GENERAL ELECTRIC REVIEW

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GENERAL ELECTRIC REVIEW

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GENERAL ELECTRIC REVIEW

During the new year a number of improvements have been planned for the REVIEW; the editorial force will be increased, and less technical and more practical articles will be published. In the January issue of a year ago, we stated that in future the technical articles would be restricted to those having a direct bearing upon practical engineering, purely theoretical discussions being eliminated. Throughout the new year this policy will be carried further, and it will be our endeavor to present all subjects as simply as possible, it being our desire to make the contents of the REVIEW more widely available and to reach those to whom a highly technical and mathematical education has not been vouchsafed. This is to be the keynote of future issues.

The REVIEW will continue to be the exponent of the latest methods of engineering practice, inventions, results of scientific research, etc., which, through its close association with the experts of the General Electric Company, it is enabled to present considerably in advance of the ordinary channels.

Of the articles promised for this year, among the most important is a series by Dr. C. P. Steinmetz, on transient phenomena. Dr. Steinmetz is the first authority on this subject, and his book, Theory and Calculation of Transient Electrical Phenomena and Oscillation, is the one standard treatise on this topic. In the REVIEW series, Dr. Steinmetz will translate the higher mathematics into English, presenting these exceedingly important phenomena in a simplified form available to all our readers.

Prof. Elihu Thomson, whose inventions under nearly every field of electrical development today, and whose ability to present facts and phenomena so clearly that the reader instinctively forms a perfect physical conception of them, as remarkable as it is rare, will also contribute to the REVIEW for 1911.

Dr. W. R. Whitney, formerly Professor of Chemistry at the Massachusetts Institute of Technology and at present Chief of the Research Laboratory of the General Electric Company, will contribute the results of research in the Chemistry of Light and kindred subjects.

As pointed out by Mr. Lyman in his article on Hydro-Electric Developments, the increasing demands placed upon long distance transmission have resulted in the employment of higher and higher voltages; today the phenomenon of corona discharge precludes an indefinite increase in voltage. Such, then, is the importance of corona that it has been made the subject of special research on the part of the experts of the General Electric Company. As results are obtained, the REVIEW will present these to its readers.

Another important series of articles is one on the Diagnosis and Remedy of Alternating Current Apparatus Troubles. Notwithstanding the importance of this subject, its literature is exceedingly meagre. It is our desire to have this series fairly complete, and through it to furnish a key to all ordinary troubles and a means for promptly locating and remedying them. These articles, which we mentioned last year as being promised, have been delayed, but we have reason to believe that we can now begin them in an early number.

A branch of electrical engineering that has called for much study and research work is that of Lightning Arresters. Professor E. E. F. Creighton, of Union College, will contribute a series upon this subject that will comprise the first complete authoritative information that has been published thereon.

A series of original articles on synchronous generators and motors by Professor V. Karapetoff, of Cornell University, author of Experimental Electrical Engineering, The Concentric Method of Engineering Education, etc., will begin in the February issue. These articles will be fully illustrated by numerical examples of actual machines.

A series of articles on Illuminating Engineering will be prepared under the direction of Prof. Sidney W. Ashe, Ph.D., the author of

Electric Railways, etc. The first article will probably appear in the February number.

The course of Commercial Electrical Testing will be continued until completed.

Articles on switchboard apparatus and engineering will appear in alternate issues, and a valuable series on the subject of meters will be a feature of the year.

These are a few of the series that have been promised at the present time. Arrangements for other contributions are pending with noted specialists in various electrical fields, and we can unhesitatingly promise REVIEW readers more valuable information on the important electrical problems of the day than has ever been published in the same space.

FEEDER REGULATORS

The article which appears in this issue by Mr. E. F. Gehrkens on Feeder Regulators very clearly describes the different types of feeder regulators and gives the manner in which the ratings are determined and the comparative losses of each type.

The introduction of feeder regulators came with the tendency of modern generating stations toward the installation of large alternating current units. The concentration of large a.c. generating units in the power house with distributing circuits to substations, and with a large number of feeders emanating from each substation, necessitated individual control of these feeder circuits. Advances in design of feeder regulators has accompanied advances in design of a.c. generator apparatus.

When it is considered that there may be a large number of feeder circuits tapping a common bus, it is readily understood that, with a diversity of load centers, each feeder circuit must be treated individually, in order to operate it most economically. The characteristics of feeders vary in accordance with the locality which they supply. Thus, a feeder supplying a semi-manufacturing district, combining the power and lighting load, would be subject to more rapid fluctuations than one which fed a purely lighting section. A careful study of the characteristics of incandescent lamps shows the need of a constant normal voltage supply at lamp terminals. The exacting conditions required at the present time by the public, necessitating a high standard of illumination, forces the central stations to the adoption of automatic feeder regulating devices, which, while apparently of benefit to the consumers, is, in fact, of far more benefit to the central stations themselves. This fact has been realized in the past two years very forcibly by the majority of stations in this country.

The author calls attention to the different methods of figuring efficiency of regulators, and to the comparative efficiency of the induction and switch type regulators. It will be well to remember that the efficiency of a regulator is figured in percentage of kilowatt capacity of the regulator itself, and not in percentage of the kilowatt capacity of the circuit which it controls.

F. W. SHACKELFORD

GOLD DREDGING BY ELECTRICITY

Within recent years a process of gold mining by dredging has been developed which, in point of effectiveness, under the right conditions, exceeds any method of mining that has gone before. By this means, a large quantity of gold-bearing material is manipulated, and the metal can be advantageously extracted from deposits that it would not otherwise pay to work. In fact, the process may be, and for the most part is, employed in grounds that have once been mined. A description of these dredges, the history of their introduction and the method by which they operate are the subjects of the article by Mr. C. M. Bliven and Mr. H. W. Rogers in this issue of the REVIEW.

Sixty-eight dredges are now operating in California and about thirty more in other portions of the United States and Alaska. Recently the building of two very large dredges that are practically duplicates of each other was undertaken, one for use in Alaska, and one in Montana. An idea of their size may be gathered from the fact that approximately 750,000 square feet of timber is required for the hull. A 300 h.p. motor, geared from 360 to 500 r.p.m., drives the main bucket line, which consists of 88 buckets, each having a capacity of 15 cubic feet, or more than four times that of the buckets on the early type of dredge which, at the time, was considered a powerful and massive structure

It is estimated that one of these dredges, under the conditions obtaining in the locality contemplated, will deliver gold to the value of $150,000 a month.

Of these two giant dredges, the one for Alaska has been finished and is in operation; that for Montana is now in the course of construction. When completed, it will be fully described in the REVIEW.

RECENT HYDRO-ELECTRIC DEVELOPMENTS IN THE WEST*

By James Lyman

Some of the larger and more recent power developments which I have just visited and will briefly refer to involved great engineering difficulties, interesting features of design and operation and were built at a cost of millions of dollars. The following is a brief sketch of several of these interesting developments.

First, there is the Central Colorado Power Company with its two power houses, one at Boulder, thirty miles north of Denver, and the other at Shoshone in the wild canyon of the Grand River, high in the Rocky Mountains, fifteen hours ride by train from Denver but only one hundred fifty miles by air line. The 100,000 volt transmission is carried over the Leadville Divide to 14,300 feet elevation and across the roughest country; the most difficult piece of transmission work ever undertaken. The placing of the steel towers and stretching of the heavy cables in spans, some of more than 2000 feet, was a hard task, but so well done that little trouble has been experienced in the year's service.

The Shoshone power development consists of a masonry dam and a tunnel, seventeen feet wide by twelve feet deep, two and one-half miles long, cut through solid granite rock close to the face of the canyon, down stream 170 feet above the power house tail race. Here two 5000 kw. horizontal water turbine units are installed.

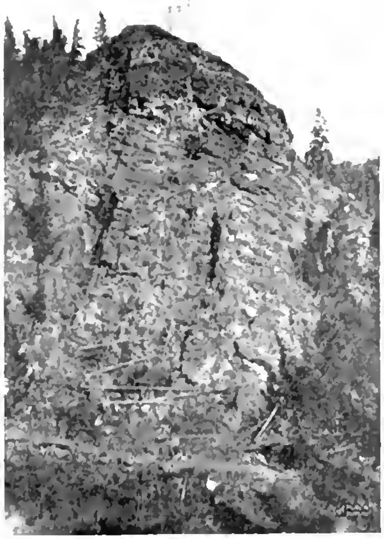
The Boulder power development is equally interesting. A little stream of but ninety foot-seconds minimum flow is piped down a precipitous mountain side through a vertical height of 1800 feet to two 5000 kw. impulse wheels and passes out into the atmosphere as white foam and a rainbow; while the electric power joins that from Shoshone at Denver Terminal Station, over the 100,000

Transmission Line of the Central Colorado Power Company Near Hell Gate

*Paper presented to the Chicago Electric Club, November 9th, 1910.

volt transmission line. At present the Denver Gas and Electric Company is the largest customer.

Passing on to the Coast: the high fuel cost has made California one of the largest fields for hydro-electric developments. Water power of every size and description aggregating great amounts of horse power are in service.



A Difficult Piece of Transmission Line Construction. Central Colorado Power Company

Among the larger recent water power developments, three groups are of special interest, as they demonstrate the feasibility of successfully and efficiently supplying current for all kinds of work over hundreds of square miles of territory; the power being furnished from any number of water-wheel and steam turbine-driven units located at widely different points.

As a rule the endeavor in connection with the water powers in this locality, feeding over long high tension transmission lines, is to operate under nearly constant load, thereby obtaining the maximum efficiency of the water-wheels and transmission, while the turbine stations, generally located nearer the center of the distribution system, take the load fluctuations and control the frequency; the voltage of the distribution system generally being controlled by a TA potential regulator connected to the excitation circuits of synchronous motor-generator sets or rotary condensers. The first of these groups of water power development is the Pacific Gas and Electric Company of San Francisco. This company has developed the largest distribution system in the world. With more than 1000 miles of three-phase 60,000 volt transmission lines, they supply nearly 100,000 kw. for power and lighting—over an area approximately 200 miles north and south, and 100 miles east and west—to one-half the population of California, in 153 cities and towns. Power is supplied from eleven water power houses and three steam power houses, some of them more than 300 miles apart. All are controlled by a single power despatcher who has become so expert that trouble occurring at any point, can generally be located and the section cut out in three or four minutes, usually without cutting off any of the power houses or disturbing the voltage regulation of the system for more than a few minutes.

The largest power supply for this company is from the Feather River power house of the Great Western Power Company, located 154 miles north of Oakland. This plant is remarkable for the size and the high efficiency

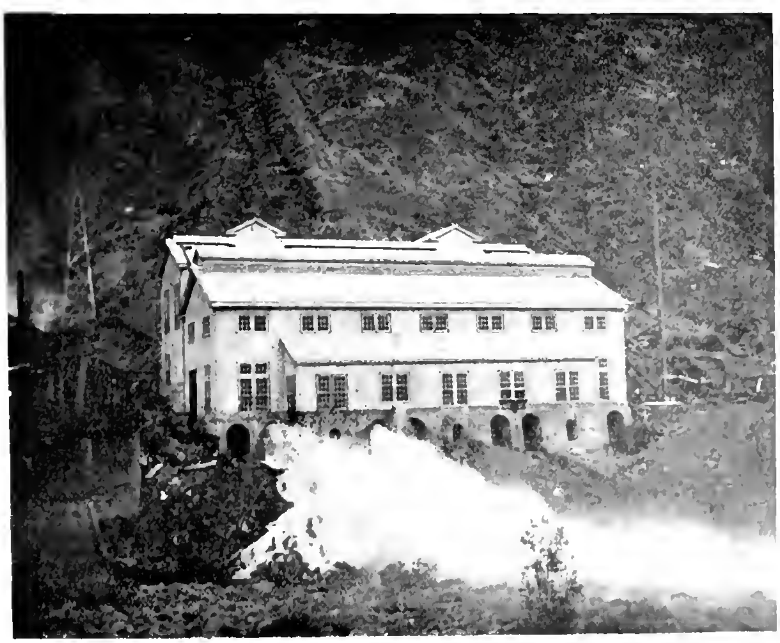
Along the Route of the Transmission Line of the Central Colorado Power Company

claimed for the water turbines, water-wheel-driven generators and step-up transformers. Each generator is normally rated 10,000 kw. and is capable of 25 to 50 per cent overload. Further, the water head (430 feet) is the highest under which the turbine type of wheel has, to the best of our information, yet been installed.

The full load efficiency of the wheels is claimed to be 89 per cent, that of the generators 97.1 per cent, and that of the transformers 99 per cent, giving a total efficiency from water to the line, at 104,000 volts, of 85.4 per cent. With a transmission line loss of 13 per cent and a step-down transformer efficiency of 99 per cent, the total delivered efficiency from water to the 60,000 volt distribution system 154 miles from power house, is claimed to be 73.5 per cent. The Great Western Power Company's present development consists of four of these 10,000 kw. units. The company owns rights available for development further up the river, for approximately 200,000 kw.

Wood Stave Pipe Line of the Stanislaus Power Company. Forebay Dam in Distance

The second of these groups is the Stanislaus power development, 130 miles due east of San Francisco, which, operating over 104,000 volts double transmission line, supplies the United Railways Company of San Francisco with a large part of their power in parallel with steam turbine units. It is one of the most difficult water developments in the West.



Power House of the Stanislaus Power Company

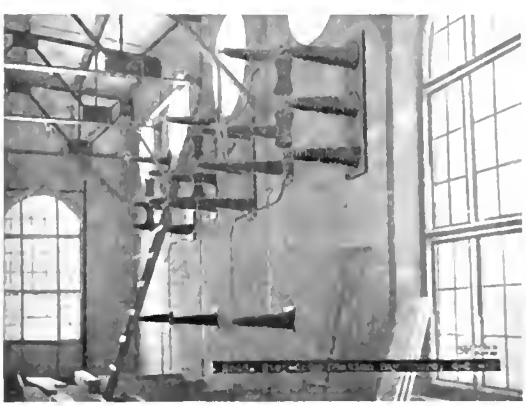
The power house is situated in the middle of a great bend in the deep canyon of the Stanislaus River, a sheer 1500 feet below the canyon's rocky rim where the sun only shines a few minutes of each day. The water is brought fifteen miles along the edge of the canyon in a large wooden flume to a point above the power house, and from thence in steel pipes to four 7500 kw. impulse water-wheels operating under a 1500 foot head.

The third group supplies power to Los Angeles. The Kern River development, consisting of four 5000 kw. water-wheel units supplying power over an eighty mile line to Los Angeles at 80,000 volts, runs in multiple with a half dozen smaller water powers and a steam turbine power house. The power is controlled and regulated substantially as described above with most successful results.

A large part of the power is supplied to the Pacific Electric Railway Company, one of the largest and best managed interurban systems in the country. Several hundred miles of road connect all the little towns and seashore resorts out of Los Angeles. It has also contributed much to the phenomenal growth of this beautiful "Playground of America."

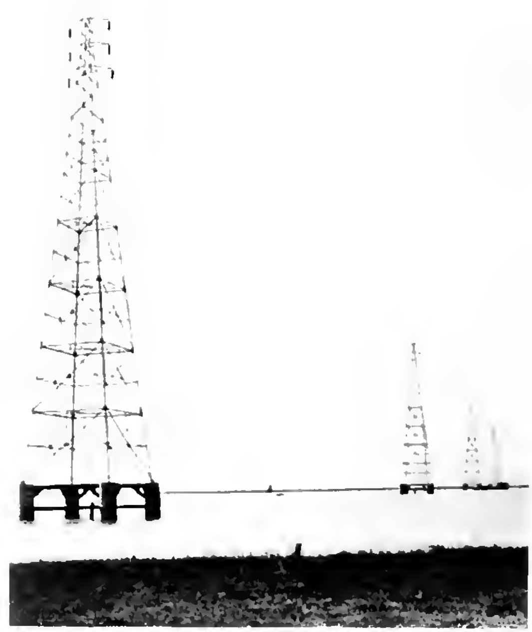
High Tension Oil Switches in Substation of Stanislaus Power Company

Here I should mention the Owens River Aqueduct, now being built by the city of Los Angeles at a cost of $23,000,000. It is 240 miles long, with a capacity to deliver 260,000,000 gallons daily, or 400 second-feet. Construction work began three years ago and will be completed in a little more than two years. It starts at the base of a group of twenty-four snow-capped mountains in the Sierra Range, each more than 13,000 feet high; Mt. Whitney, 14,500 feet high being in the center. Thirty-five small streams flow together making the Owens River, a stream of pure, sparkling mountain water which is brought through concrete ditches and tunnels in the mountains and through a closed concrete aqueduct 125 miles across the Alkali Desert. It is claimed that there will be one hundred twenty thousand electrical horse-power available from the water of the aqueduct, from three falls located respectively forty-five, thirty-six and twenty miles from Los Angeles. After passing the last falls the water enters two large reservoirs 1000 feet above the city of Los Angeles. From these reservoirs it will be conducted to the city and surrounding country for water supply and irrigation.



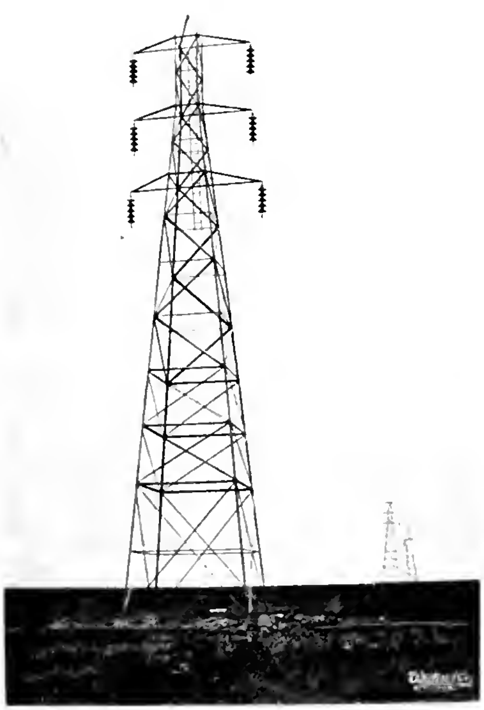
Choke Coils and Disconnecting Switches on Incoming Line Substation of the Stanislaus Power Company

One thousand acres of cotton were planted a year ago, two hundred miles south of Los Angeles. A large yield of cotton of unusually fine quality was obtained, and this year 30,000 acres have been planted. This bids fair to open up a new industry and a large market for power at Los Angeles. The city and surrounding country are now using 65,000



Alviso Crossing, Stanislaus Power Company electrical horse-power, and since in ten years Los Angeles has grown from 100,000 to 300,000 in population, within five or six years there will undoubtedly be a market for all the power that is available.

William Mulholland, the chief engineer, believes that the income from the power developed will pay for the aqueduct in twenty years. Five thousand men are employed in its construction, and a special cement plant producing 1000 barrels per day furnishes cement. Electric dredges and electric-operated shovels make all the excavations, and a 3000 kw. power plant supplies the power. Only by electric power, the telephone and the automobile is it possible to construct this 240 miles of aqueduct across a broiling desert in five and one-half years. Its value to Los Angeles and the whole San Gabriel Valley is incalculable.



Standard Tower on Concrete Foundation near Guadeloupe Slough, Stanislaus Power Company

At Spokane, the Washington Water Power Company are just completing one of the best hydro-electric developments I have seen, at

Bay Shore Substation, Stanislaus Power Company

Little Falls, thirty-five miles northwest of the city. The four 5000 kw. horizontal generator units, each driven by a pair of turbine wheels under a sixty-seven foot head, are good for a total continuous load of 25,000 kw. The power is sent to Spokane over two single steel-tower lines at 60,000 volts and the plant runs in parallel with several other water powers and steam turbine units.

This company has 150 miles of 60,000 volt lines supplying power not only for all purposes in Spokane, but also to the Cœur d' Alene mines one hundred miles east of that city. New developments under consideration will soon bring the total capacity to 100,000 kilowatts.

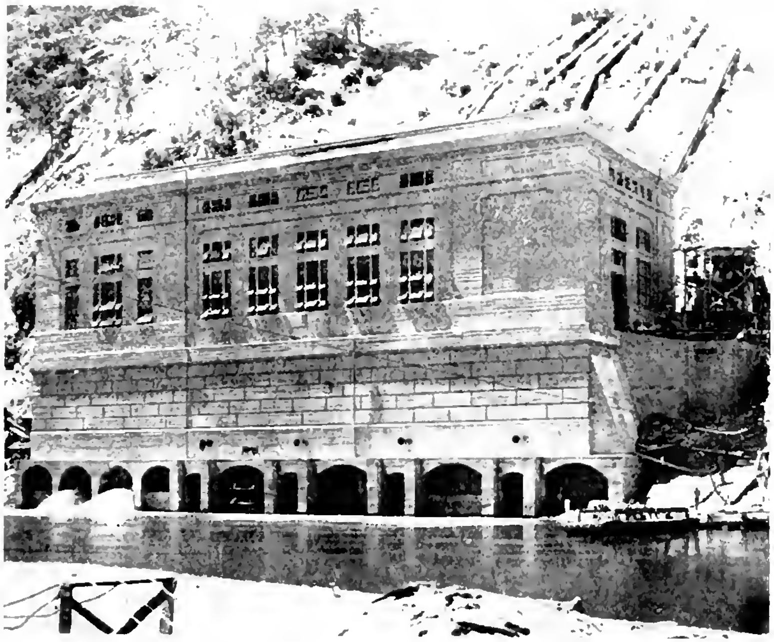
At Rainbow Falls the Great Falls Power Company have just completed an hydro-electric development of 21,000 kw. in six 3500 kw. horizontal generator units running under a head of 107 feet. Two independent transmission lines on steel towers carry the power at 100,000 volts the 150 miles to Butte. A proposed development at Great Falls, six miles below Rainbow Falls, will provide a large amount of additional power.

It is proposed to do away with the large steam plants at the thirteen Butte copper mines and operate the hoists by compressed air, furnished by electrically-driven air compressors. These plants now use 25,000 h.p. in steam hoists.

SUMMARY

Great advances have recently been made—

1. In the building of masonry dams, aqueducts, flumes, etc.



Feather River Power House of the Great Western Power Company

2. In the design, size and construction of water-wheels, both of the reaction and impulse types.

3. In the development of high tension electrical apparatus, including transformers, line insulators, steel towers, etc.

4. In control and protective devices.

5. In the systematic operation of large interconnected power lines.

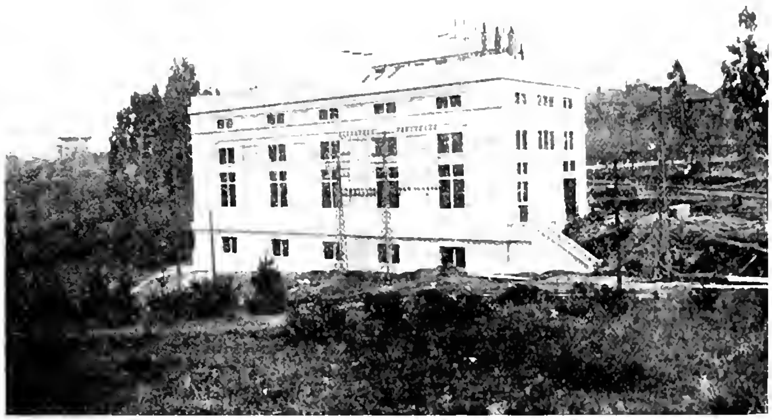
At least five heavy power transmissions are successfully and economically delivering current from 50 to 150 miles at from 100,000 to 110,000 volts.

All apparatus used is standardized.

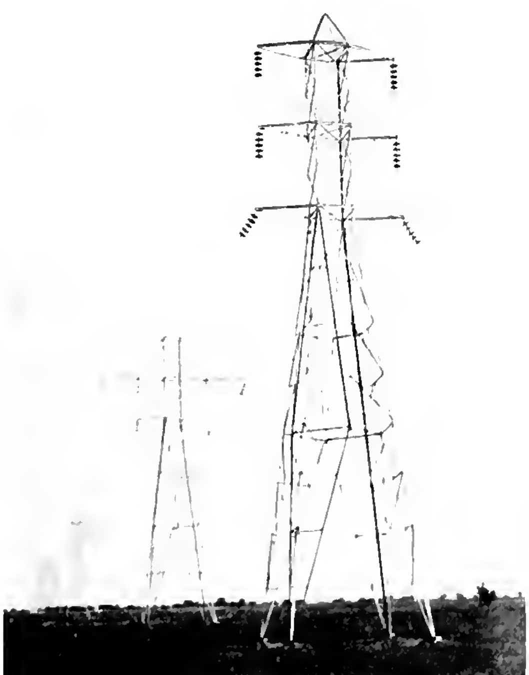
The aluminum cell electrolytic arrester has largely disposed of disturbances from lightning and surges. The line charging currents, in combination with synchronous motor-generator sets or rotary condensers regulate for constant delivered voltage.

Today power is being handled at 100,000 volts over 150 mile lines as successfully and as efficiently as ten years ago it was handled at 50,000 volts over half of this distance. Above 110,000 volts air begins to lose its perfect insulation qualities and a slight leakage or discharge from the conductor takes place, known as the "corona effect." We cannot say to what extent potentials higher than 110,000 volts can be efficiently used. Transformers, oil switches and line insulators can all be built for much higher voltages; the insulation of the air alone, therefore, limits the line potential.

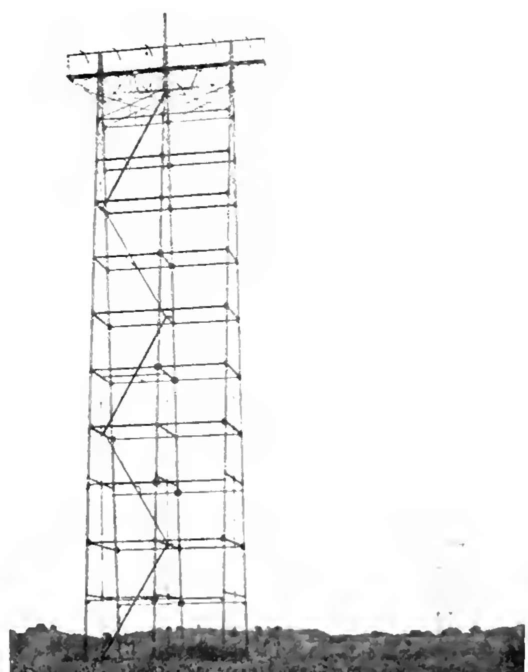
Interior of Power House, Great Western Power Company



Oakland Substation, Great Western Power Company



Transmission Line of the Great Western Power Company Showing Transposition



3000 foot Span over San Joaquin River, Great Western Power Company

THE FAN MOTOR IN WINTER

It is the popular opinion that the range of usefulness of the electric fan motor is limited to the summer months and that its sole utility lies in its application as a means of reducing the temperature of a room or an office. This is not true, however, and slowly but surely the public is beginning to understand that the usefulness of the fan motor is by no means confined to the hot days of summer, and that paradoxical as it may seem, the electric fan blows hot or cold; and incidently while it is blowing hot it cuts down the fuel bill.

Following are a few of the more important applications of the fan motor to winter use:

The efficiency of the hot air heating system may be greatly increased by placing a fan motor in the cold air box to force the air through the registers to all parts of the house. On particularly cold days, when the wind is so strong that it forces the air through the furnace into the rooms without having become heated, a fan motor placed in the cold air box, after having closed the slide which permits air to come in from the outside and opening the slide which lets the air in from the cellar, will cause an appreciable rise in the temperature of the room, without making any increase in fuel consumption.

As is very often the case, the house contains a room or rooms which under certain conditions are difficult to heat. This difficulty can be overcome by placing a fan motor in front of the hot air register, or over it in case the register is located in the floor. This plan will prove more efficient if the register and fan motor are covered by a box or hood of some kind which will cause the fan motor to draw air from the pipe only, and not from the room.

Another manner in which the fan motor may be used to advantage in winter is to prevent the accumulation of frost on show windows of stores. The air from the fan motor directed against the glass of the window will keep it practically free from frost. This application of the motor is a boon to merchants who have heretofore lost during cold weather practically all the advantage which their window display affords them.

Photographers find small eight-inch fan motors to be particularly valuable in dark rooms for drying negatives.

THE APPLICATION OF ELECTRIC MOTORS TO FARM AND DAIRY MACHINERY

By John Liston

Notwithstanding the tremendous growth which has in recent years characterized the manufacturing industries and transportation systems of the United States, the prosperity of the country as a whole is still fundamentally dependent upon its success as an agricultural nation.

Due to the ever increasing area of the American farm and to the pressure of competition combined with the high wages which must now be paid in order to secure competent help, the American farmer has generally been eager to adopt improved machinery, labor-saving devices and methods of cultivation and handling of finished products, when such machinery or methods have proved their practical value. Long familiarity with the operation of modern agricultural machinery and the very extensive adoption of the internal combustion engine have served to develop his knowledge of applied power and an understanding of the benefit to be derived from labor-saving devices, which facts render him peculiarly capable of grasping the significance of the widespread adoption of electric drive in manufacturing industries and its practical and economic possibilities as a method of applying power to farm and dairy machinery. That these possibilities have already been fully demonstrated in actual service is indicated by the variety of motor applications which are shown in the accompanying illustrations. As a rule these applications have been made upon the initiative of the farmer, and the initial installations have been generally followed by an extension of the electric system as its value for the service was demonstrated.

Until very recently the adoption of motor drive on farms has been limited by the difficulty of economically securing current, but the rapid and widespread extension of central station transmission lines and the feeder systems of electric railways has brought the benefits of central station power within the reach of a large percentage of American farms, especially those in the Eastern States. Combined with this has been the development of small compact generating sets of moderate cost, using as prime movers either gasolene engines, small steam engines or steam turbines, which may be installed on those farms that are beyond the reach of central station circuits, and safely operated by the class of labor usually found on farms. There has also been a number of small water-power plants where the hydraulic development work was performed with entire success, either by individual farmers or by a community, utilizing various forms of high efficiency water turbines for driving automatically-governed generator sets.

Fig. 1. Portable Motor Outfit Used for Driving Auxiliary Farm Machinery

While fully recognizing the inherent advantages of motor drive, the practical farmer must be convinced of its economic value for his own farm as compared with methods he has already adopted, the operating costs

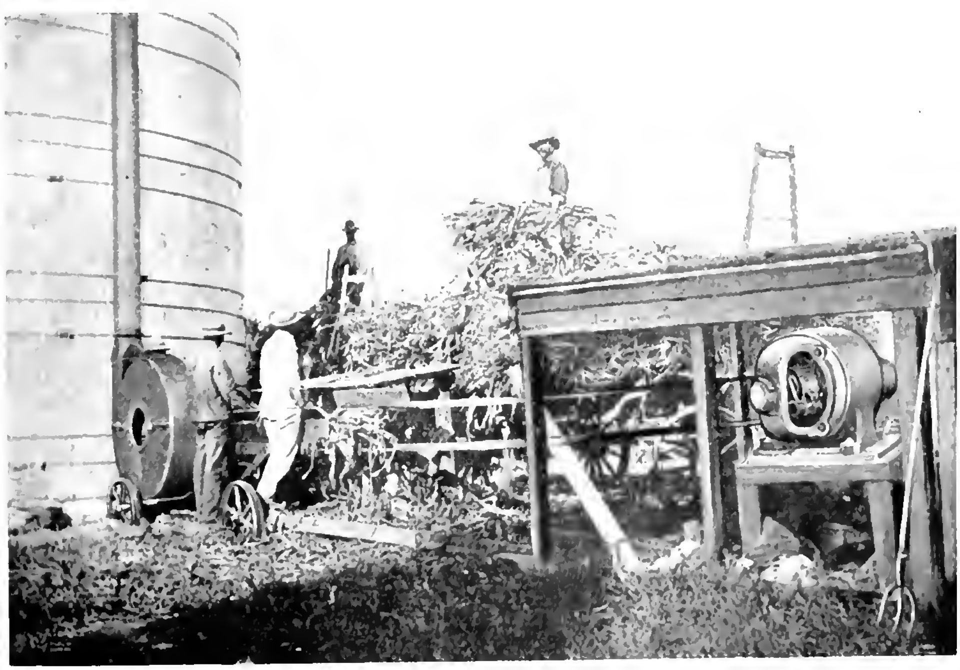


Fig. 2. Motor Driving No. 19 "Ohio" Self Feeding Blower Ensilage Cutter

of which have been fully demonstrated. Since the best demonstration of the value of any system of power application is given by the performance of installations operating

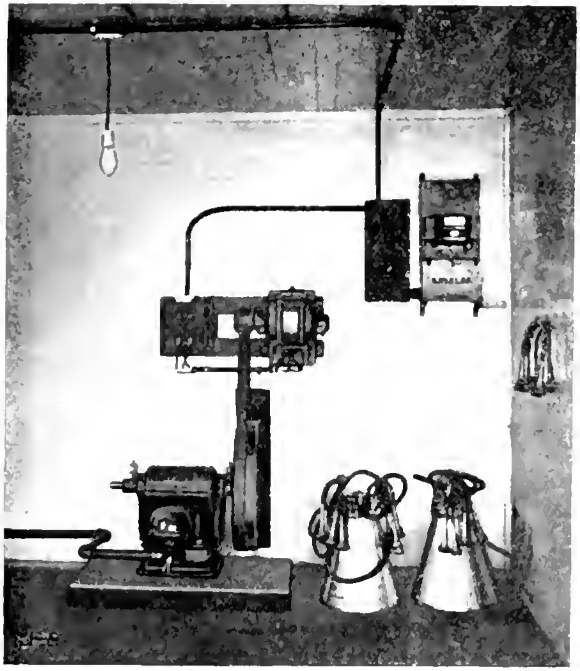


Fig. 3. Motor-Driven Vacuum Milking Outfit

under similar conditions, the following instances of what has actually been accomplished in the electrical operation of farming and dairy machinery cannot fail to be of interest to the agriculturist and the dairy farmer.

The extent to which motor drive can be profitably adopted and the character of the equipment required will vary with the special conditions on each farm. While theoretically each machine should be provided with individual drive by means of a motor which will meet its exact power requirements, it is usually found advisable, in order to limit the investment entailed in the electrification of the farm, to adopt both individual and group drive for the same reasons which have governed the application of the two systems in manufacturing industries. The peculiar requirements of farm work due to the intermittent operation of various machines enable the farmer to take the fullest possible advantage of portable motor outfits, which can be transported from one building to another, or into the field, thereby permitting the operation of a variety of machinery by means of a single motor. When used for field work a portable outfit is usually provided with a cable reel, with the cables connected to the permanent conductors and fed out as the motor advances, in a manner similar to the operation of gathering locomotives in coal mines. The cables may either be laid directly on the ground or, if liable to injury under this condition, supported on temporary posts or poles. It is entirely practical to supply an outfit of this kind with a lighting equipment so that when necessary the field work may be carried on efficiently at night.

