no doubt, of course, that from a purely engineering standpoint these "near city" lines are very much better constructed than the rural lines just referred to, but beyond a certain point it is a difficult matter to improve construction at a justifiable cost: a betterment of one per cent, for instance, beyond a certain stage, can not be obtained except at an increased cost of a much higher ratio.

Experience counts for much in line work. For example, no one can learn anything about setting poles from text books; in fact, one does not begin to learn very much about it by doing the work for six months or so. Many poles are today set in concrete, and in many soils this is not only good but economical practice. For example, with concrete the average hole does not have to be dug so deep, yet the pole is firmer. It may be pertinent to here give you a little "wrinkle" which has come to my notice in connection with pole setting in concrete. Instead of using broken stone, use cinders from the power station. This does not make as good a concrete for ordinary purposes, but for pole setting it is better, for, without other sacrifice, it has the advantage of materially lessening the labor and reducing the time necessary to break the poles out when this becomes necessary.

For the sake of estimate making, it may be assumed that the average cost of construction of alternating current lines in this country today, that is, lines of three wires, is probably about \$750 to \$800 per mile.

One of the most difficult problems for the electrical engineer to solve in connection with central station practice, is to determine what will be the cost, in relation to derivable revenue, of running an extension from the end of this sysem to some small community desiring service. There are a dozen or more such communities within twenty miles of most electrically served towns today crying for electric service, but the cost of running lines to them is high, and is commonly regarded as larger than the returns will warrant. This is one of the detail studies of the electric lighting industry which has as yet been gravely neglected. The engineers of the Pacific coast, however, are doing all sorts of things along this line: things which few eastern engineers would think of attempting. I know of one engineer of high standing in the far West who is operating a very large system and who has some hundreds of miles of power transmission under his supervision. I asked this engineer to how small a community he would go from his main line over a distance of say two miles. His answer was startling. He said, "It doesn't have to be a community; I never let any farmer within two miles escape me." His power is water-power, and he has more power than he needs for the present. He has capacity to spare, and it is his doctrine, probably a sound one, that his system can afford to take individual losses for the sake of upbuilding the system as a whole; in short, this man believes in the saying that, "where the wires go the load will grow," and it must be said that the history of his system justifies his faith.

(To be continued)

THE UNION BAG AND PAPER COMPANY, HUDSON FALLS, N.Y.

By John Liston

The group of paper mills operated by this company constitutes an important factor in the paper industry of the United States, as they have a combined production of 370 tons of paper per twenty-four hours. There are eight mills in the group, distributed as follows: One at Hadley, N. Y., three at Ballston Spa, N. Y., and four on the banks of the Hudson River, at Hudson Falls, N. Y., the location of the latter group being indicated by the accompanying chart.

The mills at Hudson Falls produce bags and Manila paper, and use both ground wood and sulphite, the total production of this group amounting to approximately 265 tons of finished paper per twenty-four hours.

In addition to the pulp and mill buildings the company operates a paper bag factory at Hudson Falls, which consumes practically the entire product of the mills.

The main forest preserves are located in Canada and in the Adirondacks, the wood being shipped from Canada by boat through Lake Champlain to Whitehall, from which point it is carried by rail to the wood yards at Hudson Falls. The timber from the Adirondack preserves is floated down stream to a saw mill located about 100 yards north of pulp mill No. 2, as shown in the chart.

The present company was organized in 1899, and thereafter acquired the various mill buildings which constitute the present Hudson Falls group. The machinery in these buildings was originally driven by water power supplemented by steam engines, but at present the water power is used largely for the generation of electric current, 71 motors having an aggregate horse-power of 4000 being employed for driving practically all the auxiliary machinery. The grinders,

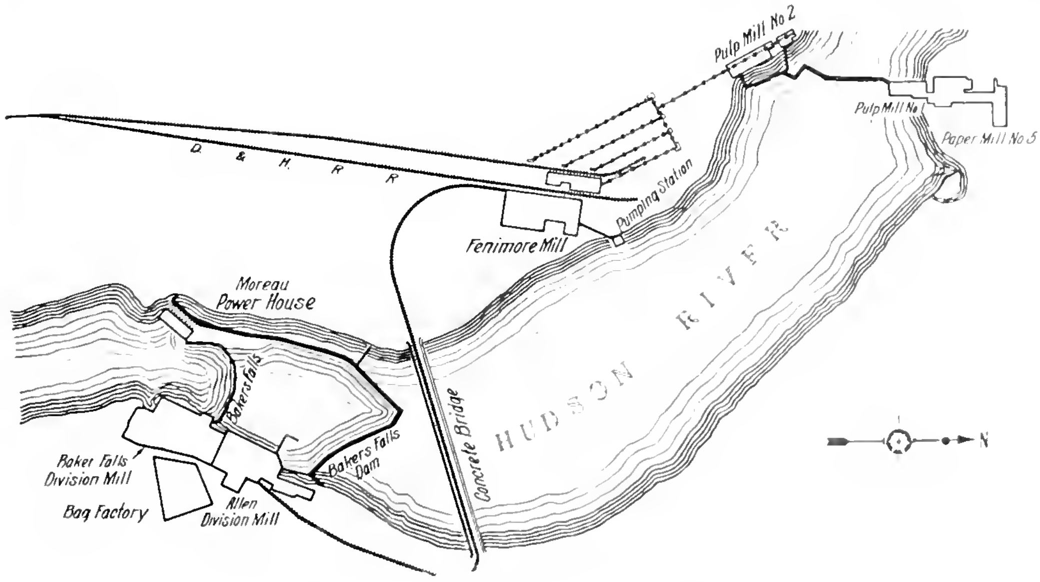


Fig. 1. Map Showing Arrangement of Buildings of Union Bag and Paper Company

however, are waterwheel-driven and one of the paper machines is driven by a steam engines, while others utilize motor drive.

Fig. 2. 175 H.P. Induction Motor in Beater Room Allen Division Mill

At this point the Hudson River affords excellent water power facilities, as there is available at Bakers Falls an effective head of 58 feet, and in 1901 the first hydro-electric development was undertaken. This comprised an equipment of three 750 kw., 6600 volt, three-phase, 40 cycle generators connected to three 1200 h.p. Morgan & Smith double runner water turbines (Fig. 3). The exciters are direct connected. The effective head was obtained by means of a horse-shoe shaped crib dam thrown across the river just above Bakers Falls.

As the demands of the electric service increased it was decided to construct a second power station, which was erected on the opposite bank of the river and is known as the Moreau Station. A concrete canal was extended from the crib dam already referred to, and provision was made for the installation of five 2000 kw. generators, with separate penstocks for the operation of two exciters. The effective head in this station is also fifty-eight feet.

At the present time a single 2000 kw., 6600 volt, three-phase, 40 cycle generator direct connected to a double runner Hercules turbine, has been installed; a 150 kw., 125 volt exciter being separately driven by an 18 inch single runner turbine. This generator unit is shown on page 530. The available water at this point is ordinarily sufficient to supply the power demands of the plant, but in order to insure uninterrupted electric service in the event of low water or injury to any of the units in the hydro-electric station an auxiliary generator outfit has been installed in the Fenimore mill. This reserve equipment (Fig. 4) consists of a 1000 kw., 550 volt, three-phase, 40 cycle generator direct driven by a Hamilton-Corliss engine and provided with a belt connected exciter. An air blast