A typical portable motor outfit of this kind, mounted on a sledge and provided with a simple drum controller is shown in Fig. 1.

The type of motor selected for farm service will depend largely upon the available current supply, as both alternating and direct current motors have given highly satisfactory service on numerous farms. Due to the absence of a commutator or other moving contact in the polyphase induction motor, this type is especially well adapted for installation in farm buildings which contain combustible materials or inflammable dust, such as grist mills, barns, and storehouses for hay, grain, etc. The induction motor can be operated with absolute safety under these conditions; but where direct current motors are of necessity used, the enclosed type should be installed, or the motors should be housed in a separate building or otherwise safeguarded against contact with inflammable dust.

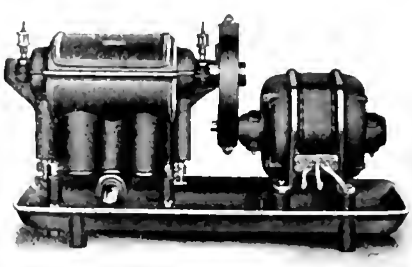


Fig. 4. 1½ H.P. Induction Motor Direct Geared to a No. 4 "Burrell" Vacuum Pump

Motor drive for barn machinery, including hay hoists, elevators, food grinders, huskers, shredders, grist mill machinery and all forms of fodder cutters, can usually be best provided for by the permanent installation of motors.

For driving ensilage cutters, either portable or permanently installed motors are used; the motor being generally belt connected to the driving shaft of the cutter. An example of this application is shown in Fig. 2.

The cleanliness made possible by the use of the electric motor for power purposes renders this machine pre-eminent in the operation of dairy apparatus, and motors have therefore been adopted to a very large extent for the operation of vacuum milking outfits, separators, churns, etc. Fig. 3 shows a typical compact vacuum milking outfit, with the motor belt-connected to the shaft of the vacuum pump and mounted on the wall where it occupies no useful space. Even the short connecting belt used in this instance may be eliminated by gearing the motor direct to the pump as shown in Fig. 4.

In addition to the operation of vacuum milkers, motor-driven pumps of this type have been utilized to operate vacuum cleaners for cattle. It has been found that one of the most frequent sources of contamination of milk is the dirt and hair from the hide of the cow, and when cattle are cleaned in the ordinary way dirt is stirred up and disseminated about the stable. Special vacuum tools for cleaning cattle, as shown in Fig. 5, are now available and can be operated from the milking machine vacuum piping system

Fig. 5. Burrell Vacuum Cattle Cleaner in Use

so that the dirt is drawn from the cow's hide and deposited in a dust collector. These tools are, of course, equally well adapted for the cleaning of horses and other animals.

Motor-driven rotary brushes for cleaning cattle may be advantageously used where the dust raised will not contaminate food products, and the clipping of horses, shearing

Fig. 6. Motor-Operated DeLaval No. 4 Separator

of sheep and other operations of like nature have for some time past been successfully performed with flexible shaft motor-driven machines.

For the operation of separators, a small motor can be assembled with the separator upon a common base or mounted on a shelf which is supported by the separator body. Where large separators are used the heavier motors required may be mounted on the floor, wall or ceiling and belt-connected to the separator. For small sizes light belts are generally used and on account of the short centers between motor and separator, the pulleys are provided with belt tighteners, as shown in Figs. 6 and 7. With some types of separators vertical shaft motors are used, in which case they form an integral part of the separator and constitute an even more compact set than those illustrated.

For driving rotary churns, motors can usually be direct geared to the operating mechanism of the churn and the gearing completely enclosed, insuring absolute cleanliness and rendering possible the manufacture of butter under perfectly sanitary conditions. For the operation of barrel or factory type churns similar to the one shown in Fig. 8, the motors are connected either through gears or belts, and auxiliary belting or gearing can be arranged so that one motor will drive both churn and

Fig. 7. Motor-Operated DeLaval No. 15 Separator

butter worker. Where it is necessary to pump the milk into the churn, it is customary to use small centrifugal or reciprocating pumps. When pumps of the former type are used, the motor, on account of its high speed characteristics, can usually be connected direct to the pump shaft, thereby forming a compact, self-contained unit. For the reciprocating type of milk pump it is of course, necessary to interpose gearing or belting.

Practically all the auxiliary apparatus in a modern dairy, such as bottle and can washers, pasteurizers, testers, etc., can be readily equipped with motor drive. The separators and most of the auxiliary machines in the average dairy require very little power for their operation, and if provided with individual motors can as a rule take the necessary supply of current from the ordinary incandescent lighting circuit. Where the dairy machinery is compactly arranged it may be found economical to drive it by means of a single motor with the necessary belt connections between the main shaft and the individual machines.

Cold storage or an ample supply of ice is essential for the successful operation of the up-to-date farm, and while natural ice is still employed to a large extent there are serious objections to its continued use on any farm supplied with electric current. Natural ice when utilized for cold storage has three inherent defects: the presence of a considerable amount of moisture or dampness; the impossibility of regulating and controlling the temperature; and the constant wasting of the active material. In addition to this there is the cost of labor and time involved in cutting and storing the ice and the potential danger from impurities which do not exist in ice artificially made from pure spring or well water.

The indisputable financial advantage of being able to keep products in cold storage renders it advisable, even on relatively small farms, to adopt refrigerating or ice making machines which are easily installed and maintained and which are reliable in operation and capable of extremely close temperature regulation. The electric motor affords an ideal drive for this type of machinery as is indicated by Fig. 9, and can readily be made automatic by means of a thermostat placed in the chamber where refrigeration is required, and electrically connected with the motors which drive the circulating

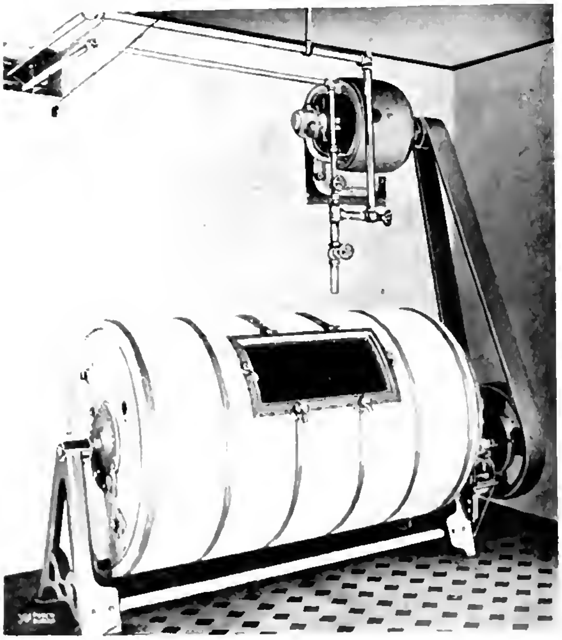


Fig. 8. Fargo Barrel Churn Operated by Belt-Connected Motor

pumps. These pumps will thus be automatically started or stopped by fluctuations in the temperature and will thereby tend to maintain the temperature at a predetermined point.

In considering the cost of refrigerating or ice making plants on a farm provided with an isolated generator it should be borne in mind that the variation in the daily period of daylight throughout the year is very nearly in proportion to the variation in temperature, so that for the small refrigerating outfit which will meet the requirements of the average farm, it will not be necessary to provide any greater generator capacity than that already required for power and lighting.

If central station power is being used, in this as in all other instances where the operation of the motors is intermittent, the cost for current is entailed only during the time that the motors are in service. As a large percentage of motor-driven machines used for farm and dairy work do not operate continuously or during long periods, the purchasing of power from central station or railway circuits reduces the cost for operating the motors to an amount directly proportional to the work performed. If a farm is equipped with an isolated generating plant the intermittent operation of the various motors can be so scheduled that at no time will a large percentage of them be in service, and the power plant can therefore be safely equipped with a much smaller generator than would be required if a majority of the motors were operated simultaneously.

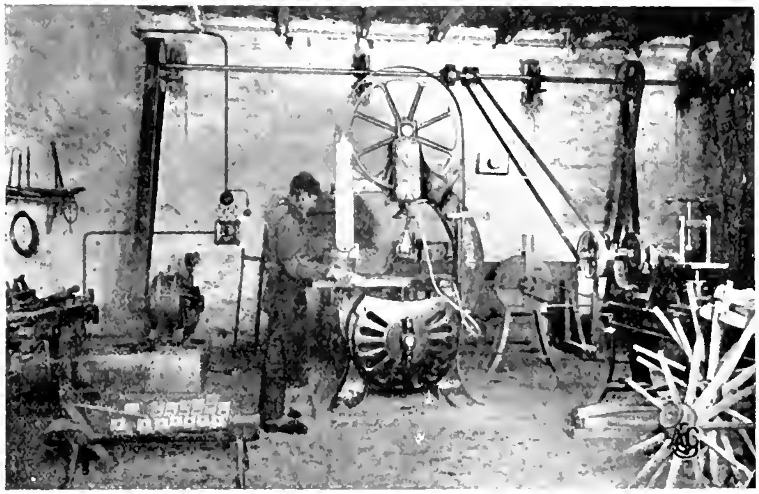


Fig. 10. An Example of Motor Group Drive in Repair Shop

The conditions characterizing farm work are such as to involve the necessity for occasional repairs to buildings, wagons or machines, and every farm is provided with facilities necessary for ordinary repair work; the equipment usually comprising some woodworking machinery, a blacksmith shop and a variety of metal working tools or machines. The serviceability and economy of motor drive for the operation of woodworking machinery has been so conclusively demonstrated that it has been very extensively adopted in saw mills and other woodworking plants, and it will be found equally valuable for driving the machinery of farm repair shops. Fig 10 shows a typical farm shop in which saw, grindstone, lathe and other

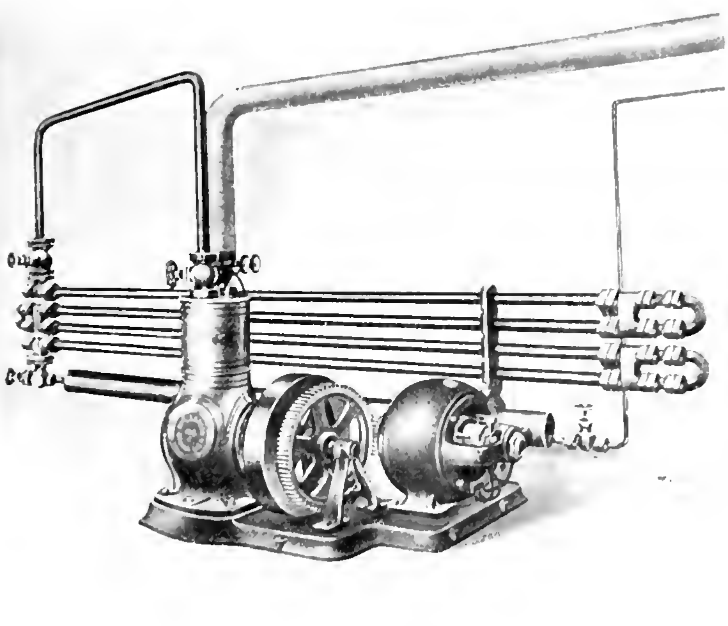


Fig. 9. Motor Direct Geared to Larsen Ice Machine

machinery are driven in a group by a single motor belt-connected to a main driving shaft. Where the equipment of a shop of this kind includes a large number of machines economy in current consumption and the highest possible efficiency for each machine can ordinarily be obtained by providing each unit with an individual motor which will most nearly meet its exact power requirements; and for the operation of circular saws, grinding wheels and all types of metal-working machinery, motors may be either direct connected or operated through short belts or gears. In a blacksmith shop a large part of the arduous work involved in the holding and shaping of forgings may be eliminated by the use of small electrically-operated drop hammers which, in addition to reducing the manual labor required, insure greater rapidity and accuracy in the handling of the work, while motor-driven forge blowers permit a more positive control of the forge blast than that obtainable with any hand-operated mechanism.

Fig. 11. 3½ Ton Electric Truck Used in Harvesting

Farm work shops that are provided with electric current may be benefitted thereby in other ways than through the driving of machinery by means of motors, owing to the development of highly efficient electric heating units which have been applied very successfully to various auxiliary devices commonly used in such shops. Among these are electrically-heated glue pots, solder melting pots, soldering irons, leather burnishers, etc. An important auxiliary machine that will be found extremely useful in both metal and woodworking shops is the portable electric drill, which can be readily connected to convenient outlets at different points in the wiring circuit, thereby avoiding to a considerable extent the handling or moving of heavy units during repair work.

One of the possible uses of electricity on farms where electric current is available is that indicated by Fig. 11. The auto-vehicle there shown is a three and one-half ton electric

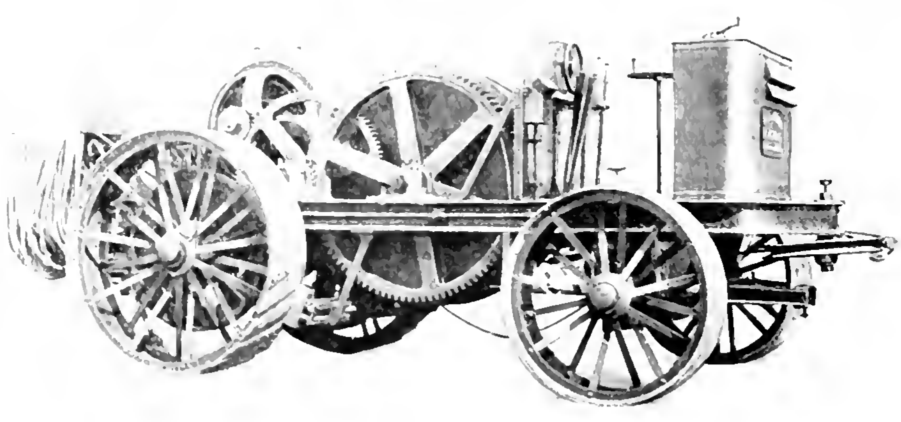


Fig. 12. Jack Carriage for Electric Plow Carrying Motor Controller and Cable Drum

truck, which is ordinarily used for delivering produce to the depot. During the harvest season, however, it is used in the manner shown, for gathering hay and wheat. A comparison of the loads of the horse-drawn and the electric vehicle clearly indicates the superiority of the latter, which, in addition to its greater carrying capacity, has greater speed than the horse-drawn vehicle and can therefore make more frequent trips during a given period. It has been found that an electric truck of this type can be safely run on practically any farm land. The load of wheat on the electric truck shown consisted of 617 bundles, which, after being threshed, yielded forty-five bushels; the regular two horse load being only 260 bundles.

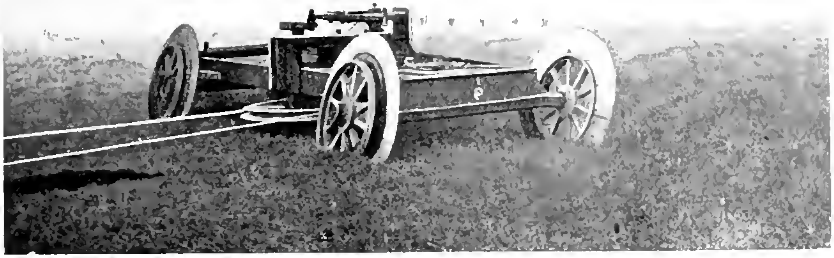


Fig. 13. Anchor Carriage for Electric Plow

There are far reaching possibilities in the use of electric vehicles of this type on farms, not alone in the field where the time element in getting the wheat to the thresher due to variable conditions of the weather may render speed very important, but also in the transportation of products to market or to points of shipment. With such trucks, farms which are located at a distance from the railroad and which as a consequence can usually be cheaply bought, are made almost as valuable as farms near cities. With the electric truck they will in effect no longer be far away, as their proximity to the market or shipping points will be measurable, not by distance, but by time; and the ability to quickly deliver a load of grain to the elevator or depot will place the farmer in a far better position to get the best prices for his products in a constantly fluctuating market.

While mechanical plowing has been generally adopted on large farms in the United States, very few attempts have as yet been made to operate plows by electricity, and up to date the steam plow occupies a predominant position. In European countries, however, where the farms are of smaller average size, a number of interesting and successful experiments have been tried with motor-operated plows, and at the present time there are in Germany about a dozen electric plowing outfits which have demonstrated their economy in direct competition with steam plows. In its present stage of development the electric plowing outfit has some disadvantages as compared with the steam plow, but with more extended use these disadvantages, which are of a minor

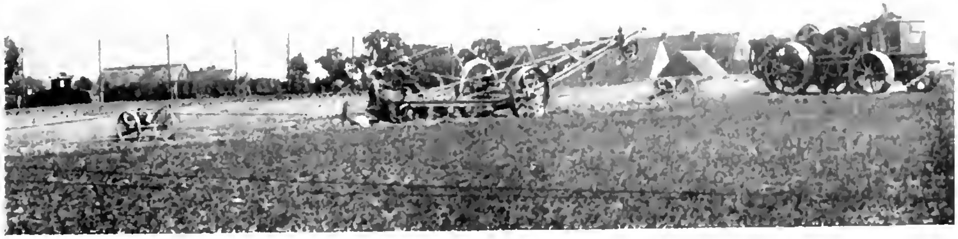


Fig. 14. View Showing Jack Carriage and Plow in Operation

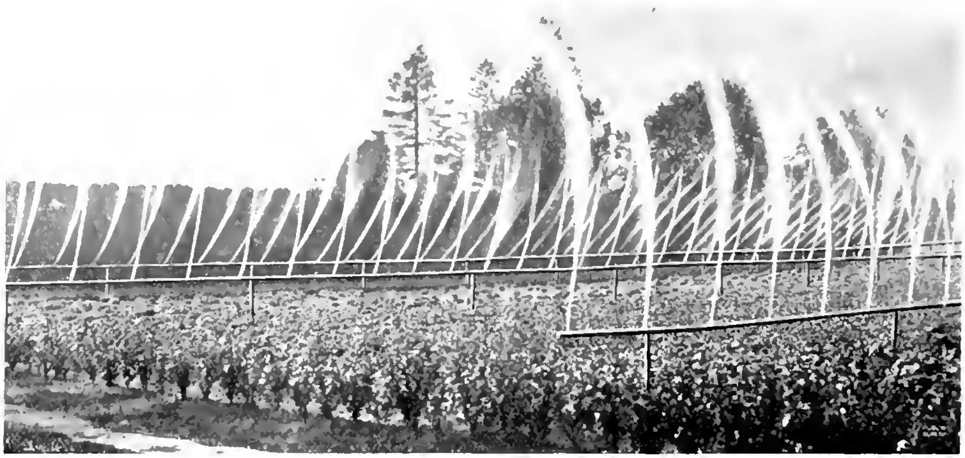


Fig. 15. Sprinkler System on Farm, Supplied by a Motor-Driven Pump with Remote Control

nature, will undoubtedly be eliminated. The steam tractor can be readily moved from place to place under its own power, whereas the electric plowing equipments heretofore used have had to be drawn to the field. The success which has been achieved by equipping gathering locomotives in mines with cable reels has made it entirely feasible to construct electric plowing outfits which will be automobile in operation. As a very large amount of power is consumed in electric plowing the adoption of the system involves the necessity for a larger generating outfit than would usually be found in an isolated power plant on the average farm; but on large farms and on those accessible to central station or electric railway circuits this objection does not obtain. On the other hand the electric plowing outfit weighs about 50 per cent less than the steam plow, and can therefore be run on fields, bridges and roads where the steam plow could not safely pass, and even in the case of the early experimental electric plows the first cost and operating expense was much lower than that of the steam plow. The use of electricity for this work obviates the necessity for carrying fuel and feed-water for the boiler and eliminates the labor involved in maintaining the steam pressure. There is no boiler to burn out, dangerous sparks to guard against, or refuse of combustion thrown on the field. The wearing parts are few in number and the simple and rugged con-

Fig. 16. Motor Driving Pump for Farm Irrigation

struction of the equipment minimizes the cost of maintenance and depreciation. In plowing irregular contours the use of the steam tractor is frequently hazardous, such as when operating on steep slopes, in which case the water does not cover the fire box and accidental burnouts or other injuries are liable to occur. The work of the electric plow is not interfered with even by extremely steep slopes.

Finally the cost of the steam plow is such that the average farmer cannot afford to purchase it and therefore hires it, whereas the electric plow can be constructed much more cheaply and may therefore be purchased outright by the owners of large or medium sized farms where mechanical plowing can be effectively adopted.

While varying in details the electric plow heretofore used has consisted of three principal units, namely: the plow itself; the jack carriage, as shown in Fig. 12, on which are mounted a motor, a drum for the cable which draws the plow, and the motor controller; and a simple anchor carriage, as shown in Fig. 13. In operation the plow is dragged in both directions across the field by means of an endless cable which passes between the jack carriage and the anchor carriage and which is alternately wound in opposite directions by means of the motor-driven drum on the jack carriage, as indicated in Fig. 14. There have been a few equipments of this same general type in which two jack carriages provided with motors have been used instead of the single motor outfit described above. Two men are normally required to operate the outfit—one on the plow itself and the other to manipulate the motor controller on the jack carriage. The motors used in the electric plowing outfits heretofore constructed vary from 80 to 120 h.p. in capacity, the jack carriage ranging in weight with the different sizes, from eight to thirteen tons. In order to insure the stability of the anchor carriage the wheels are mounted at an angle as shown in the illustration, and provided with wide vertical steel flanges. The weight of anchor carriages of this type varies from two to three tons, depending upon the character of the ground and the size of the motor equipment.

That the economic value of properly controlled irrigation and drainage systems is now very generally appreciated is indicated by the vast sums spent by governments and individuals in the development of numerous irrigation and drainage projects, depending for their operation upon either gravity or pumping equipments. The reasons which have been responsible for these larger developments apply with equal force to the reclamation of arid or submerged land on individual farms, and as a result many motor-driven pumping outfits have been installed for this work on farms where the gravity system was not available. Electric motors can be readily adapted to the operation of all types of reciprocating and centrifugal pumps, and due to the fact that the latter type ordinarily requires a high speed of rotation, motors can be designed for direct connection to the pump shaft, thereby insuring its operation at maximum efficiency.

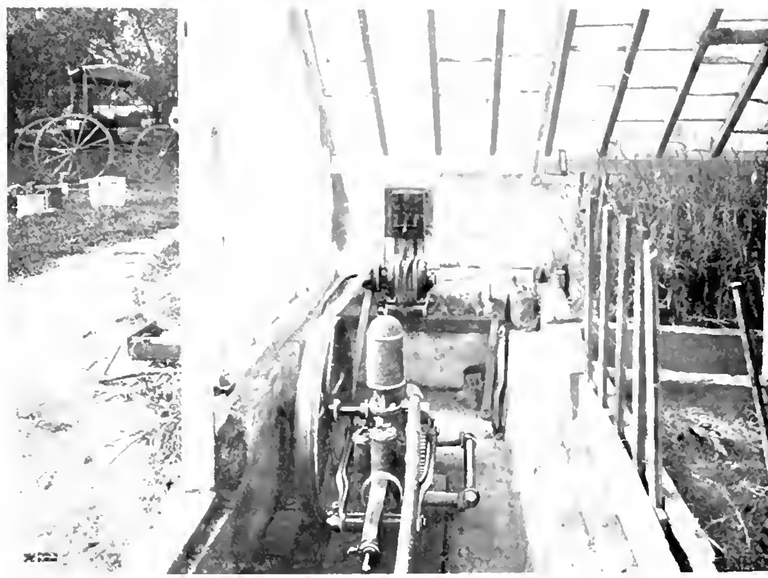


Fig. 17. Induction Motor Belt-Connected to Pump Located in Green House

The widespread adoption of motor drive for this service where electric current is available is due to its inherent superiority over the use of engines, in that the starting and stopping of motors does not require any special knowledge and may be safely performed by the class of labor ordinarily employed on farms or irrigation projects. Aside from starting, stopping and occasionally oiling the motor-driven pump, it will operate without attention. A small motor-driven pump used for farm irrigation is shown in Fig. 16.

In general the motor should be direct connected or geared to the pump, but in cases where irrigation pumping is required for short periods only owing to prevalence of drought or other causes, portable motor outfits similar to those previously described may be temporarily connected to pumps which are permanently located at the source of water supply. Under these conditions the motors are usually belt connected. The energy and initiative of progressive farmers have developed some unique applications of motor drive for pumping service. An interesting example of this is indicated in Fig. 15, which shows a sprinkler system on a farm near Rochester, N. Y. It consists of lengths of piping which are loosely mounted on small uprights and extend across the field in the manner shown; the distance between the pipes varying from thirty to approximately seventy feet. This system, which was first applied to an area of ten acres, has been extensively duplicated on other farms and in some of them the piping has been arranged at heights of from three to twelve feet above the ground; the object of elevating the piping in the latter instance being to permit the unobstructed movement of farm wagons. The sprinkler pipes are provided at short intervals, with small spraying nozzles, and the system is connected to a motor-operated pump located near a well or other source of water supply. As the electrical outfit can be controlled from a distance, the usual method on those farms where this system has been adopted is to mount the starting switch in any convenient building near the sprinklers, thereby rendering the operation of the latter wholly under the control of the man on the ground. Fig. 17 shows an example of this system applied to greenhouses, the sprinkler pipes being centrally located and the pump, motor and switch located in the greenhouse itself.

For water supply on farms the electric motor is incomparably superior to the windmill for the operation of pumps, both in regard to economy and efficiency. For the amount of water required on the average farm, a small compact motor-driven pumping set would cost approximately one-tenth as much as a windmill of equal capacity. Aside from the question of economy the motor-driven pump is always available and is susceptible of automatic regulation so that the water in a storage tank may be maintained at any required level by means of either float or pressure switches connected in the motor circuit.

Due to the prevalent use of lumber in the construction of farm buildings, and to the necessity of storing therein combustible materials, the matter of fire risk is of vital importance on farms, which, as a rule, are situated beyond the reach of efficient outside help in case of fire and must therefore depend upon their own equipment for protection.

The severe losses sustained in rural communities as compared with urban communities where adequate fire fighting facilities are available, is indicated by Government reports, which show that out of a total fire loss of over $215,000,000, in the year 1907, the loss sustained in rural communities was equal to more than 50 per cent of the total, while the number of fires was only slightly in excess of 36 per cent. The use of high pressure motor-driven pumps for fire protection on farms will provide the necessary facilities with a minimum outlay, as the cost of windmill structures and large storage tanks may be thereby avoided. The fire pump may be ordinarily connected in the water supply system, and on the breaking out of a fire, by simply throwing in a switch, the full water pressure is instantly available.

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.

The fact that the value of the products of American farms for the year 1910 is estimated at approximately $9,000,000,000, suggests the vast economic possibilities involved in the adoption of electric motors for the operation of farm and dairy machinery.

NOTES ON ELECTRIC LIGHTING

Part IV

By C. D. Haskins

Manager Lighting Department General Electric Company

I referred a little earlier to lightning arresters. The safety and success of rural overhead systems, particularly those systems which run through open and rolling country, depend to a considerable extent upon the use of lightning arresters in the proper way and in the proper place. The theory of the lightning arrester is no doubt well known to all of you. Its purpose is to provide a path to earth to carry off static discharges, and the structure of the lightning arrester must be such that it will take off this discharge without detrimentally affecting the line and especially without establishing a short circuit.

There is no more typical form of lightning arrester than the so-called multiple gap type. In its simplest form this arrester consists of a number of metal cylinders mounted on an insulating base of suitable material and separated by small air gaps, as shown in Fig. 3. These cylinders act like the plates of condensers in series, this condenser action being the essential feature of the operation of the multigap arrester.

When a static stress is applied to a series of cylinders between line and ground, the stress is instantly carried from end to end. If the top cylinder is positive, it will attract a negative charge on the face of the adjacent cylinder and repel an equal positive charge to the opposite face, and so on down the entire row. The second cylinder has a definite capacity relative to the third cylinder and also to the ground; consequently, the charge induced on the third cylinder will be less than on the second cylinder, due to the fact that only part of the positive charge on the second cylinder induces negative electricity to ground. Each successive cylinder, counting from the top of the arrester, will have a slightly smaller charge of electricity than the preceding one. The condition has been expressed as "a steeper potential gradient near the line."

When the potential across the first gap is sufficient to spark, the second cylinder is charged to line potential and the second gap receives the static strain and breaks down. The successive action is similar to overturning a row of nine-pins by pushing the first pin against the second. This phenomenon explains why a given length of air gap concentrated in one gap requires more potential to spark across it than the same total lenght made up of a row of multigaps. As the spark crosses each successive gap, the potential gradient along the remainder readjusts itself.

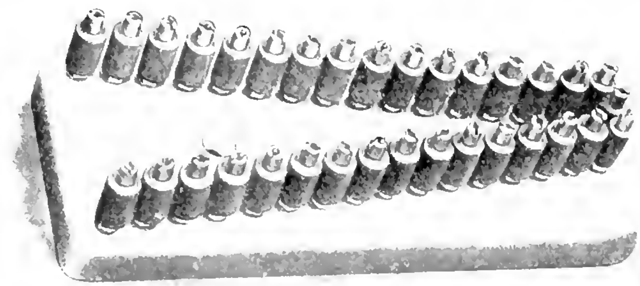


Fig. 3. V-Type Multigap Lightning Arrester

When the sparks extend across all the gaps the dynamic current will follow if, at that instant, the dynamic potential is sufficient. On account of the relatively greater current of the dynamic flow, the distribution of potential along the gaps becomes equal, and has the value necessary to maintain the dynamic current arc on a gap. The dynamic current continues to flow until the potential of the generator passes through zero to the next half cycle, when the arc extinguishing quality of the metal cylinders comes into action. The alloy contains a metal of low boiling point which prevents the reversal of the dynamic current. It is a rectifying effect, and before the potential again reverses, the arc vapor in the gaps has cooled to a non-conducting state.

In Europe a unique form of lightning arrester for high voltages has been built which excellently exemplifies the desired principle of all arresters. This form consists of a jet of water playing on a copper plate, with a gap between the jet nozzle and the plate of six to ten feet, depending upon the potential. When a discharge goes across, it is completely taken care of by the water jet but the dynamic current following breaks down and volatilizes the water, thus discontinuing the circuit for an instant and breaking the "short." In this country, the water jet system has not found favor because it is rather an unmechanical contrivance, and especially because it is space consuming.

Ordinarily, the best location for lightning arresters on pole lines is on the poles where the lines cross the highest points of land.

The latest and most highly perfected type of lightning arrester is commonly known as the "aluminum cell" arrester. This device is dependent for its proper functioning upon a peculiarly and highly interesting natural phenomenon—a principle so interesting as to merit special consideration.

Considered as a piece of apparatus, the aluminum cell arrester may be described as consisting of a series of aluminum cells between each line and ground, with intervening horn gaps. Now, an aluminum cell consists of cone-shaped aluminum vessels on the surface of which has been formed a film of hydroxide of aluminum with the electrolyte between these surfaces. The arrangement of these aluminum vessels is shown in Fig. 4.

The aluminum cell offers a high resistance to the flow of current *up to a certain potential*, but when that point, known as the "critical voltage," is reached, the film appears to break down, offering a free path to the discharge. The "critical voltage" has practically a fixed value (between 335 and 336 volts), and hence, by putting a number of cells in series, a structure is built up which offers no path for current at the normal voltage of the system. When, however, the voltage on the line rises, as in the case of static, to a value exceeding the critical voltage of the cells, a free flow of current due to the excess voltage will pass through the arrester to the ground. The action is somewhat analogous to that of a pop valve on a steam boiler.

The film of the cells gradually dissolves while standing in the electrolyte, and for this reason it is necessary to put current through the cells periodically to "rebuild" them. This is accomplished by closing the horn gaps, thus allowing dynamic current to flow through the cells and build up the films. The horn gaps are necessary because of the condenser action of the cells. If the cells were connected directly to the line without any intervening gap, charging current would continually flow through the arrester and this action would result in overheating the cells. In actual service, the cells complete are placed in steel tanks which are filled with oil.

Aluminum cell arresters are not used extensively for pole line duty, but are fast becoming universal for large power station service on the incoming and outgoing lines.

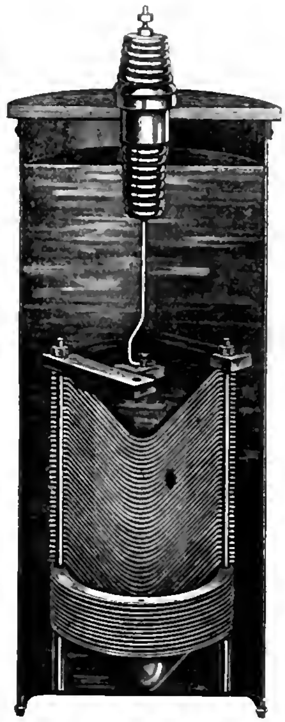


Fig. 4. Aluminum Cell Lightning Arrester

It should be remembered that lightning discharge is one of the most serious foes of all overhead systems. It is not only destructive to apparatus, coming into the station over the lines and breaking down the insulations of machines, etc., but it has also been responsible for very many disastrous central station fires. It is the purpose of the station arresters to "catch" and "send to ground" all such discharges.

On many alternating current distribution systems, we often find yet other steps taken to guard against this dangerous discharge. We find, for example, the grounding of transformer cores so that the breakdown, if it comes, may occur to the core of the transformer and thence to ground. We also sometimes find the grounding of transformer secondaries, a practice prompted by the same general considerations. These practices are to be commended under many conditions.

Another protective device which is often used on direct current systems is the "choke coil" or reactance, this commonly taking the form of a relatively small number of turns of conductor which offers no impediment to the passage of direct current but which inductively chokes down a static discharge.

I have already referred to the use of transformers in connection with secondary meshworks. I failed to state that the same three-wire distribution which is used so generally for dense territories on direct current is also used in the secondary distribution of alternating current. In fact, most houses today of any size are wired three-wire. It has always been practicable in transformer design to secure good regulation and small full load losses by the use of transformers large enough to take care of all possible load fluctuations. The matter of core loss, however, on all alternating current systems is a very serious matter. Twenty-four hours per day core loss is a very serious drain on the coal pile of any system. For this reason, there has always been a recognized demand for a device which would cut out the transformer when the load goes off, and vice versa. It is probable that every embryo electrical inventor has tried to devise something of this character. It is usually about the second thing at which they direct their efforts and the devices which result seem to be always and historically bad. Such was my first inventive effort.