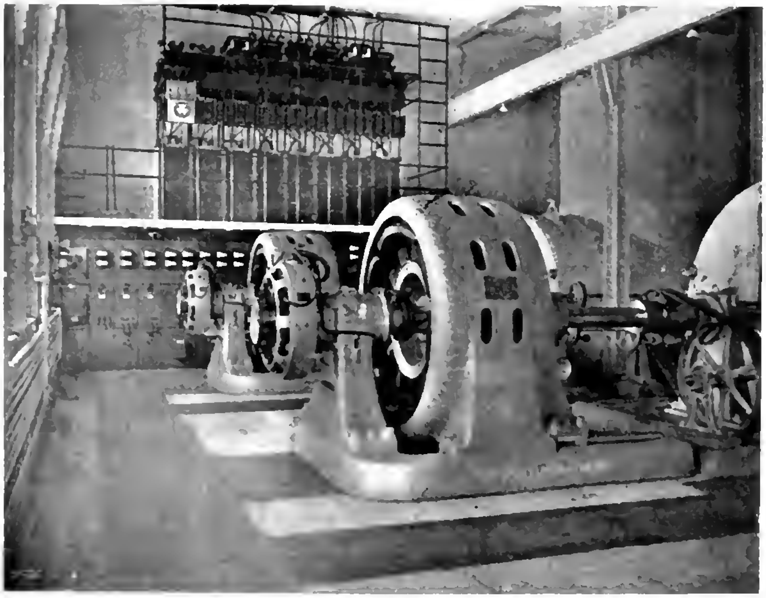


Fig. 3. Two of the Three 750 Kw. Waterwheel Driven Generators in the Bakers Falls Power House

transformer of 1100 kw. capacity is used to step up the potential to 6600 volts, so that the current from the Fenimore power station may be switched onto the mill bus-bars and the reserve generator operated in multiple with either hydro-electric plant. The generators and exciters in all three power stations are of General Electric manufacture, and the type of air blast transformer installed in both the Fenimore and Bakers Falls power station is shown in Fig. 5. It consists of a three-phase Type AB transformer mounted over an air chamber, to which pressure is supplied by means of duplicate rotary blowers direct driven by 2 h.p. motors, one blower being held as a reserve.

The extent to which electric drive is employed in these mills is indicated by the following description:

All the motors used to operate the machinery of the sawmill, paper mills and bag factory operate on 550 volt, three-phase, 40 cycle circuits, the General Electric induction motor having been adopted as a standard throughout.

In the saw mill, which is located some distance up stream from the mill buildings, all the machinery, consisting of two 65 inch circular saws, an air compressor for the log kickers, and a chain log conveyor, is driven in a group by a 400 h.p. motor. Current for these motors is transmitted to the saw mill at 6600 volts, and stepped down through transformers to the motor voltage.

Connecting the saw mill with pulp mill No. 2 are two wood conveyors, each of which has two branches driven by a 50 h.p. motor. The wood conveyor system is clearly indicated in the chart of Fig. 1, and for the various sections two 50 h.p., one 75 h.p. and one 20 h.p. motors are used.

When wood is received by rail it is rapidly unloaded into hoppers at the foot of the wood piles, and piled by means of extendable "butterfly" conveyors. These conveyors were especially designed by the engineers of the Union Bag & Paper Company and are motor-operated. They consist of a chain conveyor which starts from the hoppers already referred to and piles the wood rapidly as it is unloaded from the cars. Two of these equipments are used, both being operated by 15 h.p. motors inclosed in a small house at the top of the conveyors. When the wood pile has reached a height which limits the further operation of the conveyor, the