As a result of this well recognized condition the project fell into disrepute and came to be looked upon as more or less of a joke, as was the flying machine fifteen or twenty years ago. Nevertheless, like the flying machine, this problem seems to have been fairly well solved; at least, there is in actual commercial operation in England today just this long dreamed-of device. Its purpose is to throw the load from a large transformer to a small one and vice versa as the load fluctuates. Thus, as the load falls, it is transferred in such a manner as to avoid heavy transformer losses under light load or no load duty. Transfer devices of this character have been operated in the laboratory up to voltages in excess of 15,000 volts, and it is not improbable that such mechanisms may be made to function reliably at yet higher voltages if the conditions demand the development.

From these statements, it will be seen that the "series gear," as the commercially developed transformer transfer device is called in England, is a new line device of great promise. It may well be possible that in this one new development a sufficient gain in efficiency may be achieved to change unprofitable to profitable systems.

In high tension transmission undertakings, the problem is, of course, to transfer power very cheaply from a ready source to that point where the market for current awaits its delivery. The market must, naturally, be sufficiently large to warrant the investment; that is, the size of the market and the distance to it must bear logical relation to one another. Justification for long distance transmission lines is found in two things; first, water power generation; and second, the generation of low cost power at the culm pile, or the practical equivalent, a point where full cost is abnormally low. Culm, of course, makes steam effectively. If the generated current can be transported more cheaply, unit for unit, than the fuel, then the work is sound.

Long distance transmission lines are generally carried on steel towers, with long spans between towers, and are normally high potential undertakings. Yesterday I referred to Michigan and California properties where lines are in operation at 100,000 volts or more. In Canada there is a line under construction which is to be operated at 140,000 volts, and there has been at least one line designed, I understand, for 160,000 volts. When the voltage goes above 50,000 volts, the line problem rapidly becomes more intricate.

Today the most popular form of tower line construction provides for the support of the line wires by the "suspension system." In earlier practice it was customary to use an insulator with a grooved top, even at the highest voltages, the wire passing over this groove and resting on the insulator rather than being suspended from it as is the present practice.

We now find the wires suspended from a series of porcelain or compound discs, each of these discs being designed to insulate for a given voltage, say 25,000 volts. Then a wire supported from the tower through two such insulators would be insulated for 50,000 volts; through three insulators, for 65,000 volts, etc.

The main purpose in high tension insulator design is to provide a sufficiently long path to prevent serious surface leakage. The favorite materials for insulators of this class are porcelain, rubber, gum compounds, and shellac compounds. When porcelain is used it must be highly vitrified, that is, highly non-hydroscopic. A simple method of testing porcelain for this quality is to break a piece (a dinner plate will serve well for experiment) and drop a very little ink onto the fresh broken surface. If the porcelain is non-hydroscopic, the ink will remain in a body where placed; otherwise, it will be drawn in or absorbed by the porcelain, spreading just as it would on blotting paper. I can tell you before you try that the dinner plate will prove to be bad porcelain electrically.

One of the minor difficulties in connection with transmission and distribution systems, but one which sometimes becomes rather serious, is the interference of such lines with telephone service, that is, the influence on telephone systems of nearby alternating current lines or alternating current wires on the same poles. It used to be quite common for electric lighting companies to obtain permission from ignorant but kindly disposed telephone companies to put their wires on the telephone company's poles.

The avoidance of such inductive interference is a relatively simple matter and is dependent upon even "balancing off" by frequent crossing of the wires. The methods of coping with this rather common trouble are well covered in detail in several text books.

I referred yesterday to the part played by the substation in distribution. Very large systems distribute to the outlying sections through substations. Boston, for instance, distributes current to twenty or more towns outside of the city proper. Most of these services are through "static substations," that is, simply large transformers which "step down" from the distributing voltage, say 6600 volts, to the intermediate voltage of generally 2300, and this again is locally stepped down to the lower service voltages. In many static substations the transformers run into large sizes. This means low losses, and it is obvious that their use effects economy in labor charges for station attendants. The materials (copper and iron) composing a transformer must work at very high duty and must therefore be kept cool artificially, for in large transformers the mass is very large in relation to radiating surface.

There are two independent lines to development in the transformer cooling art; the "air cooled transformer," in which cool air is forced through air ducts by motor-driven fans, and the so-called "water cooled" transformer, where the oil in which the transformer is immersed is kept cool by circulating water through coils within the oil tank, or by forcing the oil through coils immersed in cool water, as, for example, by pumping the oil from and to the transformer tank through pipes under the surface of a neighboring pond or stream.

Where it is desired to change the character of the current for local distribution from alternating current to direct current, we find the motor-generator or the "rotary" in use, and at times where the distribution system is of a frequency other than that required at the point of use, we find the "frequency changer"—a machine which is elementally an alternating current generator of the required frequency driven by an alternating current motor of the original frequency.

In connection with long distance transmission systems where the voltage is very high, as in certain California systems, for example, or indeed on any up-to-date lines of voltages higher than 23,000 or 24,000, one seldom finds insulated wire in use. All reliance is placed on the insulators themselves. At such potentials as 110,000 or 140,000 volts, the atmospheric radiation and leakage constitutes an appreciable loss. I have in mind one line on which the no-load atmospheric radiation is reported to be between 100 and 200 kw. The lines of this system are luminous at night with a soft blue brush discharge.

Many of the very large systems, traversing as they frequently do a mountainous country, are seriously menaced at times with frost and sleet. The weight of the wire is, of course, tremendously increased by such deposits, and over this unforeseen difficulty many an engineer has come to grief through failing to figure and provide for extra load.

One more word on line construction—the maintenance of crossovers. This seems a little thing, but in many instances it has proven to be a very serious one. Wherever high tension lines cross over electric light or telephone wires, the utmost precaution must be taken to prevent the possibility of the grounding of the high potential wires on those of low potential; otherwise, disaster is likely to result. There can be but very little doubt that at least one serious fire in one of our eastern towns was caused by the falling of 2300 volt wires across telephone wires. This is a feature of line construction which is too often neglected.

(To be Continued)

COMMERCIAL ELECTRICAL TESTING

PART XV

BY E. F. COLLINS

INDUCTION REGULATORS

SINGLE-PHASE REGULATORS

The IRS, or single-phase induction regulator is built for use with electric furnaces and for the control of single-phase lighting feeders. It comprises a primary and a secondary winding, the former being placed in slots on a movable core and the latter in slots on a stationary core. The regulator may be wound with two poles, four poles, six poles, or with any even number of poles; it may be cooled by an air blast, or it may be placed in a tank and cooled by oil, or by oil and water.

The voltage induced in the secondary winding depends upon the relative position of primary and secondary windings, the primary being in shunt and the secondary in series with the circuit to be controlled. Single-phase as well as polyphase regulators have a distributed winding for both primary and secondary, but the maximum pole face which can be covered by an active winding in a single-phase regulator, in order to produce the best results, is approximately 60 per cent. In the neutral position of the regulator, the secondary winding therefore encloses an area on the primary core not enclosed by an active primary winding, and the impedance would be extremely high if no auxiliary winding were provided. The slots of the primary which are not used for an active winding are therefore filled with a short circuited winding, so that in the neutral position of the regulator the current in the secondary induces a current in the short circuited winding, thus reducing the impedance.

The tests required are cold resistances, "boost" and "lower," core loss, impedance, heat runs and insulation. Cold resistance is measured as on transformers. The "boost" and "lower" test is made at the full potential of the regulator and therefore requires care, as the magnetic leakage is greater at normal potential than at a lower potential. Connections for this test are shown in Fig. 66.

The volts primary and volts secondary should be read on the same voltmeter by using a double-throw switch. Throw the switch to the primary and bring the voltage up to the correct reading on the check voltmeter B. Throw the switch to the secondary, bring up the voltage to that noted on the check voltmeter, and read the secondary voltage. Take these readings at maximum "boost," neutral, and maximum lower positions. The turns of the handwheel from maximum "boost" to neutral and from neutral to maximum lower should be counted

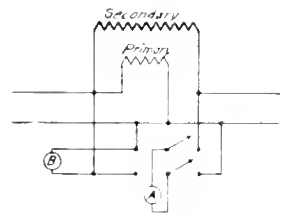


Fig. 66. Connections for Boost and Lower on Regulator

and recorded. The induced secondary voltage must be added to the primary voltage at maximum boost and subtracted from it at maximum lower.

Check the index plate on the handwheel to see if it is correct; that is, see that the voltage is boosted when the index is turned in the direction indicated by "raise." In addition to the boost and lower test, the induced voltage of the secondary coil should be taken at maximum boost and maximum lower with full voltage on the primary coil. This is to act as a check on the boost and lower test. In taking readings for the boost and lower curve, great care should be taken in obtaining points near the end of the segment. About twenty points in all should be taken from maximum boost to maximum lower, holding the primary voltage constant and reading secondary volts at different positions of the armature.

Impedance

Impedance is always measured on the secondary winding, as it is impossible to force full load current through the primary winding when at the neutral position. In taking the curve, supply full load current to the secondary, with the primary short circuited through an ammeter, and take readings of watts secondary, volts secondary, and amperes primary at various positions of the armature. At maximum boost position take an impedance curve from 50 per cent full load to 150 per cent full load. The full load point of impedance for general tests should be taken at the maximum boost position, unless other instructions are given. Always record the temperature.

Core Loss

On the IRS type of regulator with the permanent short circuit on the armature, the core loss must be taken from the primary winding. The power factor will be low, due to the air gap, hence considerable care must be taken in making the test. Take a core loss curve at maximum boost from 50 to 150 per cent normal potential, also hold normal potential and take readings at various positions of the armature, reading amperes and watts primary. In taking single point core losses for general tests, the armature should be in the maximum boost position.

Normal Load Heat Run

The heat tests are usually made by pumping one regulator back on another; they may, however, be loaded on water boxes or pumped back against a suitable bank of transformers. The permanent short circuit on the armature introduces complications in the heat run, since at any position except maximum boost and maximum lower, the short circuited coil carries some current if the impedance voltage is supplied from the secondary.

The amount of current in the short circuited coil depends upon the position of the armature; hence, in taking a heat run, connect the primaries of the regulators in multiple and apply full primary voltage at the proper frequency. Ammeters should be placed in each primary circuit and the secondaries should be connected in multiple through an ammeter. Place the armature of one regulator in the maximum boost position and shift the other until full load primary and secondary is obtained on the first regulator. The other regulator will have full load secondary current and a partially loaded primary; the short circuited winding on the armature accounting for the current not appearing in the primary. Both regulators would generally pass on the results of these heat runs. When special guarantees are required, however, the heat run should be finished on the first regulator, and then the second regulator should be run with the armature in the maximum boost position.

Overload heat runs are usually taken as a continuation of the normal load heat run. To shorten the heat run, the regulator, if of the air blast type, may be operated for a short while without air; if oil cooled, it may be operated at an overload; while if oil and water cooled, it may be operated for a time without water. Careful inspection should be made for oil leaks and other mechanical defects.

Hot resistances should be taken in the same manner as on transformers.

The insulation tests consist of double and high potential tests and are taken in the usual way. Although only a low voltage is induced in the secondary coil, it is in series with the circuit to be controlled, and should, therefore, have the same potential applied as is applied to the primary winding.

Operating Motor Tests

If the regulator is provided with an operating motor and limiting switch, they should be tested during the early part of the heat run so as to avoid rewiring after the heat run is finished. The motor and limiting switch should be connected according to the proper sketch, and readings of the current should be taken at normal potential and frequency, with the motor disconnected from the shaft and with the motor operating the regulator in both directions at no load and at full load. When the regulator is under full load, the motor should operate it from one extreme position to the other. To keep load on the regulators while this is being done, the hand-wheel of only one regulator need be turned. The time required to travel from one end of the segment to the other should be taken and recorded. The limit switch should be adjusted so as to work properly.

Induction regulators of the polyphase type are used principally with rotary converters, but are well adapted to control polyphase transmission circuits. As in the IRS type, they may be either air blast cooled, oil cooled or oil and water cooled. The primary winding is connected in shunt and the secondary in series with the circuit. In the polyphase induction regulator, the voltage induced in each phase of the secondary is constant, but by varying the relative positions of the primary and secondary, the effective voltage of any phase of the secondary is varied from maximum boost to zero, and from zero to maximum lower.

Referring to Fig. 67, which represents graphically the voltage of the three phases of a three-phase or IRT regulator, let AAA = the line voltage or the e.m.f. impressed on the primary. This is shown by the large circle. Let BA, BA and BA equal e.m.f. generated in the secondary coils, which is constant with constant impressed e.m.f. This is shown by the three small circles on the circumference of the large circle. BBB shows e.m.f. induced in secondary coils directly in phase with the primary impressed e.m.f. This is the position of maximum boost. Positions CCC represent the neutral position, and DDD the maximum lower position. EEE represents a position between neutral and maximum lower.

By changing the position of the armature with respect to the field the secondary voltage may be made to assume any phase relation with respect to the primary e.m.f.; it can be in series with it or directly opposed to it. This movement of the armature is obtained by means of a segment on the shaft which meshes with a worm on the small operating shaft. The regulator may be arranged for hand operation only, or can be motor operated. Either a direct current or an induction motor may be used. The motor is controlled by a small double-pole double-throw switch on the switchboard, by means of which the voltage is raised or lowered as desired.

To stop the regulator on reaching the limits of regulation when moving in either direction, a limiting switch is provided which opens automatically. If properly connected, however, this automatic cut-off does not interfere with movement in the opposite direction, which can be obtained by the double-pole double-throw switch.

The winding of the primary and secondary is similar to that of a Form M induction motor the primary being placed on the movable core.

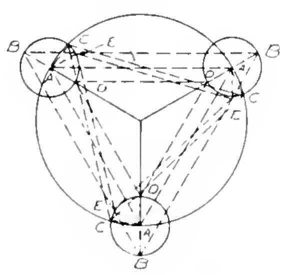


Fig. 67. Regulator Diagram Three-phase

For a three-phase or six-phase regulator the primary may be Y- or delta-connected; for and IRH six-phase regulator, the primary may be connected diametrically. The secondary or stationary winding is placed on the stationary core and is an open winding, each section or phase being connected in series with the corresponding phase of the line to be controlled.

The tests required are cold resistance, boost and lower, core loss, impedance, heat run, hot resistance, double potential for one minute, one and one-half potential for five minutes, and high potential test. If the

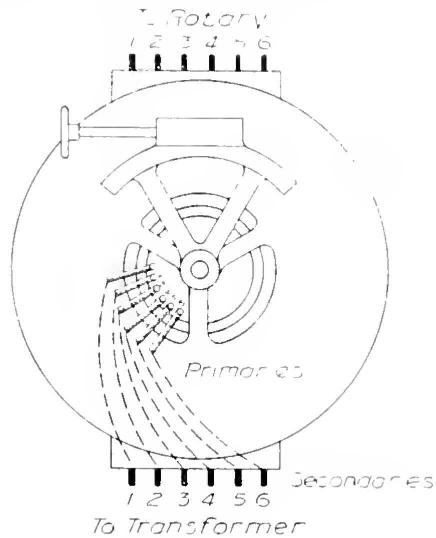


Fig. 68. Six-phase Regulator

regulator is motor operated, the motor should be tested during the heat run to save rewiring. Air readings should be taken on the air blast regulators.

Cold Resistance

Before starting the tests, carefully check all circuits. If the secondary coils have two studs on each end per phase, test to see if the studs are connected in multiple or if each secondary consists of two separate coils which are connected in multiple by the cable lugs. If the regulator is six-phase IRH, test to see if there are two primary circuits. On diametrically-connected IRH's, (Fig. 68), primaries 1 3 5 should be one set, and 2 4 6 the other. On a delta-connected IRH regulator, 1 4, 2 5 and 3 6 should give proper circuits. If each secondary circuit has two coils that are connected in multiple by the cable lugs, the top stud on one side is generally connected to the bottom stud on the opposite side, and vice versa.

Measure the resistance as on a transformer. In recording the secondary resistances, a note should be made of the place on which the drop lines were placed. Take the resistance of each secondary coil and make a sketch showing the numbers that have been given to the various circuits. Record the temperature of each coil, or of the oil.

Boost and Lower

The boost and lower test is made at normal voltage and frequency. On three-phase regulators, apply a balanced three-phase voltage to the primary, using a three-pole double-throw switch to transfer the voltmeter from the primary to the secondary. (Primary and secondary here refer to the voltage to be controlled and the controlled voltage respectively.) The regulator must be connected as in service, the primaries being in shunt and the secondaries in series with the circuit to be controlled. A voltmeter should be placed across one phase for a check. Fig. 69 shows the proper connections for a three-phase boost and lower test. Adjust the voltage by the voltmeter that is used on both primary and secondary, and note the readings on the check voltmeter. Throw the three-pole switch to the secondary and read the voltage on the corresponding phase of the secondary. Do this for all three phases at maximum boost, neutral and maximum lower. A curve of about twenty points should be taken on one phase.

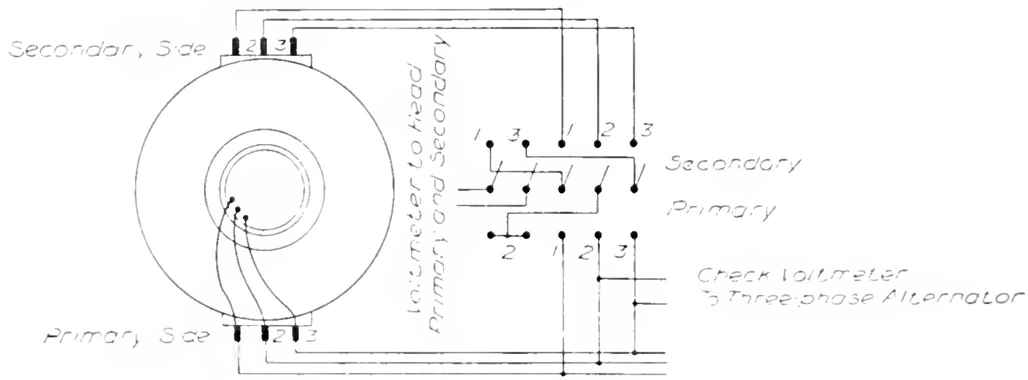


Fig. 69. Connections for Boost and Lower—Three-phase Regulator

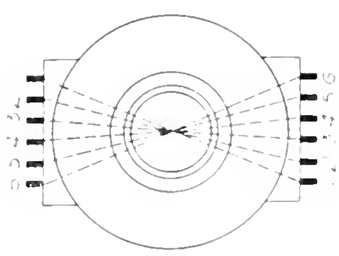


Fig. 70. Regulator—Six phase

The voltage balance should be taken at maximum boost, neutral, and maximum lower. Count the turns of the handwheel from maximum boost to neutral and from neutral to maximum lower and record the number to afford a check on the mechanical construction. Maximum boost and lower do not always come at extreme ends of segment. The voltage readings should be taken at every turn of the handwheel for a few turns from each end, to locate the maximum positions. Check the index on the handwheel to see that it indicates the proper direction for boost and lower. The induced voltage in the secondary coil should be measured and recorded, as well as the boost and lower.

In some types of IRH regulators, the terminals of the secondary coils are crossed instead of being directly opposite each other. (See Fig. 70.) In such cases take care to properly record the boost and lower and make a clear sketch showing the arrangement of the secondary terminals. Boost and lower may be taken on six-phase IRH regulators as though they consisted of two separate regulators; that is, the test may be made on 1-3-5 and then on 2-4-6. Six-phase voltage

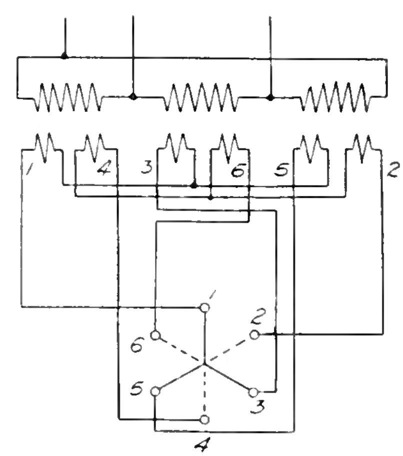


Fig. 71. Method of Connecting for Six-phase Voltage

must, however, be applied and a set of six-phase boost or lower readings taken to determine if the regulator is satisfactory.

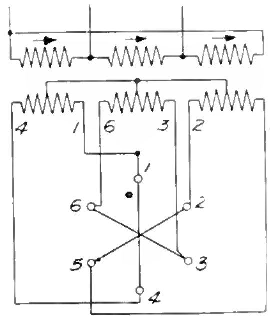


Fig. 72. Connections for Six-phase Boost and Lower

Fig. 71 gives the method of obtaining six-phase voltage, which should be tested before proceeding. With the connections shown, the voltages corresponding to the six sides of a hexagon can be obtained by reading 1-2, 2-3, 3-4, 4-5, 5-6 and 6-1. Unless six-phase voltage is used, don't try to make a boost or lower test. The induced secondary voltage of each secondary coil should be recorded.

The boost and lower test on IRH, or diametrically connected regulators, must be made by applying a six-phase diametrically connected voltage, tested as previously described. The transformer connections are shown in Fig. 72, a neutral point being made so that six-phase voltage may be read. In taking boost and lower, read the diametrical voltage, carefully checking the six-phase boost or lower and recording it as the diametrical boost or lower. Measure and record the induced voltage across each secondary coil.

(To be continued)

A MODERN INDUSTRIAL POWER PLANT*

By J. A. Wilson

American Locomotive Company

An industrial power plant to be a success at the present time must be designed and constructed for the particular purpose which it is to serve. That power-plant engineering is a most rapidly developing branch of the profession is acknowledged, and an account of one of the latest and most completely equipped power plants will prove of value to all who are interested in this subject.

The power plant of the American Locomotive Company at Dunkirk, N. Y., is described in this article, for the reason that it illustrates the advances in many features which have taken place within the last few years. All power used in the plant, which is of three kinds, i.e., steam, air and electricity, is distributed from one centrally located power house.

Perhaps the three most noticeable features are a mixed-pressure turbine for utilizing exhaust steam, a hot water heating system, and an efficient overhead lighting system. Advantage is also taken of the most modern forms of auxiliary apparatus, such as coal and ash conveyors, feed-water heaters, superheaters, condensers, inter and after coolers for air compressors, etc., etc. The electrical equipment also is particularly well adapted to the needs of a manufacturing plant.

The older method of furnishing power was by means of steam engines located in various parts of the plant. These engines drove line shafting, fans, etc., and supplied all power for shops in their immediate vicinity. The steam to drive the engines was generated in one or two boiler stations and transmitted by pipes to the prime movers. If the boilers were much scattered, as was often the case, they had to be fired by hand, and in any event were seldom fired automatically. The usual method was to wheel in the coal from the pile outside, dump it in front of the boilers and shovel it in by hand. Feed-water heaters were little in vogue and super-heaters rarely seen. The latter could have been used to marked advantage for storing up heat in steam to be transmitted to a distance and thus preventing many of the troubles due to condensation in the mains. The engines, being comparatively small, were usually operated non-condensing and were not as well designed nor as efficient as the more powerful ones now built.

With the advent of the electric motor, the generating equipment was partially centralized in two or more power houses, and the direct current power transmitted at low voltage to motors which were substituted for the main line shaft engines. This arrangement, of course, was a great step in advance, but, as the plant grew, a demand arose for higher voltages for power transmission. The simplicity and low maintenance charges of the induction motor led the officials to decide,

* Reprinted from *Loco.*

in 1907, to centralize the power at one point and install the most efficient methods for power distribution.

The modern method of supplying power is to place as far as possible all steam apparatus in one centrally located power plant, to generate electricity here, and to distribute it to motors located in the various shops. The number of men required for operating a plant of this kind is much less than for a plant of the old kind. The engines can be equipped with condensers and other auxiliary apparatus may be installed and maintained at much less cost. Loss of power by radiation is much decreased by doing away with long lines of steam piping.

The great strides made in power engineering during the past few years are well illustrated by the Dunkirk power system.

The power house is located as nearly as possible at the center of demand of the power-using shops. It is of steel construction with brick walls and is divided into three compartments; namely, boiler, engine and transformer rooms. The floor is of concrete supported by steel work with a basement under the engine and boiler rooms, and the roof is of the usual plank and gravel type supported by steel trusses.

The boilers are eighteen in number, each of 300 h.p. capacity, working at 150 pounds pressure. They are all water tube boilers of the Babcock & Wilcox type, and are equipped with B. & W. superheaters and chain grate stokers.

The coal is delivered automatically to the stokers from a bin overhead, which extends the length of the boiler room. The bin is used as a storage for coal and is filled automatically by means of a link belt conveyor, which is nothing more nor less than an endless chain of buckets driven by electric motors. Coal is brought into the plant in cars and is dumped into a hopper beneath the tracks just outside of the power house. This hopper feeds into a coal crusher through which the coal passes into a feeder for the belt conveyor which elevates it to the bin in the boiler room. Small hand cars carrying chutes run on tracks in the basement between the two rows of boilers. When ashes are to be taken from the boilers, the chute is moved under a boiler and the ashes are transferred by it directly onto a link belt conveyor which lifts them into a hopper outside of the power house in readiness to be dumped into an ash car. Coal and ashes are thus handled without manual labor, except that required for moving the chute car and to prepare ashes for dumping.

Feed water for the boilers has to be forced into the boilers against a steam pressure of 150 pounds per square inch. This is done by means of two pumps located in the basement of the boiler room. In the basement of the engine room is a hot well into which condensed steam from the various apparatus is fed, together with hot cooling water from the compressors, etc. The boilers are fed from this well, the pumps drawing the water from the well through a feed water heater and then forcing it into the boilers. The heater is of the open Cochrane type, is rated at 6000 h.p., and heats the water to about 210° F. by means of exhaust steam from the reciprocating engines. The heater is located in the boiler room floor above the pumps, this arrangement being necessary in order that the pumps shall operate at all. If the pumps were above the heater they could not be fed by gravity, and this is essential where the water is hot. If they operated on the usual suction principle, the hot water would turn to steam when a partial vacuum was created above it in the pump cylinder and the atmospheric pressure could not force water into the pump cylinder against this steam cushion.

A description of the boiler facilities would be incomplete without mention of the two 200-foot reinforced concrete self-supporting stacks.

It is a conceded fact that direct and alternating currents each have their separate field of usefulness. Industrial plants have in a majority of cases adopted either one kind or the other. In this plant we find a happy combination of the two.

Power Plant Equipment.

1. Ingersoll-Rand 4000 ft. air compressor, electrically-driven.
2. Ingersoll-Rand 4000 ft. air compressor, steam-driven.
3. Laidlaw-Dunn-Gordon 2000 ft. air compressor, steam-driven.
4-5. Two 800 h.p. tandem compound Corliss engines, direct connected to 600 kw. direct current 250 volt generators.
6. 500 h.p. vertical Buckeye engine direct connected to 350 kw. direct current generator.
7. 300 kw. General Electric reversible motor-generator set: 440 volt, 3-phase, 25 cycle alternating current; 250 volt direct current.
8. 1500 kw. mixed pressure Corliss turbine, horizontal type.
9. Alberger surface condenser.
10. Circulating pump.
11. Pump for cooling tower fans

12. Cochrane oil separator.
13. Cooling towers.
14. Underwriter's fire pump.
15. After coolers.
16. B. & W. 300 h.p. water tube boilers.
17. Coal crusher track hopper.
18. Evans-Almirall exhaust steam heater for hot water heating system.
19. Evans-Almirall live steam heater for hot water heating system.
20. Circulating pumps for above.
21. General Electric 500 kw. transformers.
22. Oil switches.
23. Cutout switches.
24. Traveling chute.
25. 200 foot stack of reinforced concrete, ten feet diameter.
26. 6000 h.p. Cochrane feed water heater.

The lighting of the plant is carried on a 350 kw., 250 volt, direct current generator direct driven by a 500 h.p. vertical Buckeye cross compound engine. A separate circuit is employed to ensure a minimum voltage fluctuation. Two hundred fifty volts are used on account of the great distances of transmission and the added advantage this voltage gives in being able to supply additional direct current power to the power lines, or of being able to draw from the power circuit in cases of a shut down on the lighting unit.

Two hundred fifty volt direct current power is supplied from two 600 kw. generators direct driven from two 800 h.p. tandem compound Corliss engines. This direct current power is used for cranes, to which service it is particularly adapted; first, on account of the great variation in speed of series-wound direct current motors for various loads, thereby increasing the speed of operation in the shops (this feature applies particularly to five and ten ton crane service); secondly, on account of the crane load having no detrimental effect on the power factor of the plant, which would have been the case if induction motors had been installed for this service. When power is purchased, the consumer usually has to pay for his maximum demand and is also penalized when his power factor is low. The locomotive erecting shop crane service is such that large amounts of power are required for short periods in the lifting of heavy engines. Although the variable speed direct current motor is not as economical as the constant-speed machine, there are cases where it is advantageous to install it, as the increase in production of the machine tool more than offsets the loss in power economy.

The 440 volt, 25 cycle, 3-phase alternating current is generated by a 1500 kw. horizontal Curtis mixed pressure turbine generator that normally runs on exhaust steam which is received from the reciprocating steam equipment at five pounds gauge pressure. The speed of this turbine is 1500 r.p.m. In the event of a shortage of exhaust steam, live steam is automatically admitted to the turbine through a separate supply line fitted with suitable high-pressure valves and nozzles. Alternating current is used for practically all the constant speed driving throughout the works.

A balance between direct and alternating current is maintained by means of a 300 kw. reversible motor-generator set. The electric wiring system has been very carefully laid out, and the investment in copper has been sufficient to insure that the drop in voltage to the most remote motors in the plant is not over 7 per cent, the average drop being 5 per cent.

In addition to the foregoing power facilities the works can receive 1500 kw. of power from Niagara Falls and the switchboards are so arranged that this power can be tied in parallel with the steam generating system. This is one reason why 25 cycle power was decided on, as the Niagara system operates at this frequency. The transformer arrangements will be described later.

The switchboard is located on a platform so that a clear view can be had of the whole engine room. The switches for the transformers are controlled from the board, as is also the starting of an electric air compressor and the reversible motor-generator set.

A surface condenser with 10,000 square feet of cooling surface is used in connection with the turbine. The condenser creates a vacuum of about thirteen pounds, or reduces the steam to about two pounds absolute pressure, thereby giving the turbine a working pressure of eighteen pounds. The condenser, together with the necessary vacuum, circulating water and condenser water pumps, is located in the basement under the engine-room floor. A large volume of water is required in connection with a condenser and, as city water is expensive and the lake too far away for water to be pumped from it economically, two cooling towers were installed so that the condenser water could be cooled and used continuously. The cooling towers are built of sheet steel in the form of stacks; they are provided with wire slats and located outside of the room. The water is pumped into the top of the towers and runs down the slats, while air is forced through by means of fans in a direction opposite to that taken by the water. The fans are operated by Pelton waterwheels driven by back water, except when atmospheric conditions allow natural draft operation. The cooled water drops into a basin at the base of the towers, from which it is pumped to the hot well.

A hot water system is used for heating the shops, the water for which is heated by exhaust steam. As water has a density of about 1700 times that of steam, it has great heat-storing capacity and the quantity of exhaust steam may fluctuate considerably without greatly affecting the temperature of the heating water. This system is, therefore, particularly well adapted to a plant in which exhaust steam is used for power, as the heating system may be shut down for a few hours while the peak load is on the power units. The water is carried to the shops in eight-inch mains heavily coated with non-conducting material to prevent radiation. Both live and exhaust heaters are provided so that live steam can be used in extremely cold weather, or in case exhaust steam is not available. This system has a distinct advantage over the present method of heating with exhaust steam, where heating coils, blowers and pumps are required in every shop, as it consists of one set of pumps and heating tanks that can be taken care of by the power-house force. The saving in labor, power and repairs is considerable.

The compressed air equipment consists of three two-stage air compressors, two of which are steam-driven, with capacities of 2000 cubic feet per minute and 1000 cubic feet per minute, respectively, and one electrically-driven with a capacity of 1000 feet. This gives a range from 2000 to 10,000 cubic feet of free air per minute. The air is compressed to 100 pounds per square inch and is carried to the shops by means of ten and twelve-inch pipes, where it is used for running air drills, hammers, hoists, riveters, moulding machines, etc. The compressors are each equipped with an inter-cooler and an after-cooler for cooling the air before it goes into the high-pressure cylinder and into the pipe lines, respectively. The electric compressor is driven by a constant speed synchronons motor, but is equipped with a governing device which automatically controls the amount of air taken into the cylinder so that the compressor can be run efficiently at light loads.

In a description of the engine room mention should be made of a thirty-ton overhead traveling crane, which has already proven itself very useful and a good investment through saving time and labor in assembling machinery. The power house is illuminated by overhead lighting units of large candle-power, thirty-two and sixteen candle-power incandescent lamps having been practically eliminated.

A continuous oiling system is being installed which will reduce labor and give great economy in oil, as the filtration and purification of the oil is carefully taken care of by suitable equipment.

In a separate room adjacent to the boiler room is located transformer equipment for handling 1500 kw. of 60,000 volt, 3-phase, 25 cycle power, which is obtained when necessary from the Niagara, Lockport and Ontario Power Company. The transformers are water cooled and connected delta-delta so that in case one transformer is out of commission the plant can operate temporarily on two transformers.

A low pressure turbine was decided upon for this plant, because the investment was much less than would have been necessary for boilers and non-condensing reciprocating engines to do the same work. The turbine, moreover, is a fuel saver. Although the new plant has not been in operation more than two months, a considerable decrease in coal burned per kilowatt developed has been noticed. Formerly thirty pounds of steam per hour were required for every kilowatt developed, when using steam from 150 pounds per square inch to one pound per square inch and exhausting to atmosphere. This steam is now directed to the intake on the turbine, and when the condenser maintains twenty-six inch vacuum, a kilowatt-hour is developed on every forty-five pounds of exhaust steam. If the conditions are favorable for condensing and a vacuum of twenty-eight inches of mercury is obtained, a kilowatt-hour is developed on thirty-five pounds of exhaust steam. This means that we can expect an increase in power output of at least 60 per cent without burning another pound of coal. Looking at the matter in another light, suppose that a load of 1000 kw. was maintained for twenty hours per day for 300 days a year. Under the non-condensing conditions, three pounds of coal would be burned per kilowatt-hour. Under new conditions, two pounds of coal will be burned per kilowatt-hour, making a saving of one pound of coal per hour for every kilowatt generated.

RECENT DEVELOPMENTS IN SMALL DIRECT CURRENT MOTOR DESIGN

THE CVC MOTOR

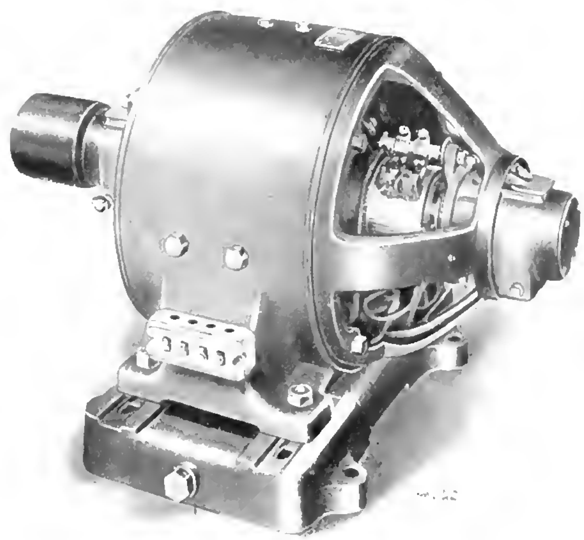
By W. D. Bearce

A moment's consideration of the problem of small electric motor design and manufacture shows that it involves nearly all the difficulties that confront the designer and builder of large machines, imposing, as well, some additional conditions. Small motors are often limited in dimensions by the design of the machine to which they are to be attached. In operation motors of relatively small output, although often called upon for just as exacting service, generally receive less care and attention than larger units. Notwithstanding these severe conditions, the design of small motors has steadily improved. Mechanical friction has been reduced in all moving parts; electrical and magnetic losses in active material have been lessened; and furthermore, the factor of reliability of the best small motors today surpasses that of the best large motors made a few years ago.

The means by which this progress has been attained are well shown by a study of the General Electric Company's most recent designs of direct current motors, designated by the type letters "CVC." The development of the CVC motor has resulted in part from the increasing application of individual drive to many machines, and more especially to machine tools where the conditions of the service often require that the overall dimensions of the motor be as small as possible; that the overload capacity be liberal; and that the commutation under varying conditions of load be substantially sparkless. In addition to the aforesaid requirements is coupled the necessity for high efficiency and in general absolute service reliability. The means employed by the designers of the CVC motors to produce a commercial motor having the required characteristics for this service are interesting because the design represents all the latest developments, including the feature of artificial ventilation, which undoubtedly marks an important step in the advance of small motor design.

In large dynamo electric machines of almost every type considerable dependence is placed upon the proper ventilation of the parts for the maintenance of low temperatures. In large alternators rotary converters, and motor-generators, by reason of the greater size of parts, more ample space factor, etc., it is possible, by the use of ventilating ducts and careful attention to the shape of the moving parts, to create artificial ventilation amply sufficient to carry away the heat.

In the smaller sizes of direct current motors, however, complete ventilation of all the parts is not such a simple matter to accomplish,



The CVC Motor

as the necessarily compact construction does not allow the use of a sufficient number of ventilating ducts in either armature or field. Then, too, the armature punchings are usually assembled directly on the shaft and, as both armature and field frame are comparatively long and of small diameter, the tendency is to form small pockets which imprison the air and therefore prevent the natural heat radiation.

It is evident that if the amount of air required for cooling be increased by providing definite circulation through the frame, all the active iron and copper in the motor can be used to greater advantage and its maximum output delivered with a much larger factor of safety.

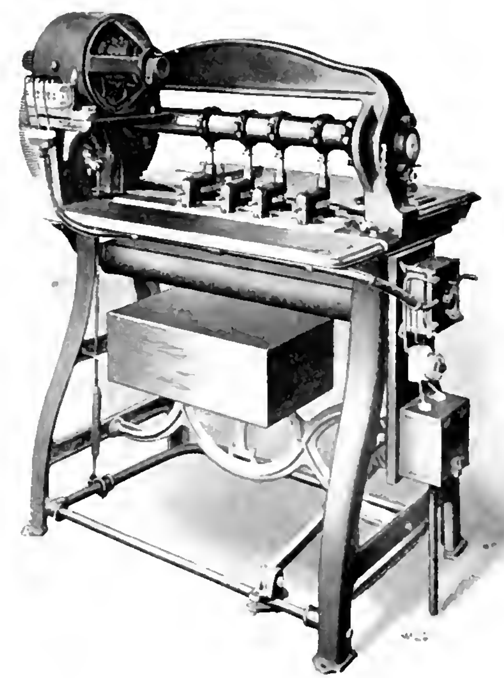
Artificial ventilation is accomplished in the CVC type by means of a fan, which is shown in its relation to other parts of the motor in the accompanying illustrations. The ventilating fan, which has been in use for some years by many of the principal European manufacturers, produces a positive circulation of air in a definite direction, resulting in a more economical use of the active iron and copper, and a more uniform temperature throughout the machine.

Armature of CVC Motor

In specifying heat rise on armature or field, the surface temperature is usually referred to; the actual temperature of the inner parts being somewhat higher. Careful tests have shown that not only will the maximum temperature be lower with forced ventilation, but that the difference in temperature between the outside and the inside parts will be notably less. This lower temperature insures preservation of the insulation as well as a safe limit for the ultimate maximum temperature. With provision for positive cooling, the overload capacity is appreciably increased without additional radiating surface.

While the power used to drive the fan must, of course, be charged to the losses within the motor, it does not necessarily follow that a motor designed for artificial cooling will have a lower efficiency. On the contrary, the watts lost by reason of the use of the fan are more than compensated for by watts gained through the elimination of heat losses.

The small motor, besides being necessarily of limited dimensions, is also frequently at a disadvantage through being installed in some inaccessible place where inspection is almost impossible. It is therefore very essential that the motor be so designed that it will operate without sparking both at partial loads and at reasonable overloads. On this account, as well as to secure good regulation at various loads, the prime requisite of a successful design is magnetic stability, or the ability of the magnetic field to resist the distorting tendency of armature reaction. The distortion of the field to any great extent has a disastrous effect on the commutation as well as on the regulation of the motor. Designers aim to secure a "stiff field," that is, they want the number of effective ampere turns, or the magnetizing force on the fields, to be large in comparison to the distorting field due to armature reaction. Under all varying service conditions a liberal allowance of ampere turns is necessary to produce the requisite "stiff" field to prevent sparking, and consequently the size of the frame would ordinarily have to be relatively large; but since the conditions of service impose limitations as to dimensions, special expedients have to be resorted to in effecting the necessary compromise in design.



Application of CVC Motor to Punching Machine

In the CVC motors, forced ventilation has enabled the designers to secure magnetic stability without increasing the size of the frame beyond desirable limits. Commutating poles have also been utilized to further perfect the commutation and render possible sparkless commutation with heavy overloads and with rapid fluctuations in the power output. Sparkless operation means reliability and capacity for long service, because the life of the motor depends largely on the life of the commutator, which in turn depends upon its capacity to carry fluctuating loads and maintain a well burnished surface.

Other interesting features of the design may be noted in the illustrations.

GRADING OF DIELECTRICS

By W. C. Smith

Only within the last few years has the subject of grading of insulation assumed much importance. When transmission voltages were comparatively low and the total thickness of insulation on a conductor was therefore small, little attention was paid to the arrangement of that insulation. At the present day, however, when commercial cable systems of twenty or twenty-five thousand volts are not uncommon, and when there is every likelihood of still higher voltages being reached in the near future, such economies as can be effected by a scientific arrangement of various insulating materials assume a very high value.

In the special case of the high voltage transformer terminal, which can be considered as a short length of high tension cable, we have an admirable field for grading; for in this instance we are confronted with a problem no less than to provide a thickness of insulation at the point where the lead passes through the cover to stand 250,000, 500,000 and even 1,000,000 volts.

The expression, "grading of insulation," was proposed by Mr. Mervyn O'Gorman in a paper read before the British Institute of Electrical Engineers, March 7, 1901. The definition as given by him was, "A method of adjusting the specific capacity, dielectric strength, and conductivity of the covering of a cable so that the materials composing it occupy the best possible positions, whether for resisting puncture or diminishing the energy loss in the insulation."

Consider two flat metallic plates separated to a given distance by some homogeneous dielectric, such as air, the plates being charged to such a potential difference that the air just barely resists breakdown. The potential gradient is obviously constant throughout the air space. Now, if we introduce a certain thickness of a second dielectric material of higher specific inductive capacity, such as ebonite or glass, we find, by experiment, that the air breaks down at once, although the resistivity of the newly inserted dielectric may be greater than that of the medium it has displaced. This experiment was conducted by Tesla, and from it he concluded that the substances which had previously

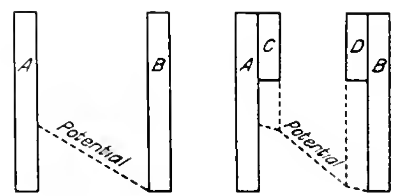


Fig. 1

been considered to have a higher dielectric strength than air were actually of less resistance than air. The true explanation, however, has since been shown by various experimenters to be as follows: The potential gradient throughout the air is just low enough to prevent breakdown, but when the new dielectric of higher specific inductive capacity is inserted, the potential gradient in the air becomes steeper, thereby causing breakdown. The strain is then thrown on the new dielectric, which becomes heated, and failure soon results. Fig. 1 shows diagrammatically the phenomenon.

We therefore see that, in general, when insulating flat surfaces from each other by a heterogeneous mass, the various materials which enter into the combination should have approximately uniform resistivity to puncture and uniform specific inductive capacity; or, in case the insulation in a given instance is not of uniform specific inductive capacity and resistivity, care should be taken to see that those materials which have a low dielectric strength have a high specific inductive capacity, and inversely, those with a high dielectric strength have a low specific inductive capacity.

The statement made above for flat surfaces does not hold for cylindrical surfaces, for the reason that the potential gradient is not uniform throughout the homogeneous dielectric medium. This is due to the fact that the charge on the various surfaces being the same, the intensity of the charge varies inversely as the area of these surfaces. In the case of a

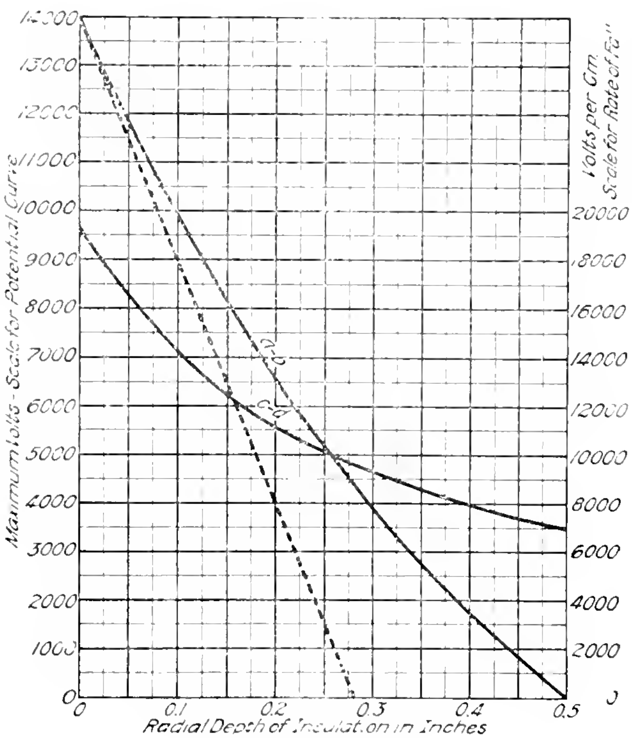


Fig. 2

lead sheathed cable, it is obvious that the areas of the various layers of insulation vary directly as the radius. The decrease in voltage in the different layers, therefore, varies inversely as the radii of those layers, and we have the curve *a b* (Fig. 2), showing the potential at any point of the homogeneous insulation.

Thus far we have dealt with alternating current phenomena. With high tension direct current cables, however, we have a curve exactly similar, for the following reasons.

With the conductor raised to a certain potential, there is a current through the dielectric depending on the total amount of resistance of the insulation. The fall of volts in each layer is proportional to the resistance of that layer in ohms; it is, therefore, inversely proportional to the areas of the various surfaces, and hence to the radii, as is the case with alternating current. Now the potential gradient, or steepness of this potential curve, is measured by the angle that the tangent at any given point makes with the horizontal. Plotting such a curve, we have *c–d*.

We have now shown that with either alternating current or direct current homogeneous cables, the potential is very unevenly distributed throughout the dielectric, being extremely high in the layers nearest the conductor and practically nothing on the outer layers. Obviously, whatever method may be employed to gain the desired result, if any given insulating material is to be used at all efficiently, each layer must be made of a strength proportional to the strain to which it is subjected.

The most obvious method of accomplishing this is to make use of dielectrics of varying strengths, placing the strongest layers nearest the conductor. In doing this, great care must necessarily be taken, however, not to change the potential gradient in the weaker layers by the insertion of "strong" layers, which have also a high specific inductive capacity.

With alternating current, we can change the potential gradient curve to a straight line by the use of dielectrics of varying specific inductive capacity properly arranged. On direct current cables, the same result is reached by the use of dielectrics of varying specific conductivity. It should be noted that a high tension cable, which is scientifically graded for maximum direct current voltages, is therefore not necessarily a cable adapted for high voltage alternating current work. In switching such direct current cables into live circuits, therefore, care should be observed not to throw too heavy strains upon them.

The foregoing, will, I trust, give a practical view of the principles of this question, although somewhat incomplete. I shall now endeavor to show mathematically the fundamental formulæ applying to the question of "grading."

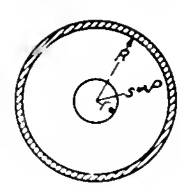


Fig. 3

Assume a lead sheathed, single core cable, with the radius of conductor equal to r (Fig. 3), and the inside radius of sheath equal to R. The conductor is connected to a source of alternating current of potential V, the lead sheath being at potential zero. We wish to first find the potential at any point P in the dielectric at a distance s from the center. It is evident that the equi-potential surfaces are concentric with the conductor. Therefore, if we imagine the equi-potential surface through P to be a thin metallic cylinder, the equilibrium of the system is not changed. We now have two condensers in series, one from conductor r to P, the other from P to R. Let C be the capacity between r and R; C' the capacity between P and R; and V and v the potentials of r and P respectively. We then have $CV = C'v$, and therefore $v = \frac{C}{C'}V$.

Now the capacity $C = \dfrac{1}{2\ log\ \frac{R}{r}}$

and the capacity $C' = \dfrac{1}{2\ log\ \frac{R}{s}}$

These formulæ come from the following considerations, applying to cylindrical condensers: $\frac{4\pi Q}{2\pi s} = \frac{2Q}{s}$. This expression is equal to the force on unit pole at distance s from center. Integrating $\frac{2Q}{s}\,ds$ between limits R and r, we have the work required to move unit pole from sheath to conductor, and this is by definition equal to the potential of conductor. Therefore

$$V = \int_r^R \frac{2Q}{s}\,ds = 2Q\Big[\log\ s\Big]_r^R =$$

$$2Q\ (log\ R - log\ r) = 2Q\ log\ \frac{R}{r}$$

Now $Q = CV$, and hence $V = \frac{Q}{C} = 2Q\ log\ \frac{R}{r}$;

$\frac{1}{C} = 2\ log\ \frac{R}{r}$, or $C = \dfrac{1}{2\ log\ \frac{R}{r}}$

We have stated above that $v = \frac{C}{C'}V$. Substituting, we therefore have v, or the potential at $P = V\dfrac{log\ \frac{R}{s}}{log\ \frac{R}{r}}$

As previously mentioned, the potential gradient is the variation of this curve along the radius, and is therefore measured by the tangent to the curve at any point. Taking the derivative of the equation for the potential curve, we have $\frac{dv}{ds} = -\dfrac{V}{s\ log\ \frac{R}{r}}$ or in decimal logs $= -\dfrac{0.434\ V}{s\ log\ \frac{R}{r}}$ Now if we put $s = r$, we have $\left[\frac{(dv)}{(ds)}\right]_r = \dfrac{0.434\ V}{r\ log\ \frac{R}{r}}$ and if $s = R$, we have $\left[\frac{(dv)}{(ds)}\right]_R = \dfrac{0.434\ V}{R\ log\ \frac{R}{r}}$

These two expressions give the stress on the innermost layer and on the outer layer. It will be seen that the ratio of the two stresses is inversely equal to the radii, as has been previously remarked.

Now there must be a certain value of r for which the maximum stress $\left[\frac{(dv)}{(ds)}\right]_r$ is as small as possible for a given R. To obtain this, we will place the first derivative equal to zero, taking the derivative with respect to r.

We then have the derivative of $r\ log\ \frac{R}{r}$ $= log\ R - log\ r - 1 = 0$, or $log\ \frac{R}{r} = 1$, or $\frac{R}{r} = e$ $= 2.718$; therefore $r = \frac{R}{e}$ or $\frac{R}{2.718}$

One other consideration: If we can allow, say n volts per mm., our formulæ give us the thickness required in any given case.

$\frac{dv}{ds} = n = \dfrac{0.434\ V}{r\ log\ \frac{R}{r}}$ whence by transposition,

$log\ R = \dfrac{0.434\ V}{rn} + log\ r.$

The fundamental data on which this article is based will be found in papers by Mr. O'Gorman of England, and Mr. Jonas of Italy. Those who care to investigate this subject more thoroughly will find these papers very interesting.

GOLD DREDGING BY ELECTRICITY

By H. W. Rogers and C. M. Bliven

Dredging is the most recent of mining methods employed for recovering values in auriferous ground located below the water level or in streams where the flow of water is too great to admit of success by other means. That it has attained an important place in the industry is evidenced by the fact that, although the first successful dredge in California only began operations about ten years ago, today more than one-quarter of the gold mined in that State is secured by the dredging process, and the bulk of this is obtained from grounds previously mined.

The development of the gold dredge affords one of the most interesting chapters in the history of mining. It is the latest of a series of successive steps in the recovery of placer deposits, following the pan, the rocker, the long tom, the sluice box the ground sluice, drift mining, the monitor and the hydraulic elevator. All of these methods had their time and place and some are extensively employed today, but it remained for the dredge to solve the problem of mining in ground below the water level and in rapidly flowing streams.

The need of such a machine was long felt, and numerous attempts were made to develop it before success was achieved. Many abandoned hulks of dredges that were inoperative lay buried in the shifting sands of California's gold bearing streams before the machine was designed that would operate successfully. The type now employed was introduced from New Zealand, but its development to the present high state of efficiency has taken place in the California fields.

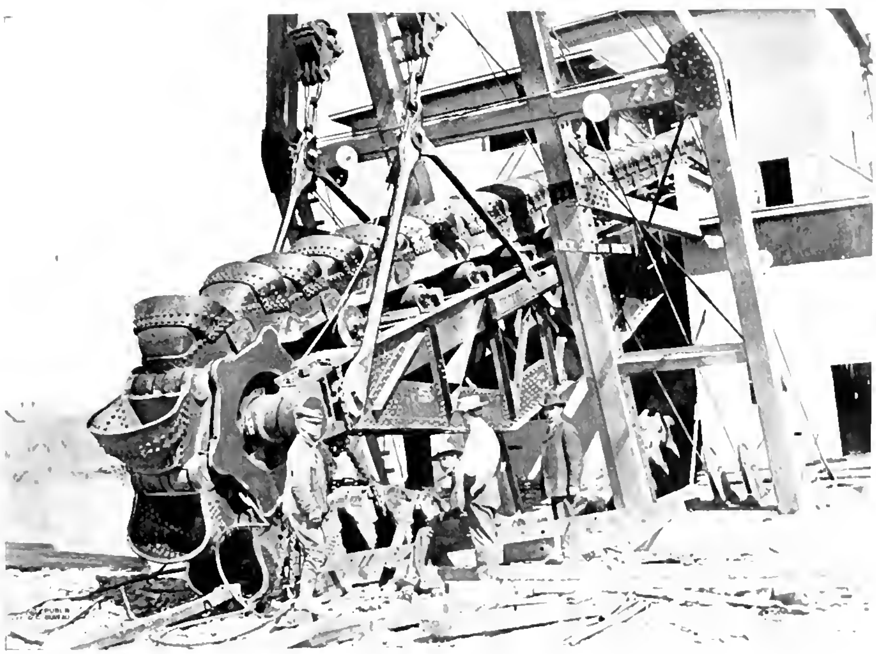
Rich deposits of auriferous earth lying below the water level in the valley of the Feather River in California led to the introduction of the machine and the establishing of this industry. The gravels had already been mined to the water level and the wealth yielded is still a legend of the days when "hundred dollars a day diggings" were not uncommon. For half a century men had striven to find a means of reaching the lower stratum, but without avail, for the water drove them back. When the dredge finally came it followed closely and was, in large part, due to an attempt to mine with the aid of powerful pumps which, although inadequate, were suggestive of a more highly satisfactory method.

The story of its success is the old, old story of prospecting and perseverance. The pumps worked long enough and well enough to prove the wealth of the gravel, and subsequent prospecting by means of shafts sunk at intervals over a large area showed the gold to be evenly distributed. The first dredge demonstrated both the feasibility and the profit, and rapid development followed this initial success.

Gold Dredge of the Natoma Consolidated Company, California

The development, however, has had its failures as well as its successes, for, be the machine ever so perfect, it must fail unless it works in ground that contains gold in sufficient quantities to be profitable and where conditions are favorable for the successful recovery of the metal. Ideal dredging ground is of limited depth with a soft bed rock, free from large boulders, and with values evenly distributed. Where these conditions are combined, dredging for gold may be a profitable industry; but, in the haste to profit by this new method, both in California and elsewhere, machines were built that did not pay. This is not likely to be the experience of the future, however, for prospecting methods have been so improved that there is practically no excuse for failure in dredge mining. No other form of mining enterprise offers the opportunity to so thoroughly test the material to be worked. In the early days, this was done by means of shafts sunk by hand, but the Keystone drill was soon substituted and by its use the testing is quite thoroughly done at a moderate cost, and no dredge is built now until the values in the ground have been approximately ascertained.

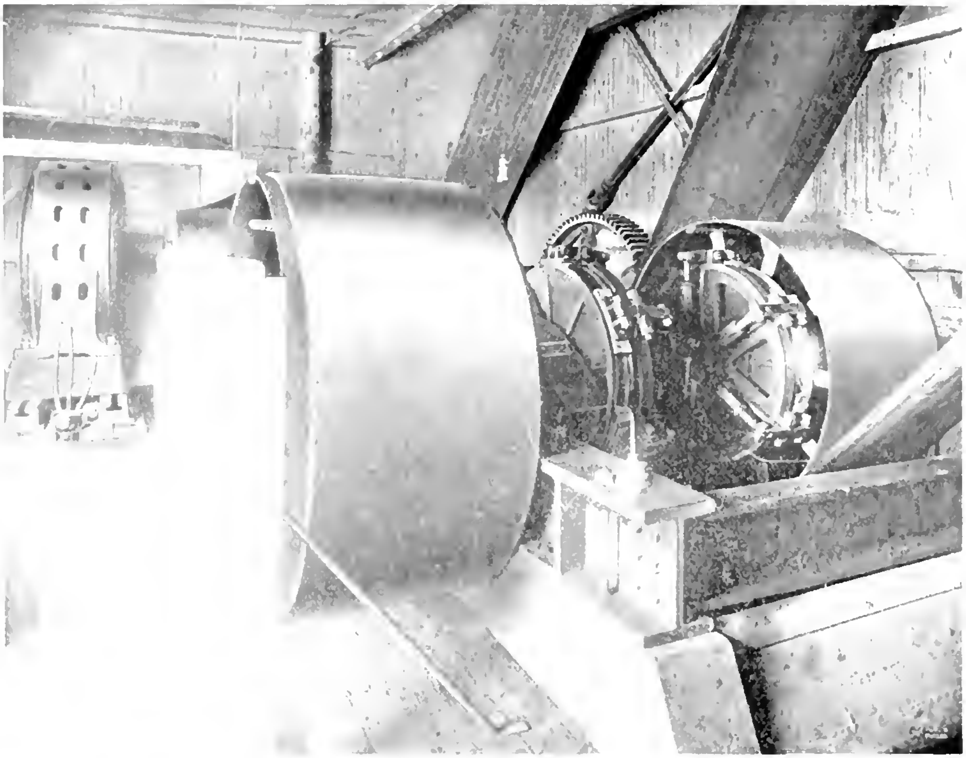
The gold dredge not only works in the stream bed but in the land. Some stream bed was mined in the early days on the Feather River, but objections from interests that desired the integrity of the stream maintained led to landlocking and today the mining is wholly outside the channel, as the greater part of it has always been. The dredge is built in a dry pit dug for the purpose, and when the hull is completed, water is let in by a ditch or flume. In operation, it floats on water brought to it in this way, and its function is to dig up the soil and gravel and wash out the gold, moving forward as the ground is mined, and depositing the tailings behind.



Motor-Operated Bucket Line, Close Connected Type

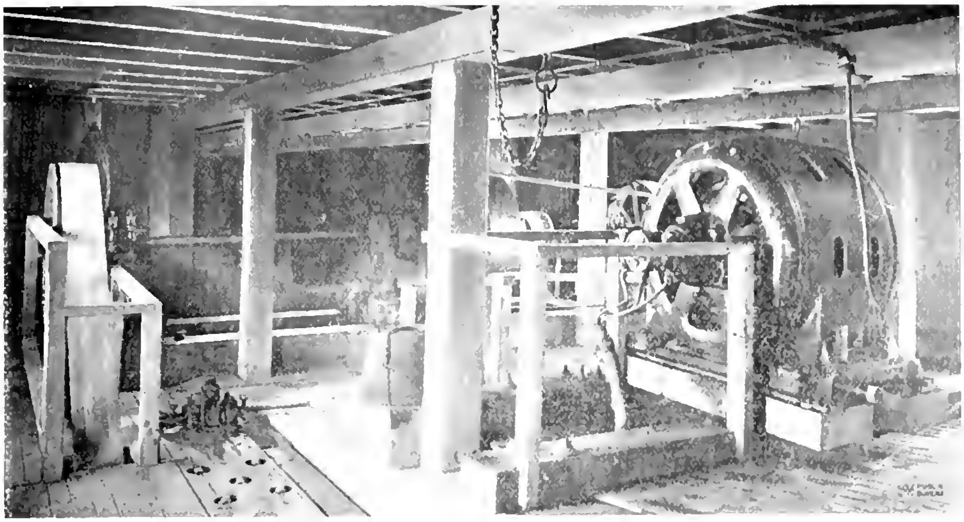
The early type of dredge, which was considered massive and powerful, is a striking contrast to the dredges of the present day. It was equipped with three and one-fourth cubic foot buckets, dug to a depth of thirty feet, and was driven by a 50 horse-power steam engine; and, although partially successful, was always very expensive owing to the scarcity of fuel and the excessive cost of handling it.

With the rapid development of hydro-electric plants throughout the West, and the insurance of a continuous, economic power supply transmitted through great distances,



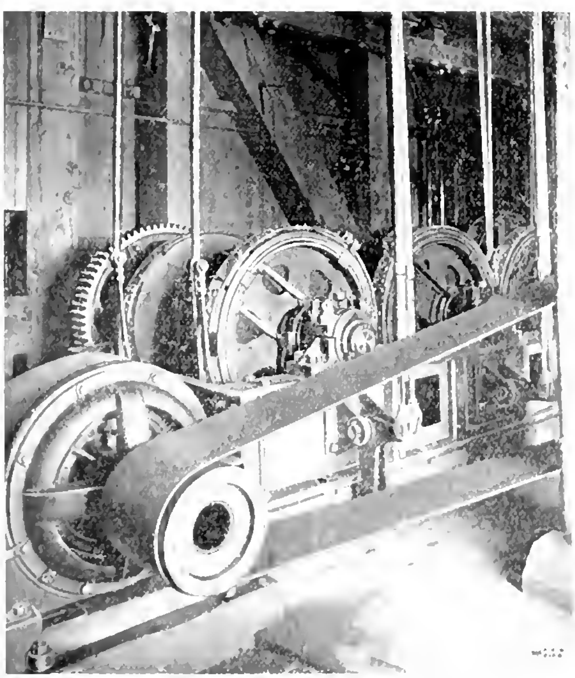
300 H P. General Electric Induction Motor Driving Bucket Line. Natoma Gold Dredge

Winch Room of Natoma Gold Dredge Showing Controllers for Operating Bucket Line, Screen and Winch Motors the mining companies soon turned their attention to the electric motor for operating dredges.



75 H.P. General Electric Variable Speed Induction Motor Operating Shakers and Screens Natoma Gold Dredge

While changes were found necessary, both in capacity and type of motor, before satisfactory results were obtained, the motor proved far superior to steam, both in cost and maintenance, and today we have machines especially designed for heavy duty, running continuously without shut-down and requiring very little attention.



35 H.P. General Electric Induction Motor Operating Shore Line Winch Natoma Gold Dredge

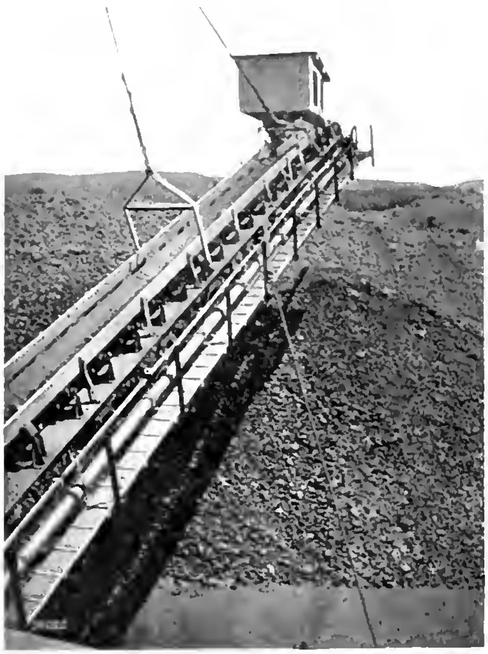
The most successful and practically standard dredge of today is the continuous chain, close connected bucket type, varying in capacity from three to thirteen and one-half cubic feet. While the details may vary slightly, in general construction it is similar to the ordinary continuous chain bucket dredge used for other work, except that it must be greatly strengthened in order to resist the excessive strains due to digging in rocky ground. The machinery consists of the digger or bucket line, revolving screens, sluice tables and boxes, stacker for carrying the tailings, high and low pressure pumps, priming pumps, amalgamator, lines and spuds for guiding the dredge, and occasionally a sand pump.

Digger

The digger consists of a steel ladder of massive construction, built to support the bucket line and resist the heavy strains while in operation, especially near bed rock. The bucket lips, bushings and rollers are made of manganese steel, which possesses the best wearing qualities and reduces the cost of maintenance to a minimum.

The speed of the bucket line varies from fifty feet (with 18 to 25 buckets) to seventy-five feet (with 35 to 50 buckets) per minute, depending upon the condition of the ground.

For the operation and control of the digger, a variable speed motor is used. This is located on the lower deck and belted to the driving pulley, which is generally situated in the rear of the pilot house on the upper deck. The duty imposed upon this motor is severe, as it must operate under conditions calling



View of Stacker Showing Shed for Motor Driving Conveyor

for power varying from 75 per cent overload down to 25 per cent of its rated capacity. The motor recommended for this service is an alternating current, induction type machine, known as Form M, designed on liberal lines and equipped with a drum type controller having fourteen running points, forward and reverse, with the necessary resistance for continuous operation on any notch of the controller from one-half to full speed.

The maximum starting torque is required and obtained at about the fourth point of the controller, thus leaving three points on which to bring the motor up to half speed, at which time nearly full rated torque is required. As a result of these conditions, the ordinary motor designed for intermittent service cannot be successfully applied.

Winch

To keep the dredge in place and to move it about or hold it against the bank when digging, head lines are used, which are controlled from the forward end and operated by a six-drum winch driven by a variable speed motor. The winch motor, while of smaller capacity, is of the same staunch construction as the digger motor, and is equipped with a suitable controller and resistance to permit its continuous operation at from one-half to full speed. It has been found advisable to equip the motors for this service with solenoid brakes, by means of which the motor can be brought to a standstill almost instantly. It is then ready for the reverse operation without the usual reversing of the motor through the controller, which is not only bad practice but may result in a burnout due to the heavy strain on the windings.

Pumps

The high and low pressure pumps for supplying water to the screens and sluices are generally connected to the same motor. A constant speed Form K motor of compact

4000 Volt Armored Shore Cable Connecting High Tension with Transformers on Dredge

construction and large overload capacity, with a speed of about 900 r.p.m., is usually installed for this work and is supplied with extended shaft at both ends, these extensions being provided with flange couplings for direct connection to the pumps. The standard General Electric Form K constant speed motor is recommended for use throughout the dredge, except on the digger and winch.

Sand Pump

To prevent the filling up of the basin in which the dredge floats, when digging in shallow water, it is sometimes found necessary to install a sand pump, which carries the fine tailings from the sluice boxes to the top of the rock pile by way of the stacker. This pump requires considerable power and is never used unless absolutely necessary.

Priming Pump

This pump is used for priming the large pumps or for supplying water to the tables during the "clean up," and generally consists of a small, high speed motor direct connected to a centrifugal pump.

Screens

Either the shaking or revolving screen may be used to separate the gravel from the clay and permit the fine particles containing the gold to pass through onto the gold tables and sluices below. For this service a constant speed motor is recommended, which can be placed on the upper deck and belted down to the driving pulley of the screen.

Stacker

After screening, the large rocks are carried on a belt conveyor to the end of the stacker and deposited on the spoil in the rear of the dredge. For operating this conveyor, a constant speed motor is installed at the extreme end of the stacker, where it can be readily housed.

The power for operating these dredges is usually transmitted by the various electric companies to a substation, near the base of operations, at three-phase, sixty cycles, the voltage varying from 2000 to 6000 volts. Current is carried to the dredge through an armored cable floated on pontoons, where it passes through the main line oil switch to the switchboard and is distributed to the various motors.

In the process of dredging, the ground is really turned bottom up, bringing to the surface stone and earth from a depth of forty to fifty feet, and, while the greater portion of earth seeps back through the stone, there is still a good quantity of virgin soil left, which is valuable. Much has been written lately regarding the reclaiming of this land after the dredges have finished their work, and from appearances one would imagine that the acres of stone piled from ten to fifteen feet high would be absolutely worthless; but the various dredge owners have lately become quite active in their endeavor to restore the land to something of its original appearance and have been so successful that some of the finest figs and grapes are being raised on the soil which is exposed after the rocks have been cleared to their original level.