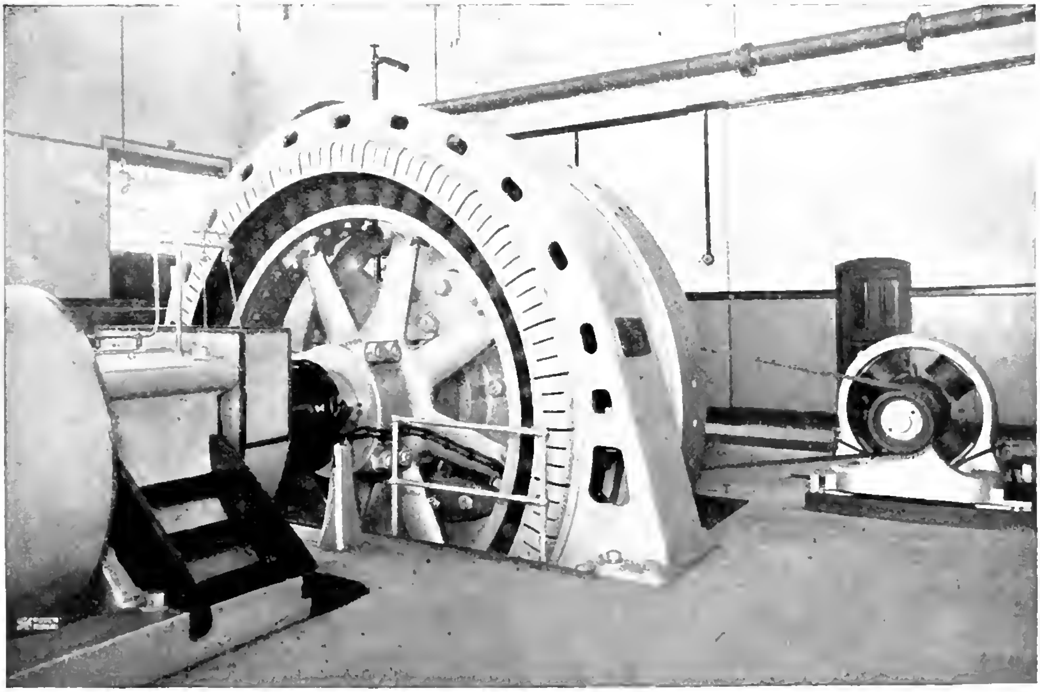


Fig. 4. 1000 Kw. 550 Volt Three-Phase 40 Cycle Engine-Driven Generator with Belted Exciter, Fenimore Mill

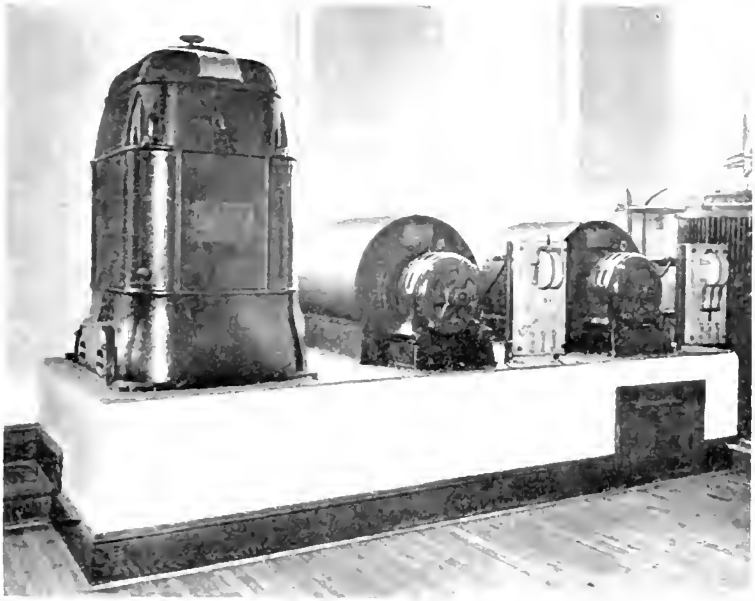


Fig. 5. 300 Kw. 6600/2300 Volt Air Blast Transformer with Duplicate Blower Outfit, Bakers Falls Power House

motor house is moved to the highest point on the pile and the conveyor lengthened by the addition of a sufficient number of chain links to give the required extension. By means of these butterfly conveyors the cars can be unloaded and the wood piled with a minimum of manual labor, and the wood pile carried to a much greater height than would ordinarily be economical. Both conveyors are provided with flaming arc lamps, so that operations can be carried on with equal efficiency day or night.

For conveying the wood from the piles to the wood room a motor-driven portable unloading conveyor is used, consisting of a 15 h.p., 1200 r.p.m. motor installed on a small truck running on rails set parallel to the wood piles. The conveyor can thus take wood rapidly from any section of the pile and transfer it to the main conveyor, which carries it to the wood room of the mills.