With this improvement in view, numerous rock and crushing plants have been built, among the largest of which are those operated by the Natomas Consolidated Company. Their first plant was installed at Natoma and had a capacity of 1000 tons per day, but the demand for good hard rock for use on the highways increased so rapidly that a second plant, at Fair Oaks, was installed at a cost of $180,000. This plant is probably one of the largest west of the Mississippi River and is as complete as any in the world. It covers several acres of ground and has a capacity of 2000 tons per day, and its arrangement for handling the material before and after crushing is most complete.

The material crushed is round cobbles and gravel, which, owing to its extreme hardness, is considered to be the finest of road and concrete material.

The entire plant is electrically-operated and has a total capacity in motors of approximately 1000 horse-power; but, in spite of its completeness, its size and its efficiency, it has proved inadequate and the Natomas Consolidated Company is now erecting another similar plant at Oroville, which will have a capacity of 1500 tons per day.

THE RATING, EFFICIENCY AND LOSSES OF FEEDER REGULATORS

By E. F. Gehrkens

In general the rating of electric generating and transforming apparatus is based on the product of the normal current and voltage delivered, and the same method of rating applies to feeder regulators; that is, a regulator designed for a line current of 100 amperes and capable of boosting the line voltage by 220 volts is rated 22 kw. All feeder regulators manufactured by the General Electric Company are, however, designed so that the voltage produced by the secondary or series coil is capable of being reversed in direction with respect to the line voltage, so as to produce a lowering effect equal to the boosting effect. A regulator having a boosting effect equal to 220 volts therefore has a range of twice this amount, or 440 volts, and a 100 ampere regulator having a boost or lower of 220 volts, although rated 22 kw., has a range of 44 kw.

The efficiency is based on the actual kilowatt rating and always with the regulator in the maximum boosting position. The work performed by a regulator depends not only on the current passing through it, that is, the line current, but also on the effective voltage change produced, depending on its boost or lower position. The regulator performs its maximum of useful work when in either the maximum boosting or maximum lowering position. The load may be varied by a change in the current regulated, with the regulator in a given position; by changing the secondary voltage of the regulator with full load current on the line; or by a combination of these changes. In the switch type of regulator, the regulation is obtained by cutting out portions of the series winding, the I^2R loss of both primary and secondary being decreased as the voltage of the secondary is decreased, until at the zero, or no-boost, no-lower position, the I^2R loss in the regulator is nearly zero, even with full load current flowing in the line. The only loss in the regulator is the iron loss and the very small I^2R loss in the primary winding due to magnetizing current. In case a split blade and preventive resistance is used to reduce sparking, or a blade made up of several contacts each having its individual resistance, there is a loss in the preventive resistance depending on the line current but independent of the boosting or lowering produced by the regulator.

In the single-phase induction type of regulator, the regulation is obtained by changing the amount and the direction of the magnetic flux through the stationary series coil by a rotation of the primary core containing the exciting winding, thus varying the induced secondary voltage of the regulator and reversing the direction of this voltage with respect to the line voltage. In the polyphase type, the regulation is obtained by changing the phase relation of a constant induced secondary voltage with respect to the line voltage by a similar mechanical rotation of the primary with respect to the secondary winding, the regulated voltage in both types being a resultant of the line voltage and the secondary voltage of the regulator. The total secondary winding of any induction regulator is therefore always in series with the line and the loss in the regulator is constant for all positions for a given line current. On the assumption, therefore, that the iron losses in both switch and induction types are equal and that with full load current the copper loss in the switch type, when in the maximum position, is equal to the copper loss in the induction type, disregarding the loss due to magnetizing current, the total loss in the former is only one-half as great as the total loss in the latter with the regulators at the neutral, or no-boost, no-lower positions and with full load line current flowing; although the total losses at full load are equal in the maximum boosting position.

As the load on a regulator can be varied by changing the line current or the position of the regulator armature with respect to the field, or by a combination of these methods, there are an indefinite number of total losses within certain limits and a corresponding number of efficiencies for partial loads. Although the partial load losses are less, and therefore the corresponding efficiencies higher, when based on changing the load by varying the line current and leaving the regulator in the maximum position than when based on varying the load by changing the effective voltage of the regulator, the former is the only method which can be applied to other electric generating or transforming apparatus and should therefore be adopted as the standard method of determining efficiencies of feeder regulators.

As has already been stated, with full load current on the line the I^2R loss of both primary and secondary windings of the switch type of regulator decreases as the voltage of the secondary is reduced. Feeder regulators are variable voltage transformers or compensators and, disregarding magnetic leakage, the ampere turns of the primary or shunt winding are always equal to those of the secondary or series winding. Therefore, as in the switch type of regulator, as the secondary turns are cut out of circuit the current in the primary is decreased in proportion to the number of turns cut out, and the I^2R loss of both windings is reduced, until at the zero position the only I^2R loss is that due to magnetizing current.

In the single-phase induction type of regulator the current in the primary or shunt winding is decreased as the flux is rotated past the secondary winding, and in the zero position the only I^2R loss in the primary is that due to the magnetizing current. In this position the primary and secondary windings are at right angles to each other, and the full load line current, in passing through the secondary, acts as a magnetizing current and would require considerable voltage from the line to force it through the winding against the reactance—thereby greatly increasing the core loss—were not an auxiliary winding provided which is in direct inductive relation to the secondary when the regulator is in the zero position. This auxiliary winding is provided on the core

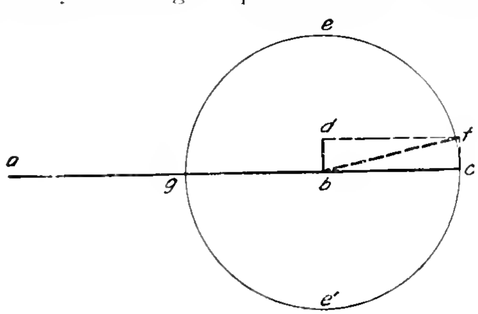


Fig. 1

containing the shunt winding and is short circuited on itself. It is, however, arranged at right angles to the primary so as not to affect this winding in any way. With the regulator in the maximum position, the ampere turns of the shunt winding are equal to those of the series winding; with the regulator in the neutral position, the ampere turns of the short circuited winding are equal to those of the series winding; and in intermediate positions the sum of the ampere turns of the shunt and short circuited windings are equal to the ampere turns of the series winding, the ampere turns of the former decreasing from full value to zero,

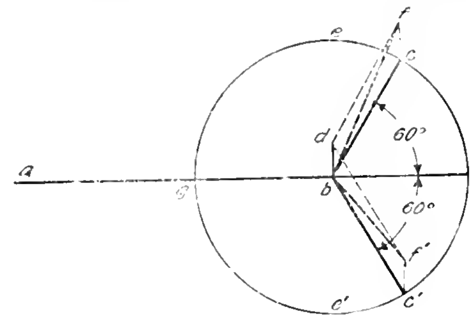


Fig. 2

and the ampere turns of the latter increasing from zero to full value, as the armature is rotated from either maximum to the neutral position. Thus, with a constant line current, the core loss remains constant and the total I^2R loss is practically constant for all positions of regulation. The magnetizing current of an induction regulator is considerably higher than that of the switch type, because the former has the primary and secondary coils wound on separate cores with quite an appreciative air gap between them, whereas the latter has a common core on which the primary and secondary windings are intermixed. The mean length of turn of the short circuited winding is, however, usually less than that of the shunt winding, so that with the regulator in the zero position the combined I^2R loss of the primary, due to magnetizing current and the I^2R loss of the short circuited winding, is approximately equal to the I^2R loss of the primary with the regulator in the maximum position.

In the polyphase induction regulator each phase is provided with its own winding, both primary and secondary, and no short circuited winding is necessary, for the reason that any secondary phase winding, in passing out of inductive relation to its own primary, passes into an inductive position with the primary of the next phase. As the ampere turns of both windings must always be equal and as the currents of two coils in direct inductive relation to each other must always be in phase but opposite in direction, the induced currents in the primaries of a polyphase regulator are constant for all positions of the armature with constant current on the line. But the direction of the phase angle of this induced primary current with respect to the line depends on the relative position of the primary and secondary windings to each other and, as the successive phases of the secondary are rotated from the maximum boost to the maximum lower position, the phase angle of the current flowing in the primaries must shift through an angle of 180 degrees; the induced current value, however, remaining constant.

Referring to Fig. 1, let *ab* equal the line current of any phase and *bc* the induced primary current, i.e., the primary current by ratio of turns. In any polyphase regulator this induced current can be made to rotate from *c*, the maximum boosting position, through *e*, or *e'*, to *g*, the maximum lowering position of the regulator, by mechanically rotating either the primary or the secondary in one direction or the other through an angle of 180 degrees, or the same results can be obtained by reversing the phase rotation of the system, the mechanical rotation being through 180 degrees in one direction only.

For all practical purposes the magnetizing current, which may be assumed to be 25 per cent for a normal design of regulator, may be considered always at right angles to the line current and always in the same direction with reference to the line current; that is, lying behind the impressed e.m.f. by 90 degrees, regardless of the phase angle of the induced primary current. The I^2R loss in the primary winding is due to the resultant of the magnetizing current and the induced current. This resultant can always be obtained by completing the parallelogram *b c f d*, the resultant being *bf*. It is therefore evident that if the phase rotation of the induced current is through *e*, the resultant current increases as the regulator is changed from maximum boost to the neutral position, until at this position the resultant is equal to the sum of the two currents. If, however, the rotation is through *e*, the resultant is equal to the difference and, assuming the induced current to be equal to 100 and the magnetizing current to be 25, the primary I^2R loss in the first case is equal to the square of 125 times the resistance, and in the second case to the square of 75 times the resistance; that is, the loss in the first case is nearly three times the loss in the second.

This value, however, only applies to the neutral position, the ratio decreasing as the regulator is rotated to either maximum position where the loss is necessarily the same for either direction of rotation.

The intermediate values of the resultant

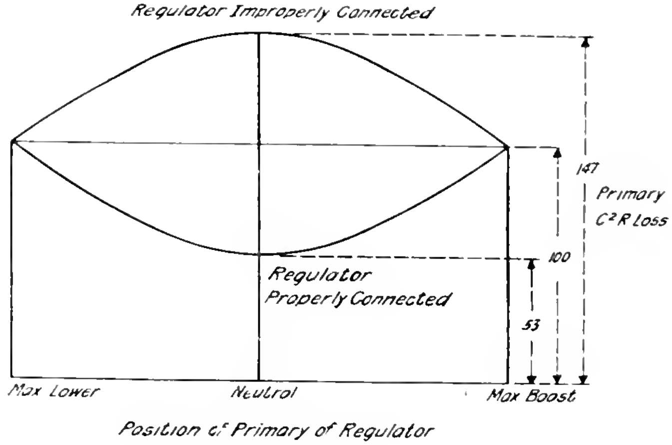


Fig. 3

are readily obtained by rotating *c* either to the right or left, as shown in Fig. 2.

In a three-phase regulator, assume that the winding of phase 1 on the secondary, the current of which is represented in direction by *ab*, has been shifted so as to be opposite the winding of phase 2 of the primary; in this position the winding of phase 1 of the primary is opposite the winding of phase 3 of the secondary and the current in phase 1 of the primary must therefore be in phase with the current in phase 3 of the secondary; that is, it is out of phase with the current in the line to which it is connected by 60 degrees (60 instead of 120 degrees, as the middle phase of both primary and secondary are always reversed in direction), as shown by positions *e* and *e*. The resultant current, therefore, is *bf* or *bf'*, depending on the phase rotation. The comparison of the primary I^2R loss throughout the entire range from maximum boost to maximum lower for a regulator having a magnetizing current of 25 per cent and full line current flowing in the secondary, is shown in Fig. 3.

The instructions for installing regulators accompanying each machine specify that they should be so connected (giving the method of procedure) so that the magnetizing current will oppose the induced current in the neutral position, and the heating guarantees are always based on this method of connection. From Fig. 3 it is evident that this precaution should be taken.

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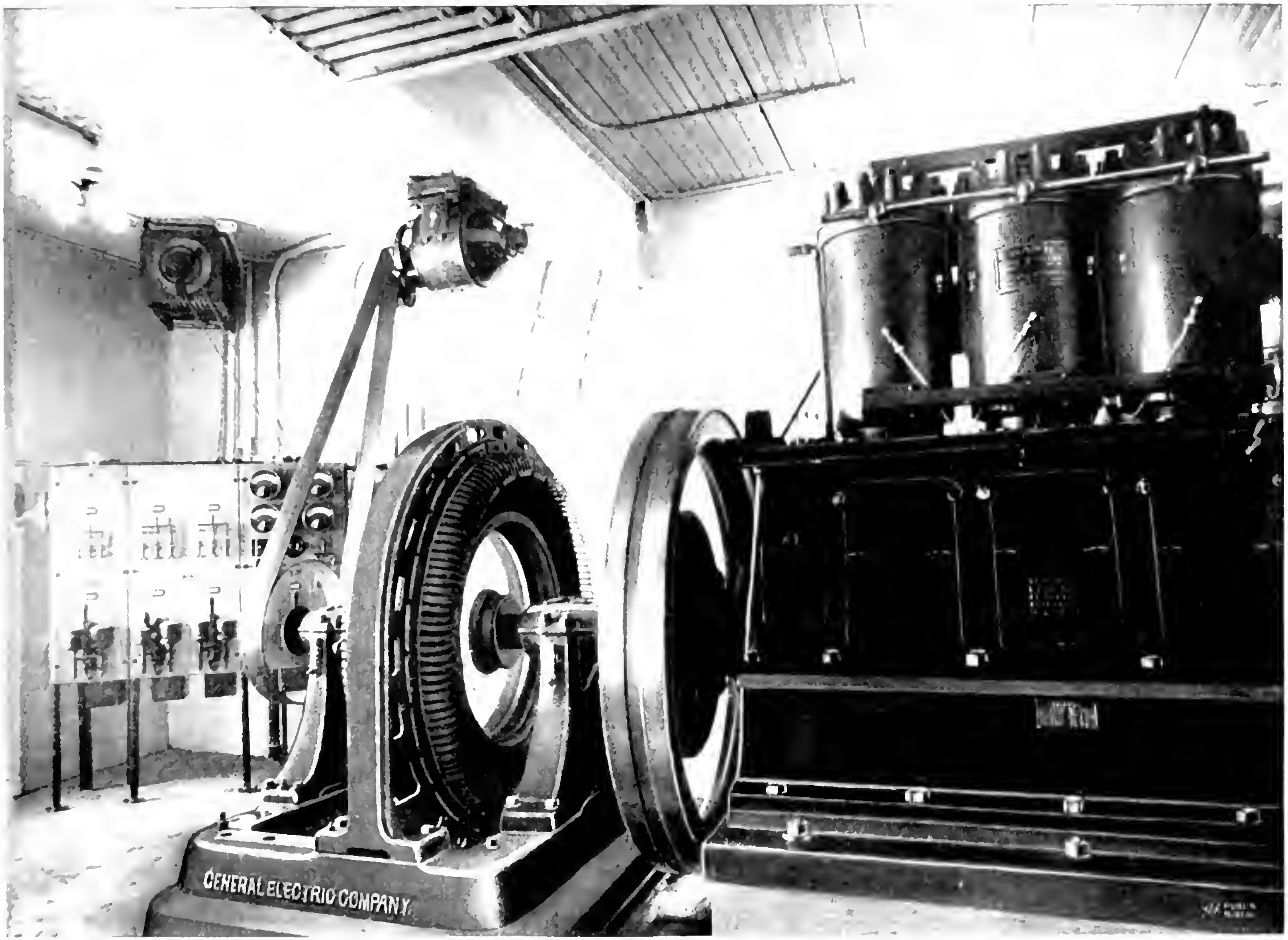


60 Kw., 2300 Volt Alternating Current Generator Direct Connected to Gas Producer Engine
Main Power House on Farm of Thomas F. Ryan

(See page 83)

GENERAL ELECTRIC REVIEW

ESSAYS ON SYNCHRONOUS MACHINERY

In this issue of the REVIEW we print the first of a series of articles on Synchronous Machinery by Prof. V. Karapetoff.

The characteristics of all synchronous machinery depend to a very great extent on the value of armature reaction, and to design machines to meet varying conditions, it is essential that an accurate method of calculating this quantity be available. A great many methods have been advocated from time to time, such as Kapp's Method, Potiers' Method, the A.I.E.E. Method, etc.—all developed primarily for the purpose of determining regulation of alternators under loads of varying power factor. All of these methods are reasonably approximate and deal with quantities that can be determined experimentally.

The factors which influence the regulation of alternators are the resistance of the armature, the self-inductance of the windings, and the armature reaction—or the effect of the flux produced by the current in the armature on the flux produced by the main field current. The influence of armature reaction proper is of paramount importance as its value is considerably greater than either that of resistance or self-inductance. The resistance of the armature can easily be determined and the combined effect of the other two factors can be arrived at from the open and short circuit characteristics of the machine. The regulation of alternators and the overload capacity, phase characteristics, etc., of synchronous motors can be determined approximately by using the values obtained by the above methods.

In 1895 Prof. Blondel developed a method of calculating armature reaction known as the "two-reaction" method. In this he determines the effect of the currents in the armature, in phase and in quadrature with the line e.m.f., on the main field flux; the current in phase having a distorting effect on the main field flux, and the current in quadrature either directly opposing or assisting the main field flux, depending on whether the current is leading or lagging.

Prof. Arnold in his *Wechselstromtechnik*, Vol. IV, has further developed the method and much greater accuracy is claimed for it than can be claimed for the other methods.

Prof. Haga in *La Lumiere Electrique*, Sept. 11, 1909, describes a method of experimentally determining the value of these two-reactions.

Prof. Karapetoff has made use of the two-reaction method in his calculations, suggesting some changes in the method as advocated by Blondel and Arnold. The formulæ developed have been checked with the characteristics of a great many machines, both alternators and synchronous motors that have been built and are now in operation, and the method seems to check more closely with actual results than the methods heretofore used.

The ratio of these two reactions varies with the design of the machine and is greatly dependent on ratio of pole arc to pole pitch. This ratio is usually more or less fixed in the case of alternators on account of the necessity of keeping to an approximately sine wave of e.m.f. In the case of synchronous motors more liberty can be taken if it is shown that there is anything to be gained. Prof. Karapetoff says that the cross magnetizing action of the armature affects the performance of the machine comparatively little, since the voltage induced is at right angles to that induced by the reactive current. In this he differs somewhat from Prof. Arnold, who says in *Wechselstromtechnik*, Vol. IV, p. 469, that the capacity of a synchronous motor depends chiefly on the value of the cross magnetizing ampere turns of armature reaction and it is desirable to make this value as small as possible. On the other hand he says the value of the demagnetizing ampere turns of armature reaction should be made large, as a motor will have a flatter phase characteristic, thus ensuring a good power factor throughout a wide range of excitation.

This method of calculation suggests possibilities in the design of synchronous motors for special conditions that are worthy of considerable investigation.

The second article of the series will continue the discussion of armature reaction, giving the values of ohmic drop and inductive drop in order that the diagram may be used for practical application.

H. H. Dewey

TESTING STEAM TURBINES AND STEAM TURBO-GENERATORS

The article by Messrs. Dickinson and Robinson on the subject of Testing Steam Turbines relates to a subject which is very important to power producers, since the economy of steam turbine generating units is of the utmost consequence and cannot be ascertained with any degree of certainty unless close attention is given to a great variety of possible errors in tests. Experience has shown that such tests involve the liability of many errors and this paper seeks to call attention to as many as possible of the causes which may contribute to such errors.

Most if not all of the precautions suggested in this article, refer to things that have been actually experienced as sources of error in turbine testing with which the writers of this paper have been directly or indirectly concerned. In the history of steam turbine development there have been many notable cases in which the results of tests, conducted in a very careless and inaccurate manner, have been made the basis of important decisions, and other cases where tests conducted with much care by eminent engineers have shown results which were later proved to be incorrect. The proportion of incorrect to correct tests in this art has been extraordinarily large, and those most experienced in the matter will be most disposed to insist upon the exercise of all the precautions given in this article and any others which may add to the certainty of results.

While many of these precautions would naturally be taken by experienced engineers in such work, the complete enumeration of them is very valuable, since experience has shown that almost any of them are liable to be overlooked, even by competent engineers.

W. L. R. Emmet

CORONA

The subject treated by Dr. Steinmetz in this number of the Review, Energy Losses Through Corona on Extra High Voltage Alternating Current Lines, is one of vital importance in the progress of electrical engineering. As time goes on we must turn more and more to our waterfalls for heat, light and power, and energy must be transmitted to greater distances with little loss; that is, at extra high voltages. In such transmission there is one important limiting feature, or rather a feature which we must thoroughly understand to prevent it from becoming limiting; viz., losses *directly into the air* from the line wires, that is, corona losses. Apparatus and insulators can now be easily built for potentials far in excess of our present limiting line voltages. Even at the present time, however, power is being transmitted with decided success at voltages considerably above 100,000. The first electrical phenomenon ever observed was of the same nature as corona, namely, the lightning stroke. Later, in the form of the discharges of the static machine, corona was the first one to be investigated. Some years ago, when its bearing on future transmission line practice was foreseen, investigations were taken up by engineers, and the problem which had been that of the physicist, became that of the engineer. Many able scientists have studied the subject; first with the critical visual point as reference; later by wattmeter methods.

Extensive and very careful investigations are now being made by the General Electric Company, combining the visual and energy loss methods. Reliable energy measurements are extremely difficult to make because of the nature of the load, which has a low power factor and high voltage. Previous experimenters have made their measurements on the low potential side of the transformer; this, however, involved several sources of error for which corrections are not easily made. In the present investigations measurements are taken directly on the high side, thus avoiding the former sources of error. Here Dr. Steinmetz treats the theoretical and experimental phases of corona as known at the present time, in his usual logical and concise manner. This article will be followed from time to time by others on the same subject.

F. W. Peek

ESSAYS ON SYNCHRONOUS MACHINERY

By V. Karapetoff

NOTATION

A, fictitious voltage introduced for purposes of computation. The exact value of A is given by equation (40), the approximate value by equation (44).

a, abbreviated notation for a certain voltage. See equation (10).

a_1, abbreviated notation for a certain voltage. See equation (20).

B, fictitious voltage introduced for purposes of computation. See equation (41).

b, abbreviated notation for a certain voltage. See equation (10).

b_1, abbreviated notation for a certain voltage. See equation (20).

c_1, internal energy component of the armature current, per phase.

c_2, internal reactive component of the armature current, per phase.

E, total induced voltage.

E_1, net induced voltage, obtained from E by subtracting the effect of cross magnetization.

E_2, voltage induced by the flux due to cross magnetization.

E'_2, fictitious voltage defined by equation (26).

e, terminal voltage.

e', length AH in Fig. 7.

e_c, corrected no-load voltage, defined by equation (51).

f, frequency of the supply, in cycles per second.

i, total armature current, per phase.

i_1, external energy component of the armature current, per phase.

i_2, external reactive component of the armature current, per phase.

k_1, coefficient of direct armature reaction; in these articles, its value is assumed to be equal to 0.75. See also formula (2).

k_2, coefficient of transversal armature reaction; in all the essays, its value is assumed to be 0.30 except in the problem on the overload capacity of the synchronous motor, where the value of k_2 is reduced to 0.23.

k_f, coefficient of reduction in the m.m.f. of the armature, due to the fractional pitch of the winding. See formula (4) and table.

k_s, coefficient of reduction in the m.m.f. of the armature, due to the distribution of the winding in slots. See formula (3) and table.

L_s, inductance of the armature winding per slot. See formula (8).

l_1 gross length of the armature iron in inches, less the sum of the widths of the air-ducts.

l_2 length of one end connection of an armature coil plus the sum of the widths of the ventilating ducts (free length of coil, per slot) in inches.

M, ampere-turns per field coil.

M_1, armature demagnetizing ampere-turns, given by formula (5).

M_2, armature cross magnetizing ampere-turns, given by formula (6).

M_e, ampere-turns per field coil corresponding to the rated voltage e on the no-load saturation curve.

M', $= M - M_1$, net ampere-turns corresponding to the voltage E_1 on the no-load saturation curve.

n, number of phases.

P, true power input into the revolving field structure, per phase.

p, number of poles of the machine.

q, auxiliary voltage defined by equation (54).

r, effective armature resistance per phase.

s, number of slots per pole per phase.

T, armature turns per pole per phase.

T_1, effective armature turns for demagnetizing action. See equation (48).

u_1, $=6$ to 14 maxwells per inch of length of slot per ampere-turn; in other words, the average permeance of the slot per unit length.

u_2, $=1.5$ to 2.5 maxwells per inch of the free length of the coil (end connections and air-ducts) per ampere-turn; in other words, the average permeance of the air-paths pei unit length.

v, volts induced in the armature at no load, per one ampere-turn on the field on the lower straight part of the no-load saturation curve.

x, magnetic leakage reactance of the armature, per phase.

x_1, saturation reactance (fictitious) defined by equation (52).

x_2, reactance (fictitious) due to the cross-magnetizing action of the armature, see equation (35).

z, fictitious impedance, introduced for purposes of computation, and defined by equation (42).

α, phase displacement between the voltages e and E.

β, phase displacement between the voltages E_1 and E.

γ, angle between the centers of adjacent armature slots, in electrical degrees.

ϕ, external phase-angle, or the angle between i and e.

ϕ', internal phase-angle, or the angle between i and E.

ξ, ratio of pole arc to pole pitch.

ζ, winding pitch in per cent.

PART I. ARMATURE REACTION IN ALTERNATORS AND IN SYNCHRONOUS MOTORS

The purpose of this article is to give a fundamental theory of the electromagnetic phenomena which take place in the armature of a synchronous machine under load. Alternating currents flowing through the armature constitute a magnetomotive force which modifies the flux produced by the field winding. This magnetomotive force is known as the *armature reaction.* The same armature currents produce stray fluxes in the slots and around the end connections of armature coils; these fluxes induce electromotive forces in the armature windings. The effect of these stray fluxes upon the voltage drop in the armature winding is measured by what is called the *armature reactance.* The calculation of this reactance is the subject of the second article.

The theory of the armature reaction given below is based upon the rational foundations first outlined by A. Blondel.* The theory was subsequently developed by others, notably by E. Arnold, in the fourth volume of his monumental work *Die Wechselstromtechnik.*

In a polyphase alternator or synchronous motor of the revolving field type, the wave of the resultant magnetomotive force of the armature travels along the air-gap synchronously with the field poles, notwithstanding the fact that the armature windings themselves are stationary in space. This is explained by the fact that the armature currents reach their maxima in different phases in succession, so that the resultant magnetomotive force attains its maximum at different points along the air-gap, at successive moments of time. This fact is expressed briefly by saying that the magnetomotive force travels along the air-gap. Since the armature currents pulsate synchronously with the revolving field, the magnetomotive force of the armature also travels synchronously, moving by two-pole pitches during each cycle.

In a single-phase machine the armature reaction is pulsating and is stationary in space. This pulsating magnetomotive force can be resolved into two equal magnetomotive forces of constant magnitude, one revolving synchronously with the field poles, the other revolving synchronously in the opposite direction. The effect of the latter component is rather difficult to calculate. It is considerably weakened by double-frequency eddy currents induced in the revolving part of the machine.

The magnetomotive force of a polyphase armature winding can be resolved into two components, each of which revolves synchronously with, and in the *same* direction as the field. One component is in *space* phase with the field, the other in space quadrature with the field (Fig. 1). The fictitious revolving coils, 1, 1, represent that part of the armature magnetomotive force which is in space phase with the field coils f, f, and which therefore weakens (or strengthens) the original field. The fictitious coils 2, 2 represent the part of the armature magnetomotive force which is in space quadrature with the original field and which therefore distorts this field. The first part of the armature reaction (coils 1, 1) is usually called the *direct reaction;* the second part (coils 2, 2), the *transverse reaction.* These reactions are sometimes also referred to as the *demagnetizing* and the *cross-magnetizing* actions of the armature upon the field.

It must be clearly understood that coils 1 and 2 have no real existence. They are merely intended to illustrate the action of the actual polyphase currents in the armature. In other words, let coils 1 and 2 be actually mounted on the field poles and excited by *direct* currents of suitable magnitude and direction. Then the field is weakened and distorted in (approximately) the same way

* *l'Industrie Electrique*, 1899, p. 481; *Moteurs Synchrones*, p. 154; *Trans. International Electrical Congress*, St. Louis, 1904, Vol. I, pp. 635 and 620.

in which it is weakened and distorted by the polyphase currents in the stationary armature.

In a synchronous machine working as a generator at a lagging power factor the two reactions have the directions indicated in Fig. 1 by dots and crosses. The direct reaction weakens the field, while the transverse reaction shifts the field against its direction of rotation. This can be deduced from the fundamental laws of electromagnetic induction, by considering the action of one armature conductor. Imagine first a reactive* lagging current to flow through the conductor; that is to say, a current which reaches its maximum when the conductor is distant by 90 electrical degrees from the center of the pole. Consider the action of this current upon the pole from instant to instant, and it will be found that the *average* action is such as to weaken the field.† This action is therefore represented in Fig. 1 by coil 1.

Next consider the action of an armature current which reaches its maximum when the conductor is opposite the center of the pole, i.e., a current which is in phase with the induced e.m.f. It will be found that such a current weakens the field at some instants as much as it strengthens it at other moments of time, and that it tends to crowd the lines of force to one side of the pole; namely, to the side opposite the direction of rotation of the pole. Hence, the action is such as though, in addition to the actual poles of the machine, there were provided a set of identical fictitious poles displaced by 90 electrical degrees *behind* the main poles. The coils 2 in Fig. 1 represent the exciting windings of these fictitious poles.

Having obtained the directions of the armature reaction in case of an alternator with a lagging current, the directions of the armature reaction in the following three cases can be found by a simple reasoning.

(1) In an alternator which supplies a leading current the direction of the reactive component of the current is opposite to that shown in Fig. 1. Hence, the current in coil 1 strengthens the field instead of weakening it. This explains the reason for a better regulation of alternators with leading current. The energy component of the current has the

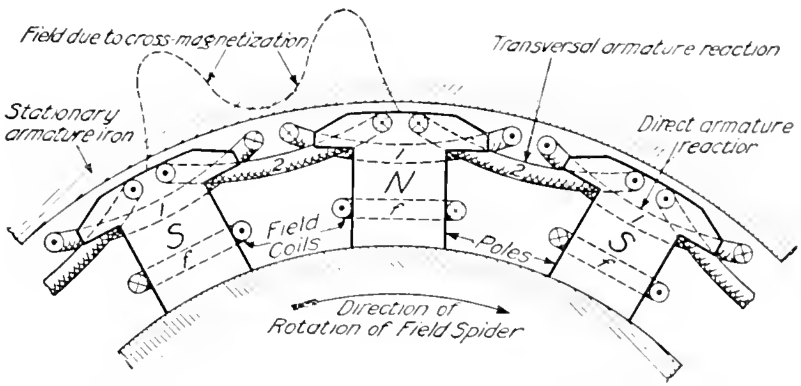


Fig 1. Magnetomotive Force in a Polyphase Synchronous Machine Under Load

same direction as in Fig. 1; hence, the action of the coil 2 is not altered.

(2) In a synchronous motor with over-excited field the current used by the motor must be such as to weaken the field in order to enable the motor to take energy from the line. As shown in Fig. 1, a current in order to weaken the field must lag 90 degrees behind the induced electromotive force of the machine. Hence, this current must be leading with respect to the line voltage, because the latter has a direction approximately opposite to that of the induced e.m.f. It is for this reason that an over-excited synchronous motor takes a leading current from the line. The direction of the energy component of the current in a motor is opposite to that in a generator; therefore, for a motor, the direction of the current in the fictitious coil 2 must be reversed. This means that in a motor the fictitious cross-magnetizing poles lead the actual poles by 90 degrees, and the flux is distorted so as to be crowded in the direction of rotation of the poles.

(4) In an under-excited synchronous motor the conditions are such that the coil 1 must strengthen the field, the current being leading with respect to the induced e.m.f. (or lagging with respect to the line voltage). The energy component is the same as in the preceding

* The author prefers the expression "reactive component of the current" to the older expression "wattless current." See A. E. Kennelly, "Vector Power in Alternating Current Circuits," *Trans. Amer. Inst. El. Eng.*, 1910.
† Hobart and Punga, "A Contribution to the Theory of the Regulation of Alternators," *Trans. Amer. Inst. Elec. Eng'rs.*, Vol. 23, p. 291.

case, so that the flux is again crowded in the direction of rotation of the poles.

The foregoing analysis can be summed up as follows: *In a synchronous generator the energy component of the armature current creates distortion poles 90 degrees behind the actual poles, while a lagging reactive component of the armature current weakens the field and a leading component strengthens it. In a synchronous motor the energy component of the armature current creates distortion poles 90 degrees ahead of the actual poles* (in their direction of rotation). *A lagging reactive component of the input current strengthens the field, while a leading component weakens it.*

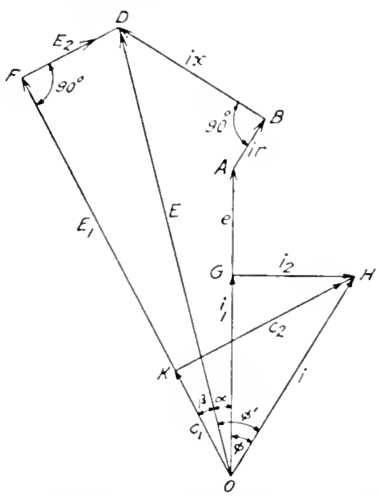


Fig. 2. Vector Diagram of Voltages in an Alternator (A Counter-Clockwise Rotation of Vectors is Understood)

It must be clearly understood that the reactive and the energy components of the current are to be considered with respect to the centers of the poles, and not with respect to the terminal voltage of the machine. In other words, the actual current in the armature must be resolved into two components, one of which reaches its maximum when the conductor is opposite the center of a pole, the other when the conductor is between the poles. The first component is in phase with the e.m.f. induced by the main poles and produces the useful torque between the armature and the field; it is the energy component of the current. The other component is in quadrature with the induced e.m.f. and produces no useful torque. It is the reactive component of the current.