The main grinder stations at Hudson Falls consist of two pulp mills located at the ends of a dam which gives an effective head of twelve feet. Pulp mill No. 1 is located on the east bank of the river and is provided with four grinders, each being driven by a 56 inch vertical waterwheel. Water power is also used for the operation of the screen room and wet machines. The product of this mill goes directly to an adjacent paper mill (No. 5), in which a 66 inch waterwheel is used for driving four beaters. A 112 inch paper machine, steam engine-driven, is also located here.

Pulp mill No. 2 is located on the west bank of the river and is provided with eight grinders, each driven by a 56 inch vertical waterwheel, while an additional wheel of 48 in. diameter is used for the operation of five wet machines.

Immediately south of pulp mill No. 2 is located the Fenimore mill, which produce all the sulphite required for the group of mills

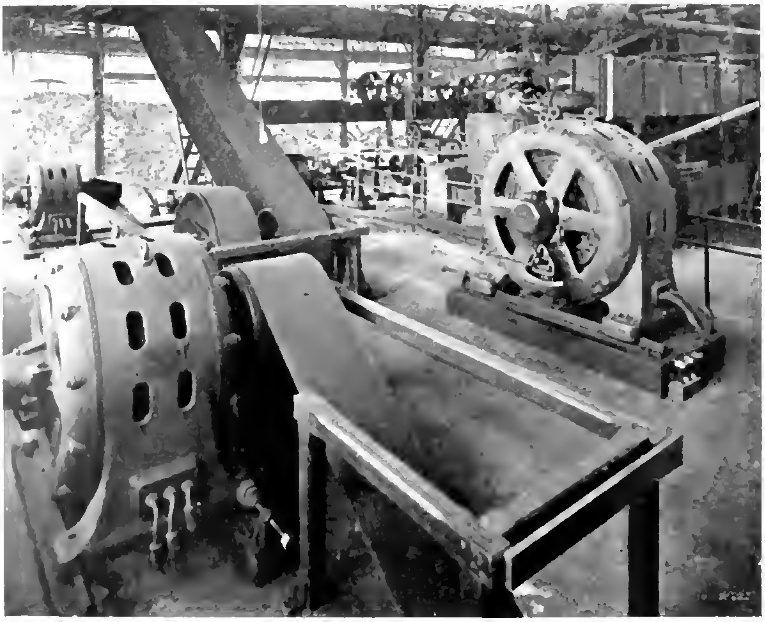


Fig. 6. 250 H.P. Motor Driving Eleven Centrifugal Screens, 75 H.P. Motor Driving Six Wet Presses and 150 H.P. Motor Driving Two 16 in. Centrifugal Stock Pumps, Fenimore Mill

at Hudson Falls. In the wood room a 200 h.p. motor drives two chippers, twelve barkers and a shavings conveyor, while a 150 h.p. motor, located in the basement, drives a splitter, shaving screen and a conveyor for carrying the shavings to the boiler house.

The conveyor for carrying the chips to the charging floor of the digester house is operated by a 30 h.p. motor, which also drives the exhaust fan for the digester house. Four digesters, 15 ft. by 49 ft., are used and for this reason a small passenger elevator is installed, being operated by a 5 h.p. motor.

The manufacture of acid is carried on in a separate tower constructed of brick; the electrical equipment consisting of a 10 h.p. elevator for conveying raw material to the charging floors, a 10 h.p. motor driving a draft fan for the sulphite burners, and two 15 h.p. motors which are direct connected to centrifugal acid pumps.

Water for the various processes in this mill is supplied by a pumping station located at the river's edge, as indicated in Fig. 1, and containing four triplex pumps and one 6 in. centrifugal pump, all driven by a 150 h.p. motor.

In the sulphite mill eleven screens are driven in a group by a 250 h.p. motor, while a 75 h.p. motor operates eight wet presses and a 150 h.p. motor two 16 inch centrifugal stock pumps, as shown in Fig. 6. These three motors are installed in a compact group, each one provided with a separate controlling panel. The stock is conveyed from the blow pits to the stock tank by means of a pump driven by a 85 h.p. motor.

Between the mill buildings and river bank two artesian wells have been sunk for auxiliary water supply, the air compressor and pumps for these wells being driven by a 40 h.p. motor.

The boiler equipment of this plant, in addition to furnishing steam for the digesters, is used for the operation of the reserve 1000 kw. steam generating outfit already referred to. Motor drive has been adopted for the boiler house, and a coal and an ash conveyor are each driven by a 10 h.p. motor. In the machine shop a 50 h.p. motor drives the entire equipment through shafting.

In order to facilitate the delivery of sulphite to other mills of the group, an industrial electric railway has been provided, crossing the river on a concrete arch bridge which, at the time of its construction in 1907, was the largest bridge of its type in the world. The motor cars for this railway consist of two street railway outfits which have been converted for the service. They operate on a 500 volt direct current circuit, current for which is supplied by a motor-generator set consisting of a 60 h.p. motor belt connected to a 400 kw. direct current generator, the set being located in the wood room of the Allen Division mills on the east bank of the river.

The group of mill buildings known as the Allen Division was originally designed for waterwheel and steam drive, and water power is still used for operating the grinders and screens in the Allen pulp mill. One 54 inch waterwheel, which formerly operated three Jordans, is now held in reserve, having been replaced by a 200 h.p. motor. The six paper machines included in the mill equipment are all motor-driven, three of them by a 250 h.p. motor and the remaining three by a 175 h.p. motor. This latter equipment replaces two steam engines which are now held as a reserve. One of these small paper machines is run at constant speed throughout, while the speed variation at the finishing end of the other two is obtained by means of a cone speed changing device on one, and a Reeves drive on the other.

In an electrically-operated mill it is possible to eliminate all mechanical means of securing the required variation at the finishing end of a paper machine, either by providing a motor-generator set and operating the finishing end by a direct current motor, or by adopting the type of variable speed induction motor which has been developed by the General Electric Company for this class of work.

In the beater room one 1200 lb. and three 850 lb. beaters and two mixers are group-driven by a 175 h.p. motor, while a 30 h.p. motor drives the elevator and cutting room machinery. A 17 h.p. motor is used for driving some minor special machines.

The last group of paper mills is known as the Bakers Falls division and is located immediately south of the Allen division; and, like the former, was originally steam- and waterwheel-driven. Some of the buildings in this group are very old, but electric drive has been as successfully adopted in their case as in the newer mills.

In the beater room a group of seven beaters and one Jordan is driven by a 250 h.p. motor, while a second group of four beaters and one Jordan is driven by 175 h.p. motor; this latter equipment being shown in

Fig. 2. Still a third group consisting of three beaters and one Jordan is driven by two 100 h.p. motors mounted side by side and belt connected to a common driving shaft. There is also a 30 h.p. motor used to drive a broke mixer.

All the paper machines in this division are motor-driven at constant speed. There are three 68 inch paper machines, driven respectively by two 50 h.p and one 60 h.p. motor, and two 59 inch paper machines, one driven by a 60 h.p. motor and the other by an 85 h.p. motor.

In the boiler house of the Bakers Falls division a 20 h.p. motor operates a draft fan and feed water pump, while various water pumps are driven by a 100 h.p. motor. The machine shop is group-driven by a 40 h.p. motor.

To the east of the Allen and Bakers Falls mills there is located the bag factory of the company, which utilizes a large percentage of the product of the mills in the manufacture of paper bags. This factory is equipped throughout with motor drive, current being taken from the circuits which serve the paper mills. The group systems of motor drive has been adopted for automatic bag machines, printing presses, embossing machines, cutters and finishing room machinery.

The entire electrical equipment at Hudson Falls is a good example of the adaptability of motor drive for mills which were originally designed for mechanical drive, and it

Fig. 7. General View of Bag Factory, Allen Division and Bakers Falls Paper Mills

ALLEN DIVISION MILLS

H.P.	R.P.M	Service	Location
60	800	Motor-generator set for industrial railway .	Wood Room
10	1200	Elevator	Store Room
30	800	$6\frac{1}{2}$ in. x 8 in. Gould triplex water pump . .	
200	480	Two Jordans	
250	480	Three paper machines (44 in., 64 in., 66 in.)	
175	600	Three paper machines, three 6 in. centrifugal pumps, three 7 in. x 10 in. triplex stock pumps, one 12 in. x 10 in. vacuum pump, one 12 in. x 12 in. duplex vacuum pump, three screens, three agitators	
175	600	One 1200 lb. beater, three 850 lb. beaters, two mixers	
1	1600	Forge blower	Machine Shop
30	800	One roll grinder, one rewinder, two paper cutters, one fan, two size mixers	Cutter Room