Having represented the armature reaction by two fictitious coils revolving with the field, the armature winding can now be considered as if devoid of any magnetizing action. The total e.m.f. induced in the armature consists of that induced by the main flux (excited by a combined action of coils f and 1) and of the e.m.f. induced by the transverse flux (excited by coil 2). Fig. 2 is the vector diagram of an alternator; i is the vector of the armature current in one of the phases. This current is assumed to lag behind the terminal voltage e in the same phase by an angle ϕ. E_1 is the voltage induced in the same phase winding of the armature by the *actual* main field, that is by the field created by the combined action of the windings f and 1 (Fig. 1). The armature current is resolved into the energy component c_1 in phase with E_1, and the reactive component c_2 in quadrature with it. These components are different from the components i_1 and i_2 in phase and in quadrature with the terminal voltage e of the machine.* The total induced e.m.f. of the machine is a geometric sum of E_1 and of E_2, the latter being the e.m.f. induced by the fictitious poles of the machine. It has been shown above that in a generator these fictitious poles are behind the actual poles; consequently E_2 lags by 90 degrees behind E_1. To obtain the line voltage e the impedance drop DBA is subtracted from E. This drop is composed of the ohmic drop, ir, in phase with i, and of the leakage reactance drop, ix, in leading quadrature with i.

In the solution of practical questions involving armature reaction, some of the quantities in Fig. 2 are known or can be calculated from the dimensions of the machine; others must be determined from the diagram. Before applying this diagram, it is necessary to give mathematical expressions for the voltages E_1 and E_2, and for the demagnetizing and cross-magnetizing ampere-turns. To avoid misunderstanding it is preferable to consider the vector diagram drawn for one phase of a polyphase machine, and to use the voltage, the current, the resistance and the reactance per phase. The only inconvenience may arise in Y wound three-phase machines, because, in this case, in plotting the no-load saturation curve, it is sometimes customary to use the line voltage and not the phase voltage. One way out of this difficulty is to replot the saturation curve, using the voltages with

* The usual components i_1 and i_2 may be called the *external* components of the current, while c_1 and c_2 are the *internal* energy component and the internal reactive component of the current respectively.

respect to the neutral point as ordinates. The other way is to use the line voltage in the diagram, but to introduce the *equivalent* ohmic resistance and reactance; that is to say, such resistance and reactance as will cause the same per cent ohmic and reactive drop with respect to the line voltage as the actual resistance and reactance cause with respect to the phase voltage. If r' and x', respectively, are the actual resistance and reactance per phase (of V), then the equivalent resistance to be used in the construction of the diagram is $r = r'\sqrt{3}$, and the equivalent reactance is $x = x'\sqrt{3}$.

Voltage E_1. Let the machine have T armature turns per pole per phase and let there be n phases. Then the effective demagnetizing ampere-turns per pole are

$$M_1 = k_1 n T c_1 \text{*} \qquad (1)$$

where the coefficient of direct reaction

$$k_1 = (4\sqrt{2}/\pi^2)(Sin\ \tfrac{1}{2}\pi\xi)/\xi$$
$$= 0.573\ Sin(\tfrac{1}{2}\pi\xi)/\xi \qquad (2)$$

and ξ is the ratio of pole arc to pole pitch. This formula was first deduced by Dr. G. Kapp, by integrating over half a cycle the instantaneous demagnetizing effects of the armature.**

Formula (1) presupposes that the outer surface of the pole is concentric with the inner surface of the armature iron; in other words, that the air gap is the same at all points under the pole. In order to improve the wave form of the induced e.m.f., poles are sometimes shaped according to a cylindrical surface eccentric with respect to that of the armature core, and frequently pole tips are chamfered. In such cases the value of k_1 calculated according to formula (2) is not quite correct; it is necessary to estimate empirically the instantaneous demagnetizing actions from point to point and to average them. Professor Arnold calculated the demagnetizing action upon poles of usual shape covering about two-thirds of the armature periphery, with chamfered tips, and found the value of $k_1 = .75$. (See *Wechselstromtechnik*, Vol. IV, p. 64). For turbo-alternators without projecting poles the coefficient $\xi = 1$, and therefore, from equation (2), $k_1 = 0.573$.

Furthermore, formula (1) presupposes that there is only one armature slot per pole per phase. Ordinarily there are more than one slot per phase so that the above given value of M_1 must be multiplied by a coefficient k_s smaller than unity. This coefficient takes into account the distribution of the winding in slots, and has the same value as the corresponding coefficient used in the calculation of the induced e.m.f. of alternators. If there are s slots per pole per phase

$$k_s = (Sin\ \tfrac{1}{2}\ s\gamma)/(s\ Sin\ \tfrac{1}{2}\ \gamma) \qquad (3)$$

where γ is the angle in electrical degrees between the centers of adjacent slots.†

The following table gives values of k_s calculated according to formula (3), for 100 per cent pitch.

TABLE OF VALUES OF K.

Slots per Phase per Pole	Two-phase Windings	Three-phase Windings
1	1.000	1.000
2	0.924	0.966
3	0.911	0.960
4	0.907	0.958
5	0.904	0.957
6	0.903	0.956
Infinity	0.900	0.955

For fractional-pitch winding the effective demagnetizing turns are further reduced, and M_1 must be multiplied by a factor

$$k_f = Cos[90°(1 - \zeta/100)] \qquad (4)$$

where ζ is the winding pitch in per cent.

Some values of k_f calculated according to formula (4) are given in the table below.

TABLE OF VALUES OF K

$\zeta = 100$	95	90	85	80	75	70	65	60	55	50
$k_f = 1.000$	.997	.988	.972	.951	.924	.891	.853	.809	.760	.707

Thus, the most general formula for demagnetizing ampere-turns per pole is

$$M_1 = k_1\, k_s k_f\, n T c_2 \qquad (5)$$

in which the meaning and the numerical values of the coefficients k_1, k_s and k_f are given above.

Let it be required in a given alternator to determine the value of E_1 which corresponds to a given field current and to a given value of the lagging component c_2 of the armature current. The net (effective) excitation M_n is equal to the given field ampere-turns M less the demagnetizing ampere-turns M_1 according to equation (5). The value of E_1 is found from the no-load saturation curve,‡ and is the ordinate corresponding to the abscissa $M_n = M - M_1$. When the current is leading in a generator or lagging in a synchronous motor the component c_2

* This formula requires some corrections, as is explained below: in practical applications formula (5) must be used.
** Kapp, *Dynamomaschinen*, Edition of 1904, p. 424
† See Franklin and Esty, *Elements of Electrical Engineering*, Vol. 2, p. 121.
‡ Whenever reference is made in these articles to the no-load saturation curve, the same is understood to give values of the terminal voltage against ampere-turns *per pole* as abscissæ.

is to be considered negative, and the net (effective) excitation is $M_n = M + M_1$ instead of $M - M_1$. The armature reaction in this case strengthens the field.

When E_1 is known and it is required to find the corresponding value of the field ampere-turns M, determine on the no-load saturation curve the net ampere-turns M_n corresponding to E_1 and increase the value so obtained by the amount M_1 according to formula (5); in other words, $M = M_n + M_1$. The reason for this is clear by reference to Fig. 1.

It will be thus seen that in the above-described method the influence of the saturation in the magnetic circuit upon the armature reaction is properly taken into account. Therefore, voltage regulation calculated according to this method checks closely with experimental results even in highly saturated machines. The precision of the method can be further increased by taking into account the increased magnetic leakage between the poles, due to the load. Namely, when using the ordinary no-load saturation curve for the determination of E_1 a silent assumption is made that the leakage factor of the machine is the same at full load as at no load. In reality, per cent magnetic leakage between the poles increases with the load, especially at high saturations and with inductive loads. Some engineers replot the observed or the calculated no-load saturation curve using a higher leakage coefficient for the purpose of predetermining voltage regulation. A method for doing this is described in Arnold's *Wechselstromtechnik*, Vol. IV, pp. 94 and 287. See also *High Speed Dynamo-Electric Machinery* by Hobart and Ellis, p. 76.

Voltage E_2. This voltage is proportional to the component c_1 of the armature current and is induced by the flux created by the fictitious coils 2 (Fig. 1). By analogy with equation (5) the magnetomotive force of coil 2, or the cross-magnetizing action of the armature per pole, can be written in the form

$$M_2 = k_2 k_s k_f n T c_1 \qquad (6)$$

where k_2 is a numerical coefficient different from k_1. By working out results of tests on several large alternators and synchronous motors the writer found that the value of this coefficient lay between 0.23 and 0.3. The cross-magnetizing action of the armature affects the performance of the machine comparatively little because E_2 is at right angles to the induced e.m.f., E_1. Therefore, a considerable variation in the value of the coefficient k_2 is of little practical importance, except possibly in special designs. The value of k_2 can be determined theoretically (Arnold, *Wechselstromtechnik*, Vol. IV, pp. 64–67), but the assumptions which have to be made are rather crude. It is therefore desirable to use values of k_2 deduced from tests on machines possessing similar magnetic characteristics. Namely, the flux created by the coil 2 (Fig. 1) is far from being distributed in space according to the sine law, but has a large "saddle" in the middle, as is shown by dotted lines. Therefore, the voltage E_2 induced by this flux also differs considerably from the pure sine wave, and it becomes a complicated matter to estimate theoretically the cross-magnetizing effect from point to point and to determine its average value over a cycle. Moreover, the value of the flux created by the coil 2 depends to some extent upon the degree of saturation of the pole tips. For all these reasons the author prefers to use an experimental value of k_2 selecting it large enough so as to cover some small secondary phenomena not taken into account directly. In turbo-alternators without projecting poles both the demagnetizing and the cross-magnetizing magnetomotive forces follow the same law. Therefore, for these machines $k_2 = k_1 = 0.573$. *

The magnetic circuit of the coil 2 is very little saturated, consisting mainly of the air between the poles. Therefore, the lower straight part of the no-load saturation curve can be used for determining E_2. Let v volts be induced in the armature when the field excitation is equal to one ampere-turn per pole; v being determined from the lower straight part of the no-load saturation curve.

Then $$E_2 = v.M_2 = k_2 k_s k_f n T c_1 . v \qquad (7)$$

The reader may object to formula (7) on first sight because v refers to the main magnetic circuit, while M_2 refers to the magnetic circuit of coil 2 that runs on its larger portion through air. It must be remembered, however, that the coefficient k_2 is calculated under the supposition that the fictitious poles are identical with the main poles, so that the same saturation curve holds for both.

Formulæ (5) and (7) are the fundamental expressions for the components of armature reaction in alternators and in synchronous motors. These formulæ are used in the applications that follow.

* One of the latest contributions to the theory of armature reaction in synchronous machines is the article by J. A. Schouten "Ueber den Spannungsabfall Mehrphasiger Synchronen Maschinen" in the *Elektrotechnische Zeitschrift*, 1910, p. 877. He shows that Arnold's values for k_1 and k_2 are somewhat low, and gives a more accurate method for the determination of these coefficients.

ELECTRICAL EQUIPMENT OF THE UNIVERSAL PORTLAND CEMENT COMPANY, PLANTS NOS. 3 AND 4

By E. A. Hultz

Plants Nos. 3 and 4 of the Universal Portland Cement Company are located at Buffington, Indiana, on Lake Michigan, between South Chicago and Gary, about eleven miles southeast of South Chicago and five miles west of Gary.

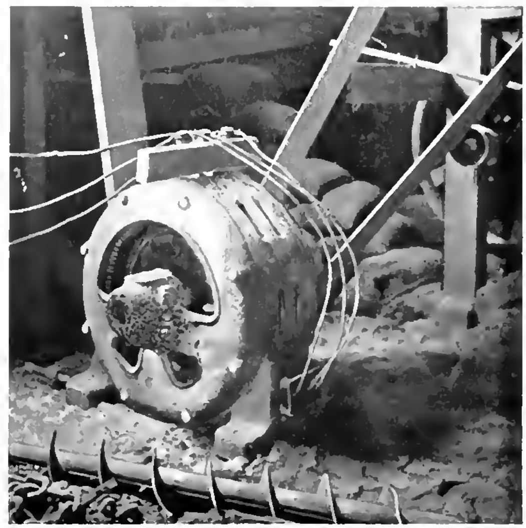
These plants are two distinct separate units, both being controlled by one head of operation and supplied from one central point of power distribution. Both plants are laid out on the same general plan, each one being divided into sections according to the different processes of manufacture. These divisions are, namely: the raw material department, burner buildings, clinker pits, finishing mills, stock houses, and shipping department.

The raw material is brought to the plant in cars and delivered onto one line of elevated track which supplies both plants. Here it is dumped into bins for the several mills, and from then on, until it is packed in bags ready for shipment, it is handled by electrically-operated machinery.

It might be well at this point to explain briefly the processes of manufacture, so that we may get a better idea of the electrical equipment. The raw material from the storage bins is first dried and crushed ready for mixing. The various materials are then mixed in their proper proportions, pulverized, and delivered to the burner building, where the raw material is thoroughly fused to clinker. The clinker is then delivered by electric cranes to clinker storage bins and allowed to cool, after which it is conveyed to the finishing mills, recrushed and pulverized, and then delivered to the stock houses as finished product. Here the cement is packed into bags ready for shipment.

Since both plants have practically the same layout, only that of No. 4, which is the more recent, will be dealt with in detail. All motors are of the squirrel cage induction type, unless otherwise specified, and the entire electrical equipment herein mentioned is of General Electric manufacture.

The raw material used is limestone and blast furnace slag. The limestone first passes through three No. 4 Gates crushers, whence it is delivered to 50 foot by 5 foot driers. One 20 h.p., 750 r.p.m., induction motor operates one crusher and one drier through group drive. The power is transmitted from the motor through a flexible coupling to a jack shaft which drives the drier and crusher. This method of drive is ideal, as all vibration and sudden strains are taken up in the flexible coupling, thus allowing the motor to operate under the best conditions.

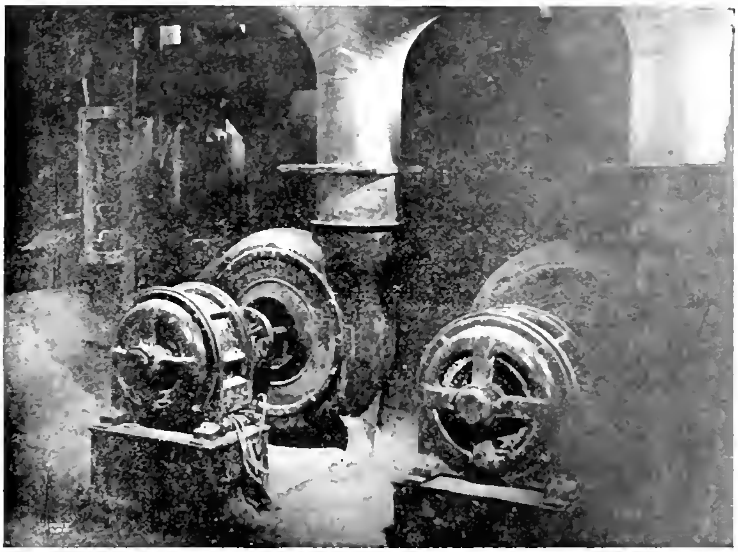


Induction Motor Covered with Thick Coating of Cement Showing Conditions of Operation

The slag first passes through four 50 foot by 5 foot driers, each drier being individually driven through flexible couplings by a 10 h.p., 750 r.p.m., Form M variable speed induction motor. A very great advantage is obtained by using these variable speed motors, for at times, if the material is very wet, it is necessary to run the drier slowly to obtain a uniform degree of dryness. This variable speed drive with alternating current motors is remarkably satisfactory.

The driers are fired by the combustion of pulverized coal with low pressure air. A little later on we shall describe the method of pulverizing the coal for the various mills. A long screw conveyor running the entire length of the raw material building delivers the pulverized coal into the drier hoppers, and is driven by a 30 h.p. induction motor. From these hoppers the coal is fed into burners by a small screw conveyor operated by disk friction from a line shaft which takes care of all the driers, this shaft being driven by a 10 h.p., 750 r.p.m. induction motor.

The air is furnished by two Buffalo blowers running at 750 r.p.m., each being driven through a flexible coupling by a 10 h.p. induction motor. This particular drive is remarkable for the smooth running of the motor, all the vibration of the fans being taken up in the flexible couplings.



Two 10 h.p., 750 r.p.m. induction motors flexibly coupled to Buffalo blowers, and used to force a mixture of air and coal dust into the slag and limestone dryers. Similar blowers are used for forcing powdered coal into the rotary kilns. The apparent fog around the right-hand machine is due to the large amount of dust in the air. Universal Portland Cement Co., Plant No. 4

From the driers the crushed limestone is lifted to ball mill hoppers by three 45 foot elevators, all three elevators being driven by one 5 h.p. induction motor. The motor is belted to the shaft driving the elevator heads and located high among the roof trusses of the building, thus illustrating the adaptability of this type of motor for use in places not easily accessible.

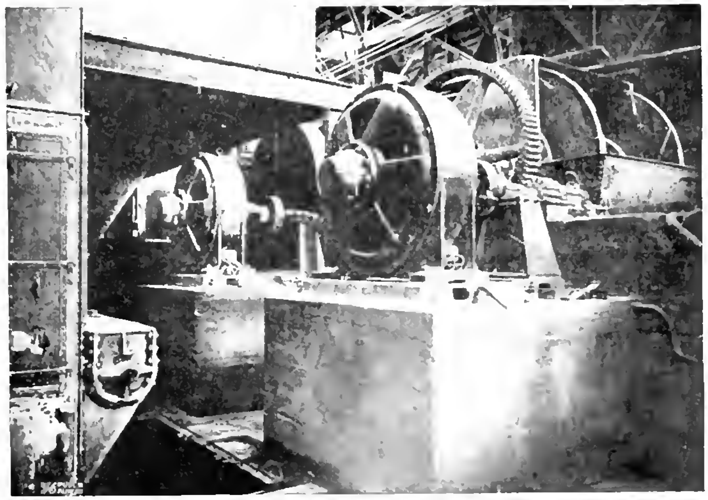
From the slag driers the material is elevated to the ball mill hoppers by four elevators of the same dimensions as the stone elevators and driven by one 5 h.p. induction motor; the method of drive being similar to that employed for the stone elevators.

From the ball mill hoppers the stone passes through eight No. 8 Gates ball mills, and the slag through three. Each of these mills contains about 4500 pounds of 4½ inch steel balls and is individually driven by a 10 h.p., 166 r.p.m., slow speed induction motor, the motor shaft being directly connected by means of a flexible coupling to the pinion shaft which drives the mill. The starting torque required by these ball mills is very high, varying from two to three times full load torque, and the running conditions are about the most severe that could be found. However, the very liberal design of the motors and the well developed flexible coupling have resulted in practically no wear and tear on the motors, although they have been running constantly day and night for nearly three years. The motor bearings are absolutely dustproof and self-lubricating and, although the motors are in the dustiest part of the entire mill, there has been no expense for maintenance of the bearings other than that of changing the oil about every three months.

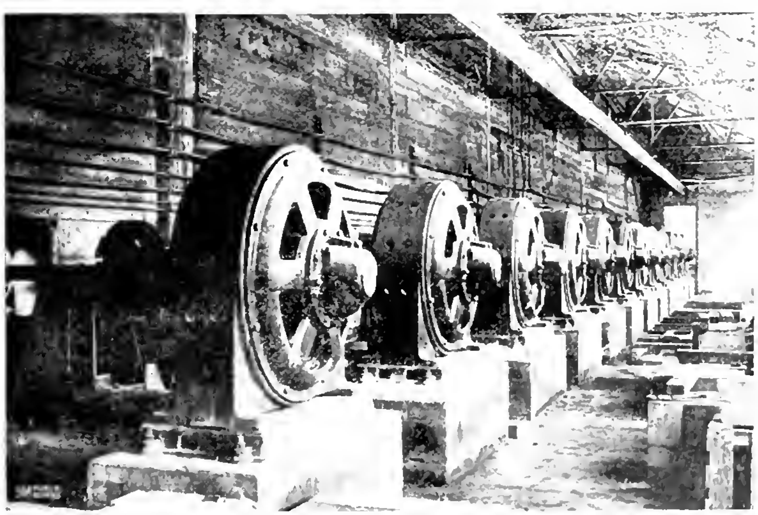
In plant No. 3 similar ball mills were originally driven by higher speed motors, both belt and gear drives having been tried. Owing to the exceptionally high maintenance cost on account of frequent changes in bearings and rewinding of motors, a radical change was desired when designing plant No. 4. Up to that time no small induction motors of sufficiently low speed to operate under these conditions had been built, but after a careful study by the engineers, it was decided to omit one gear reduction entirely and flexibly connect special low speed motors directly to the countershafts of the several mills. The wisdom of this radical selection as a remedy for the previous troubles has been proven, for the results in decreasing maintenance cost and entirely eliminating delays has been far beyond expectations. The double reduction gear and belt drive in the older plants are now being changed as rapidly as possible, and many other cement manufacturers have adopted slow speed motors with excellent results.

From the ball mills the material is delivered to twin elevators by means of a belt conveyor driven by a 5 h.p. induction motor. These twin elevators, which are each driven by a 20 h.p., 750 r.p.m. induction motor, take the material to a height of 63 feet and deliver it to scale hoppers. Material is delivered from the scale hoppers to the scales, of which there are two sets, by means of two screw conveyors. These conveyors are operated through electric clutches by a 10 h.p., 750 r.p.m. induction motor. The material is automatically weighed, registered, and dumped by electrical apparatus which gives exact results at all times and a positively uniform mixture.

The automatic electric weighing machines were developed and patented by the engineers of the cement company, and are probably the most accurate and reliable devices of this nature in existence. Each scale has two hoppers, separately balanced, and so arranged as to dump into a common mixing receptacle. The screw conveyor feeding each hopper is automatically stopped by magnetic clutches when the predetermined weight is delivered to the scale hopper, and it is impossible to dump either hopper until both have received the correct quantities of the two ingredients. The two hoppers are dumped simultaneously, thus insuring not only correct proportions in the mixture, but a perfect mechanical mixture before the material passes to the next stage of manufacture. The material is mixed by means of a mixing screw, which is driven from the shaft that drives the electric clutches. The mixture is next lifted through a height of 55 feet to the tube mill hoppers by two elevators, each driven by a 10 h.p., 750 r.p.m. induction motor. It next passes through twelve 22 foot by 5 foot tube mills half filled with flint pebbles. Each of these tube mills is individually driven by a 100 h.p., 166 r.p.m., induction motor connected through a flexible coupling to the pinion shaft driving the tube mill, the arrangement being similar to the ball mill drive.



18 h.p., 166 2/3 r.p.m. motors driving ball mills in the raw material mill. Universal Portland Cement Co., Plant No. 4. There are nine of these mills, and very satisfactory results have been obtained by this type of slow speed drive, which eliminates one gear reduction



Twelve 18 h.p., 166 2/3 r.p.m. motors driving raw material tube mills in Universal Portland Cement Co., Plant No. 4. These motors are connected through flexible couplings to the countershafts of the mills. This arrangement necessitated only one gear reduction. The concrete wall separating the motors from the mills secures an unusually clean motor room

In plant No. 3 the tube mills were driven by 180 r.p.m. induction motors connected through intermediate gears to the tube mill pinion shaft. This method of drive resulted in such high maintenance costs on account of wear on both the gears and the motors that when plant No. 1 was built, it was decided to install a single reduction drive. It is remarkable to note the results of this first trial of very slow speed motors: the first motor of this type was installed in plant No. 3 in June, 1907, and is still running, having caused no delays for repairs since it was started.

The tube mill motors are in a lean-to, which is separate from the rest of the mill, making a clean, ideal place for a drive of this kind.

All of the Form K motors throughout the plant are started by means of three-pole double-throw switches, oil switches being used on the larger motors. A low voltage line from various banks of auto transformers supplies the starting circuit for all of the motors.

Two 18 h.p., 166⅔ r.p.m. motors direct connected to countershaft of raw material tube mills through six arm flexible couplings, in Universal Portland Cement Co., Plant No. 4

From the tube mills the material is carried by means of a belt conveyor to a 47 foot elevator, from which it is delivered to a screw conveyor and then to a distributing conveyor for the kiln hoppers. The conveying machine is belt-driven by a 40 h.p., 750 r.p.m. induction motor.

The coal house which furnishes pulverized coal for the various mills is located next to the elevated track at the end of the raw mill and facing the burner building. The coal is fed by gravity into crusher hoppers, directly under the bins. There are three No. 1 Williams coal crushers and three 50 foot by 5½ foot driers for crushing and drying the coal. Each crusher and its drier is driven by a 750 r.p.m. induction motor through a flexible coupling and a countershaft. The coal is taken from the driers to the pulverizer hoppers by a screw conveyor and an elevator, driven in the group, by a 5 h.p., 750 r.p.m. induction motor.

There are eight 33 inch Fuller-Lehigh pulverizer mills which take the coal from the hoppers, each mill being belt-driven by a 40 h.p., 500 r.p.m. vertical induction motor of the two bearing type. Each bearing is automatically oiled, is dustproof and is independent of the other. The rotor is mounted on the shaft above the pulley, the latter being just above the lower bearing. The output of the entire plant depends upon the operation of these motors, as they furnish pulverized coal for all the burning. Their performance has been very satisfactory. The pulverized coal is taken from the coal house to the raw mill and burner buildings by two long screw conveyors, each driven by a 10 h.p., 750 r.p.m. induction motor.

The burner building contains twelve 120 foot by 7½ foot kilns, each belt-driven by a 15 h.p., 750 r.p.m. induction motor. The control for each kiln motor is located in front of the kiln at the hand of the operator. Three Buffalo blowers furnish the low pressure air for burning, each of which is driven through a flexible coupling by a 20 h.p., 750 r.p.m. induction motor. This drive is identically similar to the blower drive in the raw mill.

There are six 46 foot clinker elevators each driven by a 5 h.p., 750 r.p.m. induction motor, the control for which is located on the main floor, alongside of the corresponding kiln control. One elevator takes care of two kilns, delivering the clinker into the clinker pit, where it is handled by three-phase electric cranes.

Two 10 ton Alliance cranes are installed, each having the same electrical equipment.

View taken at the further end of motor annex showing 20 h.p., 500 r.p.m. motor belted to a conveyor. Universal Portland Cement Co., Plant No. 4

The 3 ton grab bucket is operated by two 37 h.p., 680 r.p.m. crane motors, one motor closing and opening the bucket, the other raising and lowering it. The trolley travel is operated by an 11 h.p., 680 r.p.m. crane motor; a 37 h.p., 680 r.p.m. crane motor driving the bridge travel. Each motor is controlled by a suitable controller, located in a cage at the end of the crane. The crane motors are of the slip ring, wound rotor, variable speed, alternating current type. The service required of these cranes is very severe, each handling 6500 barrels of clinker daily. The motors are subject at all times to constant stopping, starting and reversals, under very heavy loads. The motors are of the skeleton frame open type and operate out of doors in all kinds of weather. They have proved very satisfactory. The cranes take the hot clinker from the burner building spouts, pile it up to cool, and then carry the cool clinker into finishing mill hoppers, where it is fed into Kent mills.

In the finishing mill there are twelve 40 h.p., 500 r.p.m. induction motors, each direct connected through a flexible coupling to a jack shaft from which a Kent mill, elevator and Newaygo screen are driven. These motors are run in the dustiest part of the whole mill, twenty-four hours every day, under overloads that are very severe and frequent. This motor and type of drive proved such a success that nine more were installed in the No. 3 plant. Three 45 foot elevators deliver the cement from each group of four Kent mills to the tube mill hoppers, each elevator being driven by a 10 h.p., 750 r.p.m. induction motor.

Fifteen 5 foot by 22 foot tube mills take the cement from the tube mill hoppers. Each of these tube mills is driven by a 100 h.p. induction motor, through a flexible coupling attached to the master pinion shaft; this being the same style of drive as that used on the raw mill tube mills. At the back of the tube mills is a 208 foot by 24 inch belt conveyor driven by a 10 h.p., 750 r.p.m. induction motor. From this conveyor cement is delivered to the top of the stock house by means of a 170 foot by 24 inch inclined belt conveyor driven by a 10 h.p., 750 r.p.m. induction motor. In the top of this stock house, delivering the cement to the various bins, is a 600 foot by 24 inch belt conveyor driven by a 20 h.p., 750 r.p.m. induction motor.

All the motors in the entire plant are equipped with dustproof bearings and are blown out by compressed air every twenty-four hours.

Power is delivered to the substation at 22,000 volts from both South Chicago and Gary. The substation is so laid out that power may be transmitted from South Chicago to Gary, or vice versa, or both South Chicago and Gary may feed into the cement plant, thus insuring a constant supply of power. Each 22,000 volt line is protected by aluminum cell lightning arresters.

The incoming high voltage lines are divided into three circuits, each feeding a bank of three transformers. Two of these circuits feed banks of three 750 kw., 22,000/440 volt, 25 cycle, water cooled transformers; the other circuit feeding a bank of three 1500 kw., 22,000/440 volt, 25 cycle, water-cooled transformers. The transformers deliver current to a 440 volt distributing switchboard, each bank feeding into the common bus through a separate panel. This switchboard consists of three 440 volt alternating current transformer panels, six 440 volt alternating current distributing panels, two 125 volt direct current generator panels, and one 125 volt direct current distributing panel. Four of the alternating current distributing panels, each of which is equipped with two 6000 ampere air-break circuit breakers, and three 6000 ampere single-pole line switches, supply the two raw mills and finishing mills at both plants. Each switch unit consists of two 3000 ampere switches mounted on one stud. The remaining two alternating current distributing panels supply the two burner buildings and the stock houses of both plants. The equipment of each panel consists of two 4000 ampere air-break circuit breakers and three 4000 ampere single-pole line switches, each switch unit consisting of two 2000 ampere switches mounted on one stud. By this switchboard arrangement each mill is controlled entirely independently of the other. Thus, if the circuit breaker feeding one mill blows out, it does not in any way affect the operation of the rest of the mill.

Two motor-generator sets, one a 75 kw. induction motor set and the other a 150 kw. synchronous motor set, furnish direct current at 125 volts for lighting purposes.

As in other cement plants, new apparatus is constantly being tried out and additional power is demanded, thus causing a considerable tax on the generator and transformer capacity. Several conditions arose during the past year in this respect which made it evident that some steps must be taken in the direction of permanent improvement. The substation power factor was about 76 per cent and the generating units at South Chicago were overloaded when called upon to furnish full load current to the cement plant. Further, the heavy inductive load at

Buffington made it very hard to keep the stations at South Chicago and Gary in step. Conditions were studied very carefully, calculations were made, and it was decided to install two synchronous condensers. Operating conditions have been greatly improved by the installation of these machines, as the following statements will indicate. In addition to helping out the generating station, which was the main purpose of the installation, the high tension line losses were decreased and the efficiency of the low tension feeders distributing power to the various mills was increased. Better voltage regulation was secured at Buffington, the capacity of the transformers was increased, and operating conditions between the two generating plants were greatly improved.

As a whole, the installation has proven very successful. It has been estimated that $10,000 annually has been saved in the cost of power.

The conditions were as follows:

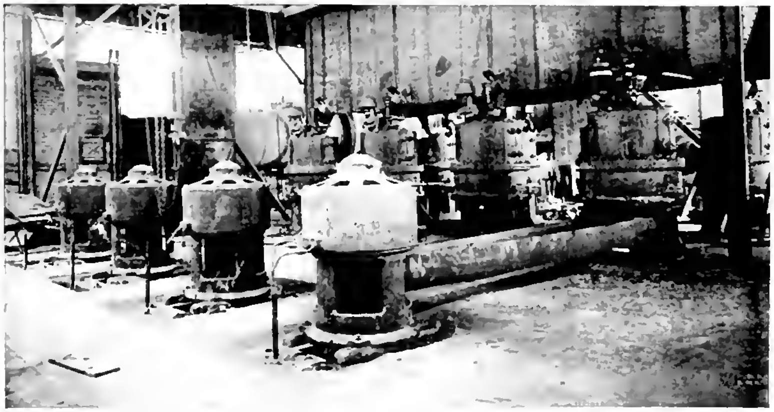
7500 kw. station load at Buffington, 76 per cent power factor; required, to raise the power factor to 93 per cent.

7500 kw. is the energy component, 9870 the kilovolt-amperes furnished by the generator, and 6416 kv-a. the lagging or wattless component at 76 per cent power factor.

By increasing the power factor to 93 per cent the wattless component is decreased from 6416 kv-a. to 2965 kv-a. This leaves 3451 kv-a., which must be corrected for by supplying leading current of proper amount. In the condenser diagram we have added 7 per cent of the leading kilovolt-amperes to the energy component for the energy losses in the condenser. The rating of the condenser is therefore 3450 kv-a. and the total energy component 7740 kw., reducing the generator output from 9870 kv-a. to 8325 kv-a. at 93 per cent power factor. A saving of 1545 kv-a. in generator capacity is thus effected.

A 7000 kw., 25 cycle, 2300 volt, mixed pressure Curtis turbine has been installed recently in the South Chicago plant of the Illinois Steel Company. This turbine furnishes additional power for the cement plants at Buffington and the steel mills at South Chicago, taking its low pressure steam from the exhaust of the high pressure reciprocating steam engines that operate the blowing engines and alternators. The valves admitting steam to the buckets of the turbine are so arranged that if the supply of low pressure steam is cut off, high pressure steam is admitted automatically. The turbine exhausts into a high vacuum condenser and operates under very favorable conditions, as has been shown by recent tests.

The above applications of electric power show that advanced engineering features can be applied to the cement industry equally as well as to any other. The power conditions of a great many cement plants now operating could be greatly improved by careful analysis and the installation of proper machines, and it is to the benefit of the industry that these conditions be looked into with a view towards economy and higher efficiency in operation.



40 H.P., 500 R.P.M. Vertical Induction Motors Belted to Fuller-Lehigh Mills
Universal Portland Cement Company, Plant No. 4

THE REGULATION OF Y-Y CONNECTED THREE-PHASE TRANSFORMERS OF DIFFERENT TYPES UNEQUALLY LOADED WITH RESPECT TO ONE PHASE

By E. Zachrisson

The object of this paper is to investigate the regulation, as set forth in the title, of three-phase transformers of different designs, all of which are Y connected on both the primary and secondary sides, with the primary neutral point insulated. The several types of transformers are: (1) a bank of three single-phase transformers; (2) a three-phase shell type transformer; and (3) a three-phase core type transformer.

In the following consideration of the subject, it is assumed that the load between the terminal of one-phase and the neutral point is the only load existing. For transformers of each of the three kinds mentioned above, the voltage drop, caused by the current between any two phases, can be readily found in a well known manner and is much less than that caused by the current between one of the phases and the neutral point of the secondary.

(1) Three Single-Phase Transformers

The significant fact shown by Fig. 1 is that the magnetic flux of each phase is entirely independent of that of the other two phases and cannot therefore have any

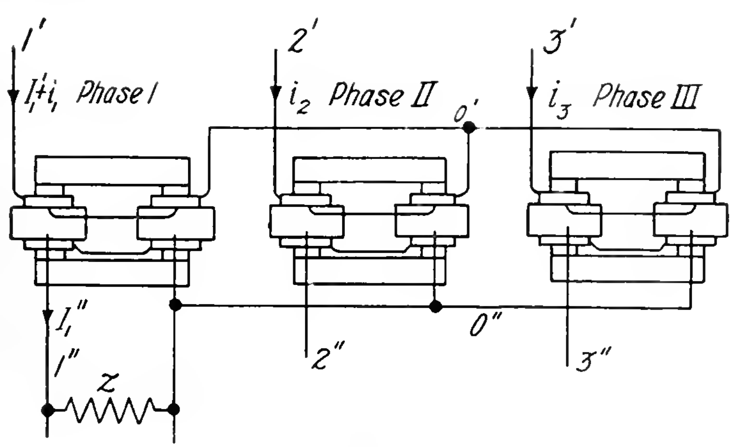


Fig. 1

influence upon the voltages and currents of the other phases.

The behavior of the transformer is also determined by the fact that the sum of the currents in all three phases equals zero.

Let i_1 = magnetizing current in phase 1

I_2' = load current in primary, phase 2

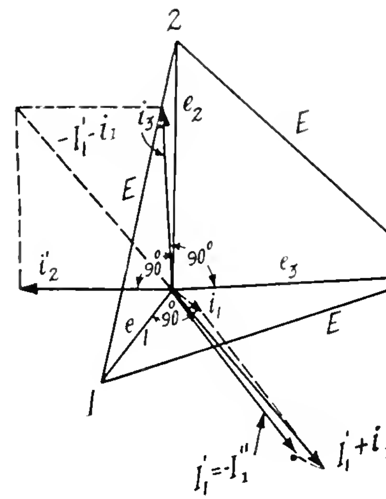


Fig. 2

I_1'' = load current in secondary, phase 1

$i = M\ (e)$, the equation of the saturation curve of one phase.

If figured with the value of the secondary current corresponding to an equal number of turns in the primary and the secondary windings, we have, (see Fig. 2):

$$I_1'' = I_1'$$

$$I_1' + i_1 + i_2 + i_3 = 0.$$

$$I_1'' = i_1 + i_2 + i_3 =$$

$$M\ (e_1) + M\ (e_2) + M\ (e_3)$$

$$e_1 + e_2 = E$$

$$e_2 + e_3 = E$$

$$e_1 + e_3 = E$$

$$e_1 = Z\ I_1''$$

wherein the impedance voltages of the transformers are neglected.

At short circuit, or Z = zero:

$$I_1''_{max} = \sqrt{3}\ M\ (E)$$

$$e_1 = 0$$

$$e_2 = e_3 = E$$

If the saturation curve is a straight line through the origin:

$I_1''_{max}$ = 3 times the normal exciting current of one transformer.

In practical cases, where this assumption is wrong, $I_1''_{max}$ will have a greater value by reason of the saturation of the iron.

(2) Three-Phase Shell Type Transformer

A transformer of this kind may be considered as three single-phase transformers,

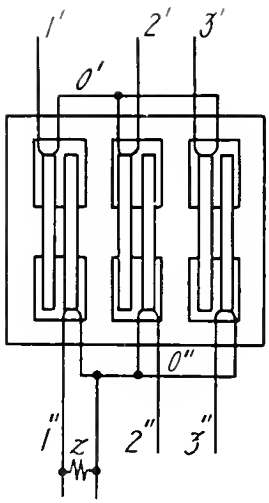


Fig. 3

located side by side. Some difference, however, is caused by the fact that a part of the iron path is common to the phases. (Fig. 3.)

The thorough theoretical investigation of this case can best be carried out in a way similar to that which will be used for the third division of the article. However, this investigation, which cannot be carried out to a relatively simple result without too great an approximation regarding the relative sizes of the reluctances in the different iron paths, may be made to produce a result rather similar to that obtained for the first case.*

(3) Core Type Transformer

This case is quite different from the preceding ones. Each phase no longer has its own path of iron for its magnetic flux, which must pass not only through one leg, that is one phase, but also through the two others in parallel, if it does not prefer the path through the air outside of the windings and through the bolts holding the transformer core together.

Referring to Figs. 4 and 5, the following equations apply:

$$I_1'' = I_1' + I_2' \qquad (1)$$

$$I_1'' = I_1' + I_3' \qquad (2)$$

because the m.m.f.s of the load currents for each magnetic circuit, indicated by dotted lines in Fig. 4, are equal to zero.

Hence $I_2' = I_3'$ (3)

Because the sum of the primary currents in all three phases is equal to zero,

$$I_1' + i_1 + I_2' + i_2 + I_3' + i_3 = 0 \qquad (4)$$

Neglecting i_1, i_2, i_3 in comparison with I_1', I_2', I_3':

$$I_1' + I_2' + I_3' = 0 \qquad (5)$$

Because I_2' and I_3' are both displaced 180° relatively to I_1', and according to (3):

$$I_1' = I_2' + I_3' = 2I_2' = 2\ I_3'$$

Inserting in (1) and (2):

$$I_1'' = 3\ I_2' = 3\ I_3' = 1{,}5\ I_1'$$

There are now two kinds of impedance voltage in the transformer, as follows:

(a) The ordinary impedance in the primary and the secondary windings of phase $1 = z_{1-1}$. $I_1' = \frac{2}{3} z_{1-1}\ I_1''$, of which half may be supposed to belong to the primary and the other half to the secondary. This voltage can be measured by short-circuiting phase 1′ and reading the voltage applied across 0″ − 1″, necessary to force through the current $\frac{2}{3}\ I_1''$ or I_1'.

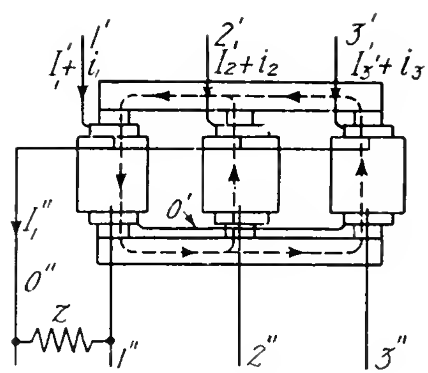


Fig. 4

(b) The voltage drop caused by the resistance in, and the leaking magnetic flux between, the legs 1 and 2 and 1 and 3 $(= z_{1-2}\ I_2' + z_{1-3} I_3' = z_{1-2,\ 3} I_2' = z_{1-2,\ 3} I_3'$ $= \frac{1}{3} z_{1-2,\ 3} I_1'')$, of which $\frac{1}{4}$ is assumed to belong to each of the primaries of the phases 2 and 3 and $\frac{1}{2}$ to the secondary of phase 1. This voltage drop $z_{1-2,\ 3} I_2' = \frac{1}{3}\ z_{1-2,\ 3} I_1''$ can be measured by short-circuiting 0′ − 2′ and 0′ − 3′ and reading the voltage across $0'' - 1_1''$ necessary to force through the current $\frac{I''_1}{3}$, or I_2' and I_3'.

Referring to Figs. 4 and 5, for the current I_1'' there will be the primary voltage drops $\frac{1}{3}z_{1-1}\ I_1''$ for $0'-1'$ and $\frac{1}{12}z_{1-2,\ 3}I_1''$ for each one of $0'-2'$ and $0'-3'$. The induced e.m.f.'s will be determined by A, B, C and the section points of medians of the triangle ABC. Secondary voltages
$e_{i1}-\frac{1}{3}z_{1-1}\ I_1''-\frac{1}{6}z_{1-2,\ 3},I_1''$, e_{i2} and e_{i3}

At short-circuit of $0''-1''$ or $Z=0_1$ if the resistances are neglected in comparison with the reactances:

$$\frac{1}{3}x_{1-1}I_1''+\frac{1}{12}x_{1-2,\ 3}I_1''+\frac{3}{2}\left(\frac{1}{3}x_{1-1}I_1''+\frac{1}{6}x_{1-2,\ 3}I_1''\right)=\frac{E\sqrt{3}}{2}$$

$$I_1''{}_{max}\left(\frac{5}{6}x_{1-1}+\frac{1}{3}x_{1-2,\ 3}\right)=\frac{E\sqrt{3}}{2}$$

If also x_{1-1} small, compared with $x_{1-2,\ 3}$:

$$I_1''{}_{max}=\frac{3\sqrt{3}}{2}.\ \frac{E}{x_{1-2,\ 3}}$$

From the above developments the following summary can be made: With a three-phase transformer set, consisting of three single-phase transformers or of one three-phase shell type transformer, connected Y-Y, with the primary neutral-point insulated, a loading of one phase of the secondary between the neutral-point and one phase will cause a heavy drop of voltage on the loaded phase and a very considerable rise on the unloaded phases. The maximum current on short-circuiting the loaded phase will in normal cases amount to upwards of 15 per cent of normal full load current of the transformer.

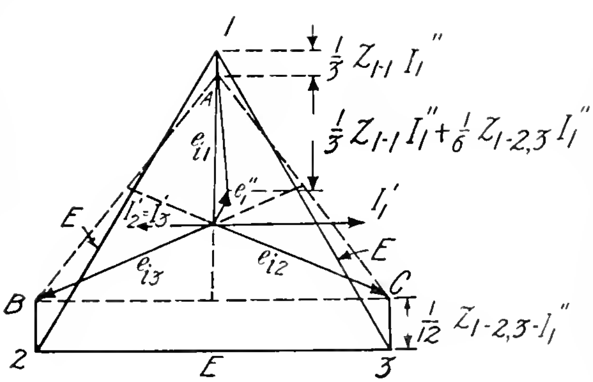


Fig. 5

In the case of a three-phase core type transformer, the voltage drop of the loaded phase will be mainly produced by the reactance $x_{1-2,\ 3}$, without which the regulation would be about as small as for transformers delta connected. Upon short-circuiting one phase the current will rise considerably, in most cases to an amount sufficient to operate the automatic switch or burn out the fuses.

This difference in the behavior of the different types of transformers may sometimes be of importance where a load on only one phase is expected, for instance, in lighting transformers.

Another case in which attention to this matter is not commonly given, as the author believes, is that of long distance high tension systems having considerable capacity against ground, where Y-Y connected step-up transformers are used with the neutral-point of the high tension grounded. In the case of three-phase core type transformers, upon the occurrence of a ground, a great rush of current will automatically cut out the damaged line, thereby avoiding an excessive rise of voltage. Compared with a delta system, an advantage is to be derived from the fact that the amount of current in the individual windings will not be so great, and thus the chances of damage to the machines and transformers will be diminished and the opening of the damaged circuit made less difficult. If three single-phase or one shell type transformer is used, the amount of current is too much limited and the conditions may be rather similar to those occurring at an "arcing ground" on an ungrounded system, a phenomenon which has been well described by Dr. C. P. Steinmetz.* Here the disturbance will naturally appear in all phases.

The author knows of such an occasion in the case of a certain high tension plant equipped with single-phase transformers. In this instance a failure to ground had occurred the night before and upon slowly raising the voltage, at the beginning of operation in the morning, an excessive potential was observed where the voltage reached a value equal to the rated voltage divided by the square root of three. Severe damage was done to the apparatus in both the step-up and step-down stations, an arc also jumping to ground from the busbar just ahead of a current transformer. Like phenomena recurred until the connections were made between the neutral points of the generators and of the primaries of the transformers. On the other hand, many plants with Y-Y

* See for instance, "High-power Surges in Electrical Distribution Systems of Great Magnitude," Proceedings of A I E E., June, 1905.

connected transformers of the three-phase core type have proved successful in operation. In America, where shell type and single-phase transformers are used almost exclusively, it is also significant that at first, if the author is not mistaken, engineers became cautious with regard to the use of Y-Y connections on high-tension transformers; while in Europe, where the three-phase core type has been used to the greatest extent, many plants equipped with Y-Y connection have been operated very successfully.

THE AGRICULTURIST'S NEGLECTED PROBLEM *

By E. P. Edwards

The beginning of the twentieth century will stand out in history as an age of marvelous achievement and any one development must indeed be most remarkable to attain individual prominence.

Nevertheless, the progress of scientific agriculture and the electrical development of the last decade will unquestionably stand out in bold relief as pre-eminent examples of our wonderful accomplishments, and it is believed that each has need of the other and that the closest co-operation and relationship should exist between them.

In comparison with other world movements the science of agriculture has lain dormant for centuries past, and not until the last few years has it moved forward at a pace commensurate with its importance and taken that place which rightfully belongs to it as the principal factor in our cosmos.

This recent awakening has not been brought about solely or directly because of the increasing demands made upon our sources of food supply by an increasing population and its expanding requirements. This demand has always outstripped our resources; this advancement has been brought about through scientific treatment of the problem which confronts us.

We are now rapidly reaching a solution of this problem and a few years more will see the abandonment of century old and primitive methods that have prevailed, and the substitution of rational, scientific, business principles is bringing about this most desirable change. The practical student of agriculture, the graduate of our agricultural college, is principally responsible, for he is taught the value of crop rotation as a means of preserving soil productiveness; the value of proper seed selection and fertilization; the proper method of cultivating the soil; the value of drainage and irrigation; the value of proper supervision in the selection and retention of livestock; the value of properly laying out his farm and farm buildings, and how to market his product. But over and above all he should be taught, and is being taught, the value of business methods and the application of those methods to his needs.

After all is said, his aim is to secure the greatest returns from the least investment, and by "returns" is meant, not only financial prosperity, but physical comfort and happiness as well.

Let us repeat that the agricultural college is bringing all this about, and bringing it about in a sane, conservative way.

This paper has been prepared with the hope that the suggestions contained in it may be helpful to a more rapid solution of the problem, and an effort will be made to point out a neglected but vital phase of the situation and an obvious remedy.

The agricultural engineer has apparently overlooked the growing importance of mechanical power as an adjunct to his line of work. Millions of dollars have been expended by our agriculturists in the investigation of plant life phenomena and in the dissemination of the knowledge so gained, but relatively nothing has been spent by the farmer in the study of the power problem which confronts him. His expenditures in this direction can be charged up principally to experience.

Why should the farmer spend money for the study of this problem? Because the great developments in all other lines outside of farming have been brought about through a comprehension of power and its economic application; because the problem is real and vital to the farmer as well as to the rest of mankind; because the farmers as a class, are our greatest users of power in its many forms, but the power that they use is not on a par

* Read before the American Society of Agricultural Engineers at Lafayette, Ind., December 28th, 1910.

with that of modern progress, considered from the standpoint of efficiency and economy.

The census of 1900 estimated that there were over 29,000,000 people in the United States engaged in gainful pursuits. Of this number more than 10,000,000 were devoting their energies to agriculture. This means man power.

The same census estimates the number of horses and mules at over 29,000,000 of which 89 per cent were utilized in agriculture. This means horse power.

Today most of the mechanical power used on our farms has the gasoline engine as its source. There are approximately four hundred manufacturers of gasoline engines in the United States and most of their product finds its way to the farm; one manufacturing concern alone selling over 30,000 gasoline engines a year to the agricultural trade. This means mechanical power. In addition, the farmer utilizes steam, water, producer gas, crude oil, kerosene, alcohol and waste products generally, as sources of power.

We know that the farmer finds use for a greater variety of implements and mechanical contrivances than almost any other industry. Is he operating these implements and contrivances most economically? Today, he does not know; today he is at the mercy of every manufacturer engaged in the building of power apparatus. He must buy power apparatus on faith and with only experience as a teacher. The reputable manufacturer endeavors, to the best of his ability, to meet the farmer's needs with reliable apparatus, but is hampered through his ignorance of those needs.

Why should the farmer remain in ignorance on this vital subject? Certainly not because he is incapable of comprehending it. It is absurd to say that any man who is capable of understanding the intricacies of agriculture, as it is now taught, is incapable of understanding the power problem and its practical applications, if he is given the opportunity to make a study of it.

Our great universities are turning out electrical, mechanical and agricultural engineers by the thousand, but there is too little co-operation between these three student bodies. The electrical and mechanical engineer is usually ignorant of matters agricultural, and can probably afford to be, in a majority of cases. The agricultural engineer is almost equally ignorant of matters pertaining to electricity and mechanical applications of power, but he should be led to feel that he cannot afford to remain in ignorance.

Let us refer to Bulletin No. 73, issued by the United States Department of Agriculture in collaboration with experts of the Minnesota Agricultural Experiment Station. The bulletin is entitled "The Cost of Producing Minnesota Farm Products, 1902-1907." It comprises sixty-nine pages of valuable information dealing with "Agriculture and the Science of Business."

A study of this bulletin will show that the greatest stress is laid on the necessity for determining costs of production in the most accurate way and this necessity cannot be too strongly emphasized; but while elaborate data has been accumulated in an effort to determine the "cost per hour" of farm labor, expressed in man power and in animal horsepower, the whole subject of mechanical power has been treated in the most casual way.

The writer is not prepared to believe that a sharp dividing line exists between the power needs of our urban and rural population. He does believe that mechanical power can be made to benefit the farmer to the same extent that it has benefitted his city brother.

It is not asserted that mechanical tractors are better suited or more economical for the work in hand than the horses which they supersede. It is not asserted that the stationary engine used for pumping, feed grinding, threshing, churning, hoisting, etc., is more satisfactory or economical than man power, but it is asserted that in other walks of life, both man power and horse power have been superseded by mechanical power, to a relatively much greater extent than on the farm, and there must be some good reason for it.

The manufacturer thinks that power can be applied to farming methods as advantageously as it has been applied to other industries, but neither the manufacturer nor the farmer knows just how it should be applied or where it should be applied.

Who is it that should bring the farmer and manufacturer into closer touch? It is the agricultural engineer, and the agricultural engineer will be an engineer in name only until he has mastered the power problem.

Today the farmer can purchase a power plant of the same horse-power rating at prices ranging between $10 and $300 per unit of power. Why this discrepancy? What does it mean? It means that there is no reliable standard to which the farmer can pin his faith. Who will determine upon such a standard? The agricultural engineer should be the one to do it.

A further study of the typical bulletin above referred to will show that he has not yet realized the necessity for doing so. This bulletin dismisses the whole subject of mechanical power with a bare statement showing the depreciation of farm implements and states that "the various factors which enter into the cost of producing the field crop may be enumerated as follows: man labor, horse labor, values consumed in farm machinery, seed, twine, etc., and the rental value of land." But what has electricity to do with this discussion and why was it mentioned side by side with the science of agriculture? Simply because it seems to the writer that the two sciences should go hand in hand, and it is his belief that electricity will do for the farmer what it has done for our manufacturing industries.

Let us mention a few things that electricity has accomplished. It has given us means for rapid and convenient communication in the telephone and telegraph. Without these devices the farmer would be isolated to a degree; he could not keep in touch with his markets or with weather conditions. With these exceptions, electricity had been of little direct benefit to the farmer until the development of our irrigation projects, which extensively employ this form of energy.

On the other hand, consider the numberless benefits derived from electricity by our urban inhabitants and manufacturing industries. They have harnessed a power possessing the greatest flexibility and adaptability; they have been able, through the medium of electricity, to utilize the vast water powers of our country in an efficient manner. Electricity has made possible the development of the steam turbine, or rotary engine, having a unit capacity undreamed of by the builders and users of reciprocating engines. The invention of the turbine antedates the invention of the reciprocating engine by many centuries, but it has only come into use during the past few years, and electricity has made this possible. Until the turbine was developed our largest power units had a capacity of only 5000 kw., or 6700 horse-power. Our largest power units of today, consisting of turbine-driven generators, have a capacity of 20,000 kw. or approximately 27,000 horse-power.

Imagine, if you can, transmitting from one point mechanical energy equivalent to 30,000 horse-power, through the medium of gears, belts, pulleys, etc.; but take this same energy, convert it into electricity, and the problem is simple. The power of Niagara can now be transmitted hundreds of miles by means of electricity, whereas, in the absence of electricity, it could not be utilized at all, except in a limited sense.

Where would we be in our cities if we did not have electricity to transport us to and from our work? Think of the congestion in New York City if its traffic was handled by horse-drawn cars. Think of the luxuries which are becoming necessities that our urban population is enjoying in the shape of electric light, electric cooking and heating devices, electric flat irons, soldering irons, vacuum cleaners, motor-driven sewing machines, etc.

If electricity has brought these things to our urban population why can it not bring them to our rural population? Why should the farmer deny himself the conveniences enjoyed by his city brother? There is no reason for his doing so and he will avail himself of the opportunities presented when he is brought to a realization of their worth.

There are approximately 7,100 public service corporations distributing electricity today, with a total daily output approximating 7,000,000 horse-power, and practically all of this power is used within our cities. Does it seem logical that the same form of energy could be used to advantage, and very largely, in our rural communities? The possibility should at least be investigated, and we repeat again that the agricultural engineer is the best medium through which to conduct this investigation. We cannot think that our educators are blind to the necessity for a thorough understanding of the power problem; rather, we are convinced that they are anxious to master it and are prevented from so doing only through lack of funds and the sympathy of the men they serve.

The remedy is obvious and should be immediately applied.

The governing factors of our agricultural colleges, the manufacturers of farm implements and machinery, and the manufacturers of power apparatus, should combine in an effort to convince the farmer that his own best interests demand the introduction of the power problem into his curriculum.

Once this has been done, appropriations will be granted by means of which the agricultural student can complete his education along lines that will entitle him to style himself an engineer. Until that time comes, the agriculturist will have to content himself with "cut and try" methods; he will have to carry on his operations with crude and inefficient machinery; he will have to secure improvements in this machinery through the slow and costly process of elimination and will have very little to say about how those improvements are to be brought about.

The manufacturer is doing the best he can but we cannot logically expect the manufacturer to do it all. If he is left unaided, the farmer will suffer the consequences that result from the ignorance and misdirected efforts of the manufacturers, manifested in crude, cheap, unsuitable machinery and so-called "fool-proof" devices which are now found in such abundance on the farm.

The farmer should be his own safeguard. Let us unite in an endeavor to convince him of this fact.

Here are a few problems that need solving: The farmer needs light and power. He is now using kerosene, gasoline and acetylene as an illuminant, and, as a result, the annual fire loss on the farm is equal to that of the cities.

The invention of the tungsten lamp offers a safe, cheap, convenient and far superior illuminant which, in itself, is an insurance policy of great value. But if the farmer can get an electric lighting outfit for a few hundred dollars, why not increase that expenditure by a few hundred dollars more, and thereby secure power available for operating milking machinery, separators, churns, refrigerating plants, hay hoists, pumps, root cutters, feed grinders, threshing machines, corn shellers, etc.; and for his wife, electric irons, vacuum cleaners, sewing machines, fans, chafing dishes, etc.

Assume that he wants to do this, how can it be done with a minimum expenditure?

If the thirty volt lighting system is the best for the purpose—and it has many advantages—is it equally adapted for power application? Apparently not, because if direct current is used it cannot be economically employed for many reasons that are obvious to the electrical engineer. It cannot be transmitted for any distance, for one thing; thirty volt motors are much more expensive than those of higher potential, for another.

Without going into a detailed discussion of the subject, it appears to the writer that alternating current is best adapted to power applications. It is much more flexible than direct current; it can be transmitted economically to almost any distance desirable, and it has this one great advantage; if the farmer installs his own plant and later on a public service corporation extends its lines to his vicinity, he can switch over from his isolated plant and benefit through the lower cost of power so obtainable without discarding his motor.

The isolated plant has its very real uses as a pioneer, but its usefulness is past from an economical standpoint with the advent of power from a concentrated source.

Again refer to the bulletin above mentioned. Man power is estimated to cost approximately 11 cents per hour. Animal horse power is estimated to cost approximately 8 cents per hour. An isolated plant can be operated at less than 8 cents per horse-power hour and the depreciation is less. Central station power is being furnished in our cities at one-third of these costs and lack of demand is all that prevents these lower costs prevailing in the country.

Another problem: There is a well recognized tendency for the farmer to purchase a portable gasoline engine, moving it from place to place. Later he adds another unit and keeps it up until he has from six to one dozen such equipments. Can he operate such an outfit as economically as he can a central power plant furnishing current for motors located in the places he needs them? If he can, then he is doing something that our manufacturers find it impossible to do except at a loss.

Another problem: Which is the more economical, a central stationary power plant, or a portable power plant, such as is available in the tractor? Perhaps both are necessary. We might go on indefinitely, but it would be too much of a tax on your patience, so just one word in conclusion. All of the possibilities mentioned above are sufficiently practical to warrant immediate study, but beyond these there are possibilities which hold out much promise.

Reference is made to the stimulation of plant life by electricity and the conversion of the air's nitrogen into fertilizer. Investigation of the first possibility is still in its infancy, but when men like Sir Oliver Lodge, Prof. Daniel Berthelot, Prof. Lemstrom and others give it their endorsement, we are inclined to believe that there may be much in it. The second possibility is already reaching commercial prominence abroad.

THE USE OF ELECTRIC POWER IN THE ICE MAKING INDUSTRY

By W. D. Bearce

Following the commercial development of ice making machinery the manufacturer of artificial ice has to a large extent supplanted the natural product. This is especially true in the more temperate climates where ice rarely forms to sufficient thickness for harvesting. In colder climates where the production of natural ice is more dependable, the cost of power for its artificial production is one of the principal factors in a successful competition with the natural ice business, and electric power is now being widely used in this industry.

With the general distribution of Niagara Falls power numerous small industries within transmission distance have taken advantage of the low rates for electrical energy thus made available. The plant of the Crystal Ice and Storage Company of Buffalo, herein briefly described, is only one of many similar enterprises which are being successfully operated from this exceptionally reliable central station power.

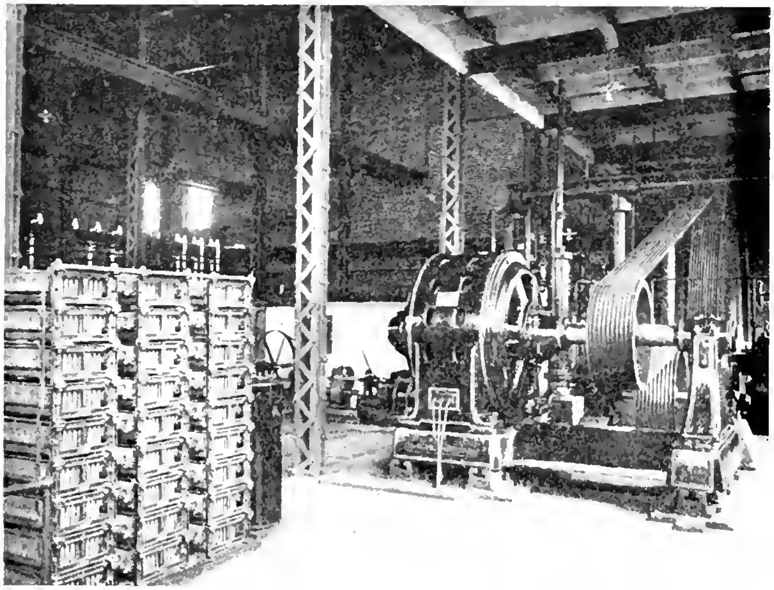


Fig. 1. 200 H.P., 2200 Volt Induction Motor Operating Ammonia Compressor Through Rope Drive

Transmission facilities between Niagara Falls and Buffalo are sufficiently ample to insure customers against interruption of service; a normal rated station capacity of 120,000 kw. being a further protection against failure of power.

The distributing agent of the Niagara Falls Power Company, known as the Cataract Power and Conduit Company, receives power at the Buffalo station over a 22,000 volt transmission line, where it is stepped down to 2200 volts for city distribution.

The large number of industrial plants using electric power in the city of Buffalo gives a relatively high load

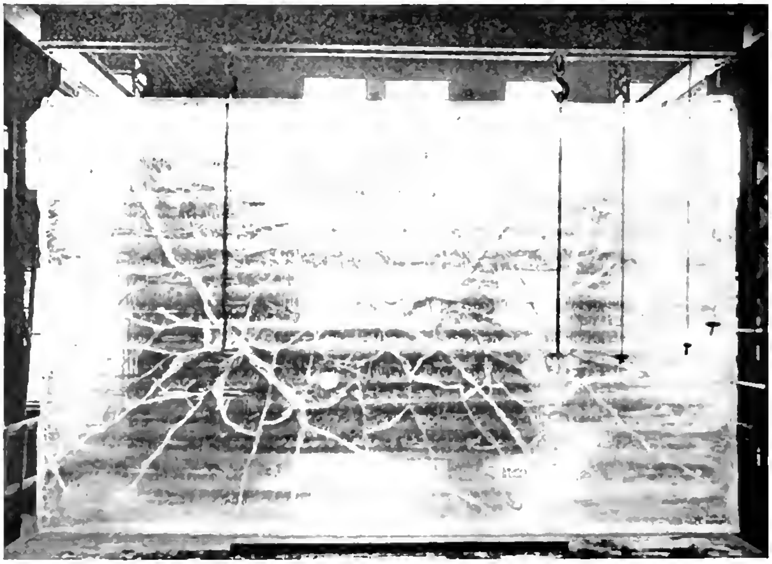


Fig. 2. Cake of Artificial Ice Weighing About 9400 lbs. being Handled by Electrically Operated Crane

factor and particularly attractive rates can therefore be offered to consumers requiring power in relatively large quantities for twenty-four hours per day.

In many ice making plants the use of distilled water is necessary, in order to produce a clear ice free from air bubbles. However, the method used by the Crystal Ice and Storage Company for the manufacture of ice employs ordinary spring water and the plant is therefore particularly suitable for electrical operation, since the need for steam is entirely eliminated.

In the manufacture of ice the main requirement is the production, by mechanical means, of a sufficiently low temperature to freeze the water. In this plant the plate system, in which the ice is formed and built up on an artificially cooled plate, is used in connection with an ammonia compressor. The evaporation of the liquid ammonia takes place in a system of coils placed between the vertical steel plates, which are fifteen and one-half feet long by nine and one-half feet wide. A cake of ice of these dimensions and twelve inches thick weighs about 9400 pounds.

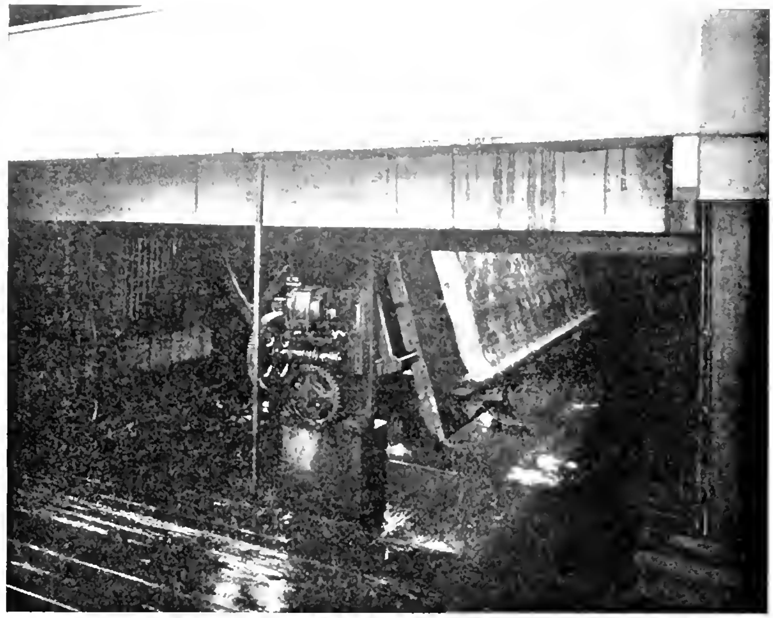


Fig. 3. Tilting Table for Lowering Ice Cakes into Horizontal Position

There are sixteen tanks in use, each containing plates for eight of these cakes. Electric drive is used for all machinery to the exclusion of steam engine, boilers and accessories.

A 200 horse-power, 2200 volt induction motor (Fig. 1) furnishes power to the ammonia compressor which is rope-driven from a large pulley located between the two cylinders. Each cylinder is rated at one hundred tons of refrigeration. In order to vary the rate of compression, the motor is equipped with a wound rotor and slip rings, the external resistance for regulating the speed being inserted by means of a drum controller. A speed reduction to one-half normal is thus made possible.

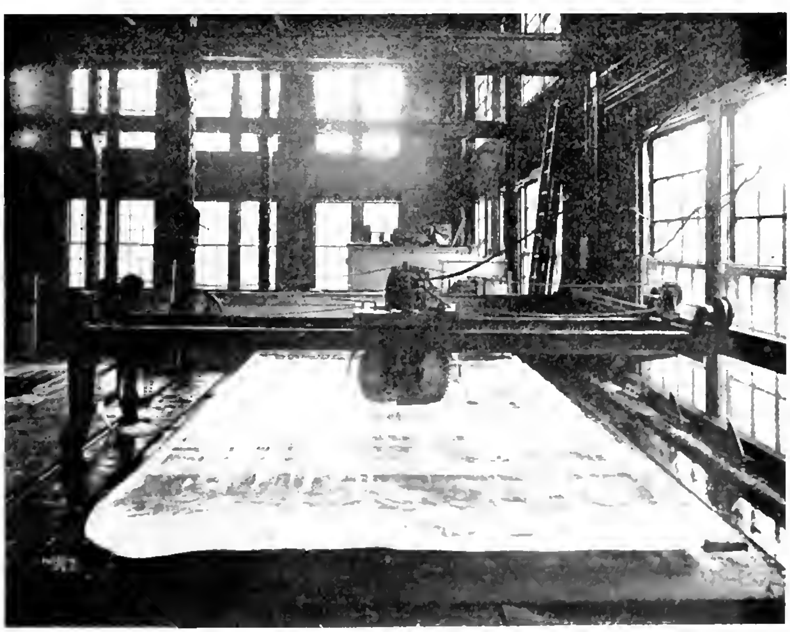


Fig. 4. Motor Operated Saw Cutting a Large Cake of Ice

The average daily production is about seventy-eight tons, but during hot weather the output sometimes runs as high as one hundred tons per day.

In order to produce ice free from air bubbles the water is kept in motion while freezing by the use of compressed air. When the cake is built up to the desired thickness a hot ammonia gas is sent through the pipe system, the heat loosening the cake ready for "harvesting."

The tanks are arranged in two rows, each served by a seven ton crane. To facilitate handling, two eye bolts are cast into each cake of ice, as shown in Fig. 2. Each crane is operated by two induction motors of 5 and 3 horse-power, respectively, which are of the slip ring type and are therefore suitable for starting under load.