BAKERS FALLS DIVISION MILLS

H.P.	R.P.M.	Service	Service
50	800	One paper machine (size 88 in.)	No. 1 Mill
30	800	Stock pumps for machine, chest, screens and agitators, two stock chests, machine striper, rewinder and header in finishing room, elevator	
30	800	Broke mixer	
*100	400	Three beaters, one Jordan, one stock pump, 6 in. x 10 in. triplex, one stock pump, 7 in. x 8 in. trip, one agitator (twin)	No. 3 Mill
100	600	One 3 in. centrifugal water pump, one 8 in. centrifugal water pump one 6 in. centrifugal water pump, one 7 in. x 7 in. triplex pump for bag factory water supply	No. 3 Mill
175	600	Four 800 lb. beaters, one Jordan, two 7 in. x 8 in. triplex stock pumps one agitator	
85	800	One paper machine, 68 in., two 12 in. x 12 in. suction pumps, one 6 in. centrifugal water pump	
10	1200	Exhaust fans	No. 3 Mill
60	800	One paper machine, two 7 in. x 8 in trip, stock pumps, two agitators	No. 2 Mill
60	800	One paper machine, 59 in.	No. 3 Mill
250	480	Seven beaters, one Jordon, two 7 in. x 8 in. triplex stock pumps one agitator, one 4 in. x 6 in. triplex pump	No. 2 Mill
*3	800	Blowers for air blast transformers	Power House
5	1200	Coal conveyor	Boiler House
20	800	Draft fan and boiler feed pump	Boiler House
40	800	Machine shop	
17	1200	Miscellaneous small machinery	No. 4 Mill

FENIMORE MILL

*10	1200	Coal conveyor	Boiler House
5	1200	Ash conveyor	Boiler House
*2	800	Blower for air blast transformers	Engine Room
12	1200	Centrifugal pump	Engine Room
150	600	Three 10 in. x 12 in. triplex double acting pumps Two 12 in. and one 10 in. centrifugal pumps, and one cylinder water screen	Pump House
150	600	14 Barkers, one splitter and one shaving conveyor	Wood Room
200	480	Two clippers, one chip screen, one chip conveyor to chip screen, chip conveyor under re-chipper	Wood Room
		One crusher, one splitter, one worm conveyor	
5	1200	Elevator (passenger)	Digester Room
30	800	Chip elevator and exhaust fan	Digester Room
10	1200	Elevator	Acid Tower
*15	1200	Acid pumps	Acid Tower
10	1200	Draft fan for tubes and sulphur burners	Acid Tower
85	800	10 in. centrifugal blow pit pump and one 48 in. exhaust fan	Press Room
250	480	Twelve centrifugal screens and four flat screens	Press Room
150	600	Two 16 in stock pumps, press room screen, knot grinder, 6 in. centrifugal pump (from Jordon to stock chest) 5 in. centrifugal tailings pump, and 8 in. centrifugal water pump	Press Room
75	800	Eight wet machines, agitator in concrete tank, two knotter screens and one stock thickener	Press Room
50	480	One 8 in. x 8 in. triplex vacuum pump, one 18 in. x 18 in. Gould single acting pump, one 4 in. centrifugal pump stock (from screens to wet machines), 5 in. centrifugal pump (hot water from tanks to blow pits) and repair shop	Press Room
50	800	One 10 in. centrifugal white water pump from wet machine to screens	Press Room
10	1200	Machine rewinder, elevator and ventilating fan, calendar reel winder	Machine Room

* Two motors.

also indicates the flexibility of the system and ease with which additional electrical equipment may be provided for by means of auxiliary generating stations. As in other paper mills which were originally designed for steam and waterwheel drive and which later adopted electric drive, the initial electrical installation in this mill has been followed by a rapid extension of motor drive, as the benefits of the new system were demonstrated in actual service. From the foregoing description it will be seen that, except for the grinders, a very large percentage of all the machinery is electrically-operated, and present plans for the extension of the electrical equipment indicate the satisfactory service which the induction motor renders under the severe demands of paper mill work.

Realizing that the induction motor can be applied with entire success to the operation of grinders, the Union Bag and Paper Company are at present equipping a grinding station with induction motor drive near their Canadian forest reserve. Twelve hundred h.p. motors will be used for each pair of grinders, the grinder shafts being coupled direct to either end of the motor shaft.

The hydro-electric plants at Hudson Falls not only supply ample power for the electrical equipment of the mills, but furnish current to the towns of Hudson Falls and Fort Edward, and also transmit current at 22,000 volts to the Mechanicville substation of the Hudson Valley Railroad.

Illumination for the mill and factory buildings is provided by means of incandescent lamps and a limited number of arc lamps; flaming arc lamps being used for outside night work, while for the bag factory, with its high ceilings, forty enclosed arc lamps are employed.

NOTES

The twenty-sixth annual meeting of the Association of Edison Illuminating Companies was held at "The Frontenac," Thousand Islands, N. Y., last September, 6th to 8th. The convention was largely attended, and a great many valuable and interesting

Charles P. Steinmetz and Thomas A Edison

papers were read and discussed. At its conclusion the President, Mr. Thomas E. Murray, was re-elected for another term, as were also all the other officers of the Association. The meeting was brought to a pleasing finale with a banquet on the evening of September 8th, at which Mr. and Mrs. Thomas A. Edison were the guests of honor.

Dr. C. P. Steinmetz was one of the delegates appointed to represent the General Electric Company, and we are able to reproduce an interesting "snap-shot," taken during the convention, of these two "Masters of Science," Thomas Alva Edison, who initiated the era of dynamic electricity for incandescent lighting and power in 1880, and Charles Proteus Steinmetz, who has devoted his profound knowledge of mathematics to the solution of the many intricate problems involved in alternating current phenomena and their practical application to commercial uses.

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During the month of October the following student engineers entered the Testing Department of the General Electric Company:

Billingsley, D. W., Mississippi A. & M. College
Bressler, R. A., Swarthmore College
Burleson, C. A., Sheffield Scientific School
Canfield, R. B., Sheffield Scientific School
Carpenter, C. T., University of Utah
Clemson, W. E., Columbia University
Coffin, L. F., Swathmore College
Collins, E. B., Worcester Polytechnic Institute
Cummings, H. L., Jr., University of Utah
Ehrlich, L. B., Alabama Polytechnic Institute
Fagley, G. H., Bucknell College
Faulkner, J. C., Alabama Polytechnic Institute
Gebhardt, E. F., Jr., University of Vermont
Kenyon, R. E., Oklahoma A. & M. College
McSpaden, L., University of California
Mohus, C. E., Alabama Polytechnic Institute
Montgomery, W. McV., Virginia Polytechnic Institute
Moyer, L. M., University of Washington
Murphy, W. P., Pennsylvania State College
Musser, H. P., Virginia Polytechnic Institute
Parker, A. A., Lehigh University
Parsons, L. W., Pennsylvania State College
Pine, P. P., University of Colorado
Schweckert, T. C., University of Virginia
Shelton, E. K., University of Washington
Shiels, R. T., A. & M. College of Texas
Sonntag, A. H., University of Illinois
Stang, P. A., Syracuse University
Summer, W. C., Pennsylvania State College
Swenson, L., Pratt Institute
Tait, W. J., University of Montana
Tull, I. N., N. C. College of A. & M. A.
Wathen, T. N., University of Texas
Watson, W. C., Worcester Polytechnic Institute
White, E. O., University of California
Williams, W. G., University of Oregon
Wise, E. M., Jr., University of Texas
Zimmerman, H. R., Oregon Agricultural School

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