After the cake is placed on the "tipping table" the supporting bolts must be removed preparatory to sawing. This is accomplished without difficulty by using a heavy current of electricity to loosen the rods. The projecting terminals at the lower end of the bolts are connected together by means of a flexible copper cable and voltage is applied to the upper ends. A specially wound Type H transformer is used for the purpose, rated one kilowatt at four volts on the secondary side. The 250 ampere current thus obtained will loosen the bolts in about one minute.

The ice cake is lowered to a horizontal position by means of the "tipping table" shown in Fig. 3. The operating motor for this table is rated two horse-power at 750 r.p.m. and is wired for reverse operation to allow a range of motion through nearly 180 degrees. This movement places the cake flat side down on the table regardless of its position when removed from the tank.

The ice is now ready for the motor-driven saw shown in Fig. 4. This saw is mounted on a revolving stand and traveller, so arranged that a cut may be made in either of two directions. The motor speed is 1500 r.p.m. and the saw runs at about 1200 r.p.m. The saving in labor over the harvesting of natural ice is evident from the fact that the entire output is handled by two men, from the freezing tanks to the loading platform.

The building is lighted throughout by tungsten lamps in 60 and 100 watt sizes, and the entire electrical equipment was furnished by the General Electric Company, including induction motors, transformers, switchboard panels and control apparatus.

COMMERCIAL ELECTRICAL TESTING

Part XVI

By E. F. Collins

THREE-PHASE REGULATORS (Cont'd)

Core Loss

For low potential three-phase regulators, core loss is measured in the usual way by applying normal potential to the primary winding. For regulators the primary voltage of which exceeds 1100 volts, core loss should be measured on the secondary winding.

For six-phase two-circuit primary regulators, one set of core loss readings on lines 1–3–5 and another on 2–4–6 should be taken. Either set should give the correct core loss. For six-phase diametrically connected regulators, core loss may be determined by applying six-phase voltage, reading the core loss in each phase and taking the sum of these losses. It may also be taken by connecting the primaries in delta, reversing one primary coil to maintain the proper distribution of magnetic flux. Apply the rated primary voltage and determine the core loss by the two wattmeter method. Another method of determining core loss is by connecting the primaries in Y and applying 1.73 times the rated potential. One coil must be reversed for the Y connection, as is done for the delta connection.

In making a core loss test, record the voltage, exciting current and wattmeter readings. The test must be made at the proper frequency and the generator supplying the loss must operate at normal voltage. The magnetizing current will vary from 20 to 40 per cent, depending upon the air gap. A curve should be taken beginning at 50 per cent normal voltage and increasing to at least 125 per cent normal voltage. Whenever possible, neither potential nor current transformers should be used with the wattmeter, in consequence of the very low power factor. During the core loss tests the armature should be in the maximum boost position. A curve should also be taken by holding normal voltage and varying the position of the armature.

Impedance

Impedance is usually measured by short circuiting the secondary and applying sufficient voltage to the primary winding to give full load current. The impedance voltage varies from 15 to 20 per cent. This test should be made on three-phase regulators by using three-phase voltage, and on six-phase regulators by using six-phase voltage. Wattmeter readings are not required, as the efficiency is calculated, using the I^2R losses as computed from the resistances. When calculating the full load primary current for this test, assume that the regulator operates at a power factor of 80 per cent.

In special cases, impedance may be taken from the secondary side, in which event connect the secondaries in Y and apply rated current. An ammeter should be placed in one phase of the short circuited primary. If the primary is permanently connected to the secondary inside the machine, each secondary coil must be short circuited on itself. On all other types, the secondary is short circuited by connecting all the secondary terminals on either side with a copper bar.

A curve should be taken ranging from 50 to 150 per cent full load, with the armature in the maximum boost position. A curve should also be taken while holding full load current and varying the position of the armature. This curve should be very carefully taken over one-half of the segment, to obtain the maximum impedance.

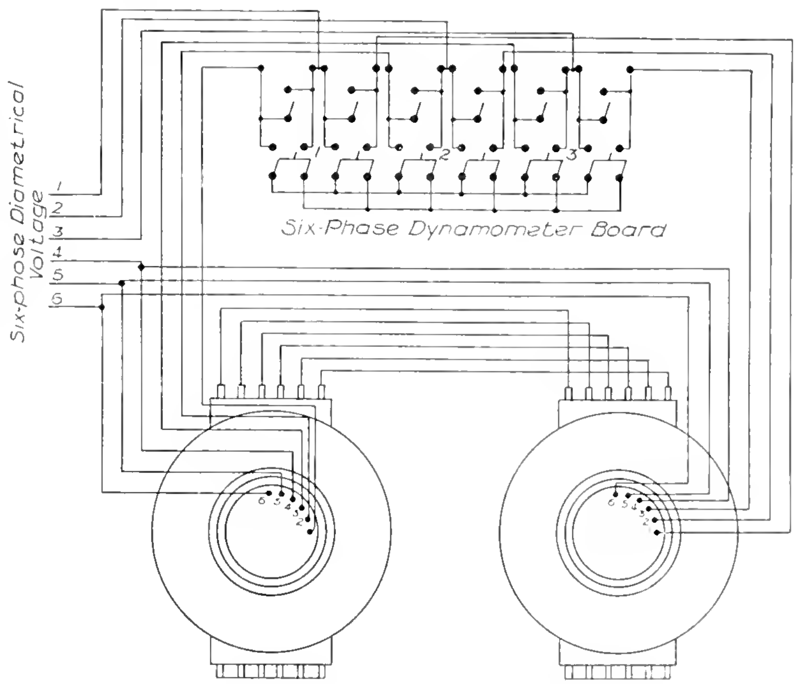


Fig. 73. Connections for Heat Run on a Six-Phase Regulator

Heat Run

Whenever possible, heat runs should be made with full load on the regulator, either by pumping one regulator back on another, or by pumping back against a bank of transformers. The heat run on two regulators of the same size and type is made by connecting the primaries in multiple through a dynamometer board. One end of the secondary coil of the regulator is connected to the end of the secondary coil of the other by short circuiting bars. The other ends of the secondary coils of one regulator must be in multiple with corresponding coils of the other regulator. Normal voltage of the proper phase and frequency is applied to the primaries of the two regulators. The handwheel of one regulator must be turned so as to cause sufficient phase displacement of the secondary voltages of the two regulators to produce full load current in the secondary winding.

In pumping back against a bank of transformers, the same general method is used. The ratio of transformation of the transformers should be about equal to that of the regulator. The same readings of temperature should be taken as on a transformer using a similar method of cooling. Carefully observe if there is any noise while under load; if humming is noticed during the core loss test, the cable lugs connecting the two secondary circuits in multiple should be removed to see if the noise is caused by exchange current.

Fig. 73 shows the connection for the heat run on two IRH regulators.

When the heat run is finished, measure all hot resistances and finish the test as on transformers. In using high potential between the secondary windings, a very high charging current is necessary on account of the large electrostatic capacity. The damper of the air-blast regulator should be inspected for proper operation. Oil cooled regulators should be inspected for leaks and pressure test should be made on the cooling coils of water cooled regulators.

Switch Type (BR) Regulator

Modern central stations employ alternating current generators of large capacity, each generator usually supplying two or more districts through independent feeders. One feeder may serve a business district, while another from the same generator may feed a residential district. As the voltage regulation required on any of the feeders depends on the amount of load carried by the feeder, and as the load peak occurs at different times in different feeders, a device to regulate the feeder voltages independently is necessary.

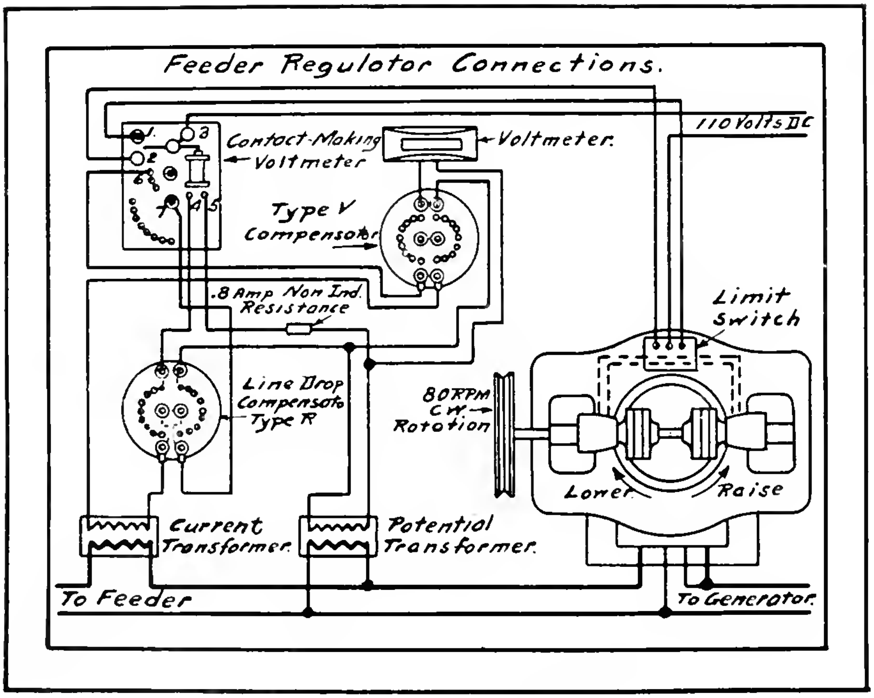


Fig. 74. Connections for BR Regulator

Induction regulators may be used, but the automatic BR feeder regulator has been expressly designed for this work. Fig. 74 shows the circuits of this regulator.

The automatic BR feeder regulator can change the line voltage quicker and with a smaller power consumption than any other automatic type. The only moving part is a small, light switch arm. The friction of a number of small switch contacts constitutes the only resistance to turning.

The moving part of the switch carries a series of fingers, the majority of which are always in contact. (See Fig. 75.) Each finger is connected to a stationary collector ring by a brush, and the collector ring is connected to the line through a preventive resistance. The resistances connecting the fingers to the line prevent excessive exchange currents as the fingers pass from contact to contact, and the line voltage is varied uniformly. The regulator transformer is oil cooled.

The tests required are: resistances, tap voltages or ratio, core loss, impedance, heat run, insulation, and checking of clutch coil and limit switch circuits.

Cold Resistance

Measure the cold resistance of the primary winding, each half of the secondary, and the iron grids. To obtain the resistance of each half of the secondary winding, turn the switch to the extreme position and take readings, showing the switch position by a sketch. Then throw the switch into the other extreme position and measure the other half of the secondary winding.

Tap Voltage or Ratio

When the switch contacts are accessible, full voltage should be applied to the primary winding, reading the voltage between the steps on the switch. This test will show any wrong switch connections immediately. Correct connection can also be checked by a polarity test on each step. If properly connected all steps will have the same polarity; that is, the voltmeter deflections are all in the same direction.

If the contacts of the switch are inaccessible, the step voltages may be taken as follows: Throw the switch to the neutral position, apply full voltage to the primary, and connect the voltmeter across the secondary. When the switch is in the neutral position, no secondary voltage will be obtained. Move the switch one step and read the secondary voltage. Then move the switch to the next step when the reading obtained should correspond to two steps in series. Continue until the switch has reached the extreme position. Bring the switch back to the neutral, then test the steps on the other half. If the sections of the secondary winding are properly connected to the dial, the voltmeter readings should increase in equal increments.

Core Loss

Core loss may be determined from the primary but is more satisfactorily determined from the secondary winding. Throw the switch to the extreme position and apply the rated boost or lower voltage, reading watts input and exciting current at the proper frequency. The per cent loss and exciting current will be about the same as for a Type H transformer of the same kilowatt capacity. Throw the switch into the other extreme position and repeat the test.

Impedance

Supply current to the primary, with the secondary and iron grid short circuited through an ammeter, the switch being in one extreme position. Increase the primary current until full rated current is obtained on the short circuited secondary, and read amperes, watts and volts primary at the proper frequency. Throw the switch into the other extreme position and repeat the test. Impedance must be taken with the switch in both extreme positions, as in either position only one-half of the secondary winding is short circuited.

Heat Run

If two regulators are in test at the same time they may be "pumped back" on each other; if only one is in test, it may be pumped back on a suitably arranged bank of transformers, or loaded on a water box. In the latter case apply voltage to the primary, connecting the secondary to a water box and adjusting until full load secondary current is obtained. The switch must be in one of the extreme positions. Read and record the temperature and also record the temperature of the iron grid resistance.

Start the test at overload so as to shorten the length of the heat run. Finish as if testing on a transformer. Throw the switch in the other extreme position and run at 50

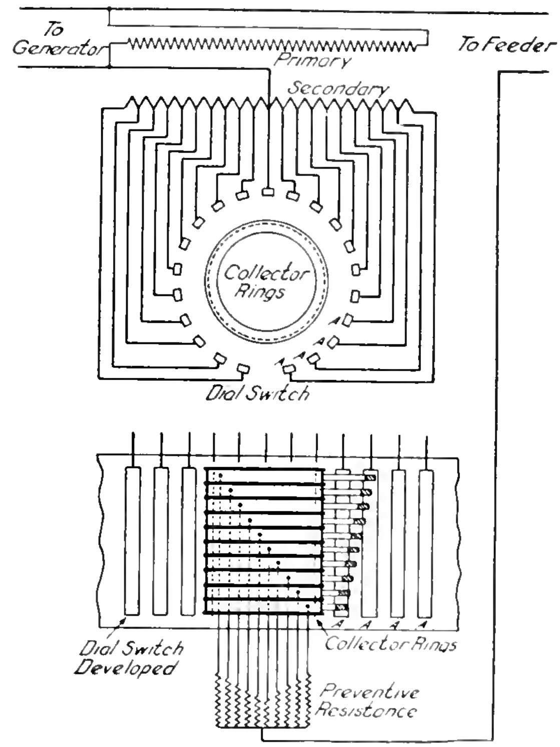


Fig. 75. BR Regulator

per cent overload current for one hour to test the other half of the secondary.

Insulation Tests

Apply double potential for one minute and one and one-half potential for five minutes. High potential tests on regulators are similar to those made on transformers. If the primary is connected to the secondary inside the tank it is not possible to test between the primary and secondary windings. If the clutch coils, relay coil, and relay voltmeter operate on a circuit of 125 volts or less, test with 500 volts between the winding and frame. The tank and oil gauges should be inspected for leaks.

TESTING STEAM TURBINES AND STEAM TURBO-GENERATORS*

By E. D. Dickinson and L. T. Robinson

Of late years an increasing amount of consideration is being given to the economic production of power, and as the cost of coal in a steam power station is the largest item of expense, it naturally follows that the efficiency of the apparatus for generating power should be high. In order to determine these efficiencies, certain accurate measurements, or tests, are necessary, and it is the intention to outline what precautions must be taken, in order that the results may not be misleading, and also to consider the relative degrees of accuracy of different methods.

The term efficiency is a fruitful source of misunderstanding. The only meaning which is of any commercial significance to the operating engineer is that which gives the ratio between the energy in the form he desires, to the energy available in the fuel. In other words, what he wants to know is, how much is he getting out for what he puts in.

There is one point that must at all times be kept in mind and that is that all tests, even when accurate, are at best but an indication of what may be expected in the overall economy of the station. A specific example of this is a certain European power house, which contained several engines of the best makes. When steam turbines were installed, the coal consumption was decreased about 20 per cent, though the test efficiency of the turbines showed no such marked superiority over that of the engines.

In the manufacturing of steam turbines a great amount of testing is necessary, to determine the effect of making changes in design or to verify theories and formulae which cannot be established by calculation; much of this is of an experimental or laboratory nature. There is also a large amount of testing done in order to establish the overall economy of the complete unit. This latter is all that is of commercial value to those operating steam turbines. The actual efficiency of the turbine alone is of some interest, but can only be determined by measuring the power delivered by the shaft to some form of brake, or to a generator of known efficiency. Any testing by allowing for the different losses by the methods often employed for electrical apparatus, is impractical and should not be considered.

*This paper was presented at the New York meeting of the A.I.E.E., December 9, 1910.

In this paper it is not the intention to elaborate all the numerous details which must be carefully taken care of when tests are being made. Many points of importance are only touched upon. Every test must be given special consideration, and the necessary precautions to be taken will depend on local conditions.

MEASUREMENT OF THE STEAM INPUT

Weighing Condensed Steam

The one positive method of testing a turbo-generator is to measure the steam that goes in through the throttle valve and the electric energy delivered at the terminals of the generator. The surest method of determining how much steam enters the turbine is to collect and weigh all the steam after it has been condensed. This necessitates the use of a condenser of the surface type. In making such a test two things are essential: First, that all the steam used on the turbine be condensed and measured; and second, that no steam or water, not used in the turbine, be allowed to enter the condenser. Should the condenser not be perfectly tight, some of the cooling water will be drawn into the condenser and mixed with the condensed steam; this is a common source of error. The condenser should have leakage checked before and after each test. With all steam turned off the turbine the condenser should be run for some time with full vacuum, and the discharge from the hot well pump very accurately measured.

Split condenser tubes will sometimes cause leakage which is extremely difficult to locate, and cannot always be determined by measuring the leakage. This is the case when the split opens up only when the condenser is heated with large flows of steam. This action will generally give erratic results, and no tests should be considered that do not show consistency with other tests on the same machine.

Measuring Condensed Steam

The most accurate method of measuring the condensed steam is by the use of tanks, so arranged that all the water can be weighed at equal time intervals during the test. The pump, piping and tanks must be free from leaks, and the condenser and pumps must be so arranged that the water will continuously flow to the pump. This is essential in order to get accurate results.

Weighing Water Fed to Boilers

This method is quite frequently resorted to when the condensed steam cannot be measured, as is the case when the turbine is operating non-condensing, or when the condenser is of the jet type, in which the cooling water is mixed with condensed steam. In making such tests, the liability to error is very great, and every precaution must be taken in order that the results may be considered reliable within any degree of accuracy.

The steam piping connecting the boilers and turbine must be disconnected from all other piping, and all openings must be blanked off; valves must not be relied on. All blow off and drain valves must have their outlets visible. All piping between boiler feed-pumps and boilers must be exposed, and have no branches. Leakage of the boiler itself is the most difficult to locate, as all water or steam escaping is vaporized and carried up the stack. The boiler leakage should be checked before and after each test by closing the throttle to the turbine, or if necessary, by blanking the pipes at the turbine and running a test measuring the amount of water required with full steam pressure on boilers and piping.

The feed water used should be weighed, and not measured by meters.

Tests which have come under our observation have shown boiler leakage of 10 and 12 per cent of the water weighed into the boilers, and one particular case showed a leakage of over 20 per cent.

Test by Heat Balance

This method of testing is based on measuring the amount of heat transferred to the cooling water from the condensed steam. It is extremely inaccurate and unreliable, and at best can give but an approximate idea of the quantity of steam being condensed. The quantity and temperature of cooling water and the temperature of the outgoing water, carrying with it the condensed steam, are measured as accurately as possible. The reason for inaccuracies is the difficulty of measuring the quantity of cooling water and its true average temperature change. The temperature of the cooling water may vary at different sides of the pipe, and small discrepancies in the reading will show large variations in the estimated steam consumption of the turbine, since the temperature rise is small.

Duration of Tests

In order to establish accurately any given point, all tests should be run with fixed conditions after a state of equilibrium is established and things are constant for an appreciable length of time. The time required will depend on the nature of the test being made. In general, when small amounts are being measured, the duration of the tests should be somewhat greater, for example, when measuring the condenser leakage, this test should be run for a sufficiently long period in order that the small quantity of water which will come through may be accurately weighed.

Efficiencies

The net overall efficiency expressed by the ratio between the kilowatt-hours output of the generator, and the available energy in the steam, is the only one of any particular commercial value. The comparison of efficiencies of different machines is the most satisfactory way of considering their relative merits. To determine the available energy in one pound of steam it is necessary to know the pressure in pounds per square inch, the quality and the temperature of the entering steam; also the pressure at the turbine exhaust. To measure the exhaust pressure, or vacuum, a gauge should not be relied on. The most accurate means is to use a full length mercury gauge, and subtract the readings given by this, from the atmospheric pressure at the time the test is made. If the steam be superheated, since there is some difference of opinion concerning the specific heat of superheated steam, the figure assumed must be given.

In testing turbines consisting of several stages, the pressures in the different stages should be measured: this affords a check, and should show any abnormal conditions existing in the interior, which might not otherwise be observed.

The kilowatt output should be net, that is, the kilowatts for excitation should be subtracted from the generator output.

Checking Instruments

All instruments, including meters, gauges, thermometers, and scales, must be very accurately calibrated or checked before and after the test. Small inaccuracies in some of the readings may entirely discredit tests which have cost a great deal of money to make.

Inspection and Adjustment

Before tests are made the turbine should be inspected to see that all parts are in proper condition. If necessary the interior should be examined to see that the buckets have not been damaged by foreign substances, and all necessary adjustments made at this time. After the tests have been completed, the machine should be ready for commercial service, and no adjustments of the turbine should be made.

Corrections

Whenever possible, turbines should be tested under the conditions for which they were built to operate. Correcting for different conditions is always liable to throw some doubt upon the accuracy of the test, and therefore on the efficiency of the machine being tested. Different machines will have different correction factors for varying conditions, and for this reason it is impossible to arbitrarily fix the allowances that should be made.

In general, the corrections for steam pressure, moisture, or superheat, are less liable to be misleading than the correction for varying vacuum, for the reason that comparatively large changes in any one of the first three, will but slightly affect the conditions in the machine; whereas, a slight change in the vacuum makes an enormous change in the available energy and volume of the steam in the low pressure end of the turbine. A turbine may show a splendid efficiency with poor vacuum, but unless it be properly proportioned, it may give a poor efficiency with a good vacuum.

Test Results

The majority of commercial tests on turbo-generators are made to determine whether or not the unit is fulfilling the guarantees made by the manufacturer of the apparatus. The steam turbine differs from the reciprocating steam engine, in that it is impossible to take any readings that will give a direct indication of the power being developed. The designing engineer with all necessary data, can estimate very accurately what power the turbine is developing under any given set of conditions. But the operating engineer has not the time, nor is he interested in making such calculations.

It will be apparent from the foregoing, that the complete test of a unit necessitates taking a large number of measurements, and small inaccuracies in taking many of the readings are liable to affect considerably the final results. For this reason, it is obvious that no machine should be discredited on account of small variation in the final results.

With the high efficiencies now being obtained, small inaccuracies in readings will show a relatively large per cent variation in the steam consumption. It is for this reason that manufacturers guarantee an efficiency which is not quite so good as may be expected from the unit. Another method is to guarantee the efficiency that may be expected, with an allowance to cover permissible inaccuracies in making tests.

The Steam Flow Meter

Under suitable circumstances, thoroughly accurate tests may be made by measuring the steam with a meter. Such tests will be more convenient than those made by any other method. Certain precautions are necessary, but there should be small expense in providing conditions that will insure reliable results with the best meters.

Even where other methods of measurement are used the steam flow meter will always be a valuable adjunct since its readings are accurately proportional to flow and show the conditions instantaneously.

MEASURING THE ELECTRICAL OUTPUT IN CONNECTION WITH TURBINE TESTS

The output of the turbo-generator may be either direct current or alternating current. We will consider first the measurement of direct current output. Usually, station instruments in connection with generator switchboard have been provided, but unless temperature conditions can be very accurately controlled and the instruments can be checked under operating conditions they should not be used. The station voltmeters may sometimes be satisfactory but it is the usual practice to supply direct current station ammeters to operate from shunts of approximately 60 millivolts drop, which requires that the indicating part of the ammeter be largely a copper circuit; therefore the whole combination is subject to considerable error due to variations in room temperature, and with some shunt arrangements, to variations in the current to be measured as well. For the precise measurement of direct current output, portable indicating ammeters should be used having 200-millivolt-drop shunts,* thereby permitting the use of indicating millivoltmeters whose circuits consist largely of resistance material having practically no temperature coefficient. It is also desirable, when possible, to measure the volts by similar portable voltmeters.

*This is not an arbitrary value but has been chosen by several makers as giving the best compensation of all temperature errors.

When using either switchboard or portable instruments the influence of any stray fields should be investigated and arrangements made whereby these stray fields will not affect the measured output. Special caution must be observed in this respect if the instruments are not of a shielded type. If the influence of stray fields is very small it may be eliminated from the final result by periodically turning the instruments between successive readings. There is also another point in connection with the measurement of amperes which is important, especially when testing large units, namely: care should be taken to correct the observed indications of the millivoltmeter for any electromotive forces that may appear in the shunt or leads due to thermoelectric effects. The amount of error due to this cause may be observed by reading the millivoltmeter at the close of the test with no current flowing in the main circuit. There may then be observed a small positive or negative indication, which should be applied as a correction to the observed ampere readings. Of course, to have this correction constant throughout the test the entire arrangement should be run under the test load until final temperature conditions in the shunt have been established. These precautions need not be observed in connection with standard precision shunts having 200 millivolts drop.

Referring again to the station type of shunts, unless the ammeter is checked with the shunt connected into the busbars great care should be taken to know that the distribution of current flow through the shunt is the same when the ammeter is used, as when it was tested. It is quite possible to have large errors due to this cause.

Measurement of Alternating Current Output

If the output is small—less than 20 or 30 kw.—wattmeters, ammeters and voltmeters without current or volt-multipliers may be used. The same remarks with regard to disturbing influences which apply with direct current instruments, apply with even greater force to instruments for alternating current. They are not usually much affected by steady magnetic fields but in many locations where large generators must be tested there may be fields which would have an appreciable effect on the indications of the instruments and which would alternate with the same frequency as the circuit to be tested. The current leads of the circuit under test may become a source of error. Such fields require the use of shielded instruments or the careful handling of those of the unshielded sort to eliminate any possible errors.

After all questions in connection with the instruments themselves have been disposed of it is necessary to consider the proper use of the instrument transformers which provide usually the only means of enlarging the capacity of the instruments to meet ordinary requirements.

The station equipment provided for use with the generator can be checked carefully and both the instruments and transformers employed for the precision test, but this is not usually as convenient as to insert transformers specially tested for the work. Of course, if the constructors of the plant have the foresight to install tested transformers, these are at any time available for precision testing. Makers of instrument transformers, can supply them with certificates showing performance under any specified conditions, when requested.

In using instrument transformers it is necessary to observe the precaution to have the secondary connected load the same as that which was on the transformers when they were tested for the certificate. It is also necessary, if the test is to be made under conditions that will give low power factor on circuits, to at least know that the phase displacements in the instrument transformers are not large enough to appreciably affect the results. It is also well to observe the precaution not to use instrument transformers with interconnected secondaries except for the common ground connection which should be employed as a safety precaution

If possible, a test should be made on non-inductive load. If this is done the indications of the voltmeters and ammeters may be used to check the indications of the wattmeters. If all the test arrangements have been satisfactorily attended to the apparent power as showed by the volts and amperes should agree within one per cent with the wattmeter indications and the watts indicated should be taken as the true output. If the test cannot be made at unity power-factor, the voltmeters and ammeters should still be included so that the general conditions of distribution of load, etc., may be known throughout the test. For this purpose the station instruments would be satisfactory.

The use of watthour meters for this class of testing should be avoided wherever possible. There are watthour meters for direct current and for alternating current circuits, and under both of these headings there are those which might be classed as accurate and those which could hardly be so described. Still the very best watthour meters that can be made are inferior in performance to the best portable indicating instruments. Watthour meters are slightly affected by changes of voltage, frequency, wave shape, etc., and by the amount of load current which is being measured. Sometimes if the load is very fluctuating and the test must be made under service conditions the output may be more accurately determined by watthour meters than by indicating instruments, but this would represent extreme conditions, and would not usually be true.

Watthour meters should never be used unless checked in place at the frequency, voltage, wave shape, etc., which are to be used in testing. If it is not possible to run a complete test on a fairly steady load it is usually possible to make a few runs on the watthour meter under load conditions and to use this check as a basis for determining the output by means of the watthour meters during the test run on unsteady load. It is still advisable to read the indicating instruments at short intervals so that their indications may be made use of in computing the final result. The fluctuations shown by the recorded values will determine how much weight should be given to the indicating instruments.

Checks of watthour meters should not, for precision purposes, be made with the meter subjected to other than exact load conditions and on the same circuit. Compromise methods of testing watthour meters, similar to the usual test of a three-phase two-element meter on a single-phase circuit, should not be used.* This is because the accuracy demanded is better than that in ordinary metering and does not mean that the compromise test is not perfectly satisfactory for ordinary service for meters known to be without interference between elements. If watthour meters are tested in place, using the above precautions, and indicating instruments are employed and read at frequent intervals during a test run of three to five hours, the watthour record should agree with the output as determined by the indicating instruments within one per cent on fairly steady commercial loads with the chances largely in favor of the indicating instruments being correct. Single-phase indicating instruments for polyphase service are to be preferred for precision work to polyphase instruments, for the obvious reason that indications of a polyphase instrument are made up by the two elements in such a way that it is not possible to apply corrections to either element to get the true total result unless the division of load is known by single phase-instruments; and if the single-phase instruments are required for this purpose they may as well be of the precision class and used for the actual determinations, and the polyphase instrument omitted.

*Meter Code VII, J. 88, I and II.

CONCLUSION

To accurately and positively determine the efficiency of a steam turbine, great care must be taken in making the tests. If all necessary precautions are not taken, the results are liable to be misleading, and will in all probability be absolutely valueless so far as determining the actual economy of the unit.

The modern steam turbine, unlike the reciprocating engine, should require no adjustments before making economy tests, that is, after it has been adjusted, any turbine should be able to stand all the sudden variations of load and steam conditions occurring in commercial operation. The turbine should be tested with the adjustments that are normally maintained. After tests have been made to establish the economy of a turbine, no adjustments should be made, that may affect the efficiency. Any such adjustments may discredit the entire test.

The testing of steam turbines in some respects resembles the testing of water turbines, and it is recognized what precautions have to be taken in testing them in order to avoid misleading results. The testing of steam turbines demands even more care, owing to the greater number of conditions which have to be maintained and accurately measured.

With the ever increasing search for higher economies in the production of power, the efficiency of every piece of apparatus that forms a link in the chain between the coal pile and the switchboard must be maintained at its best, and in a turbine power station it is not sufficient to know the efficiency of the turbine alone, but every source of loss should be run down and eliminated or reduced to its minimum. Several small losses may in the aggregate be sufficient to cause an otherwise economical plant to make a very poor showing.

ELECTRICITY ON A VIRGINIA PLANTATION

By Donald C. Shafer

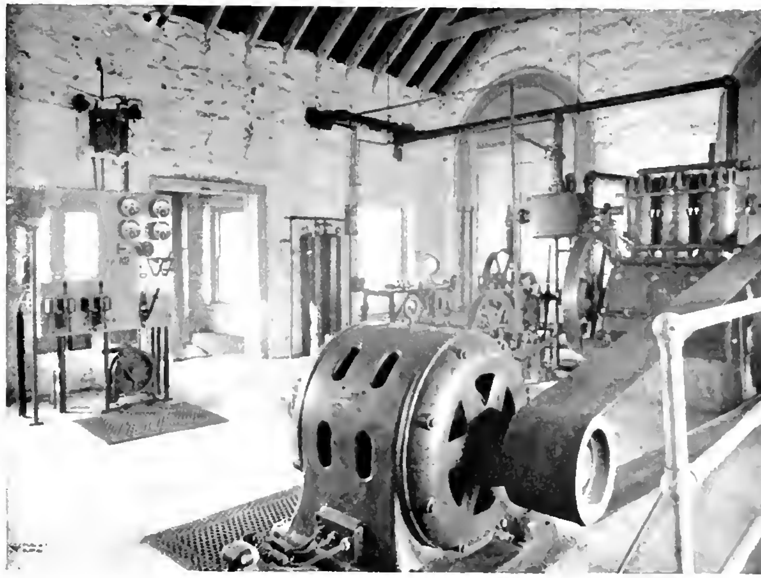


Fig. 1 37½ Kw., 2300 Volt Alternating Current Generator with Direct Connected Exciter Belted to 45 H.P. Nash Producer Gas Engine, Auxiliary Power House

On the eastern slope of the Alleghany Mountains, in the State of Virginia, is located a tract of rolling upland consisting of about eleven thousand acres, notable as the ancestral home of Thomas F. Ryan, the well known American financier. The homestead is at Oak Ridge, Nelson County, on the Southern Railroad between Charlotteville and Lynchburg. The buildings have been restored and enlarged, the plantation has been thoroughly electrified and made a model even for this advanced agricultural age, and the rolling hills which are not under cultivation have been made into game preserves.

Recently this large plantation was equipped with a complete electrical system, so that the buildings are now flooded nightly with an abundance of electric light and there is plenty of electric power to drive the farm machinery, to operate the dairy and the flour and grist mill, and to manufacture ice and do the other endless chores familiar to farm work. Without this modern power system it would require a considerable number of men and horses to do the work about this large plantation. Now the working energy of eighty horses—of 500 men—is confined in one power room where it can be instantly dispatched in any amount desired to do the hard work about the farm and the many farm buildings.

The main power house, located near the barn buildings, is of stone construction with concrete floors, and is amply large enough to house the power generating machinery and the refrigerating apparatus, and still leave sufficient space for the milk rooms and the milk handling machinery. In the power room is a 60 kw., three-phase, 2300 volt General Electric generator direct connected to a 100 h.p., three cylinder, Nash gas engine. The Nash engine operates on gas generated in the building by gas producer plant utilizing anthracite pea coal. This gas-driven generator supplies ample current for lighting the many buildings on the plantation, furnishes energy to the many motors driving the farm machinery, and provides for the operation of special heating devices, fan motors, etc. Compressed air is used for starting the gas engine, a small 1 h.p. motor operating the air compressor. Fastened to the ceiling in the power room and belted to the main shaft, is a small exciter. To the left of the engine and generator are located the necessary switchboard panels. Three 10 kw. transformers are placed in the loft of the power house for stepping the voltage down to 220 volts for the power circuits; a 110 volt tap being provided for the lighting circuits. Standard marine wiring is used throughout and all wires are laid in conduit.

A portion of the power house building is devoted to refrigeration and the manufacture of artificial ice. A ton of ice is made every day, and, in addition to this, the plant maintains low temperatures in four cold storage rooms, namely, one for meats, one for the perishable fruit products of the estate, one for milk, and one for milk products, such as cream and butter. A 15 h.p. motor drives the ammonia gas compressor in this refrigerating plant, while a smaller motor of 1½ horsepower operates the brine circulating pumps.

Another interesting installation in the power house is a small 25 h.p. low pressure boiler which generates the steam used for heating the power house, supplies energy to the small steam turbines that operate the cream separator and the bottle washer, and gives a surplus supply of live steam for sterilizing the cans, bottles and dairy machinery.

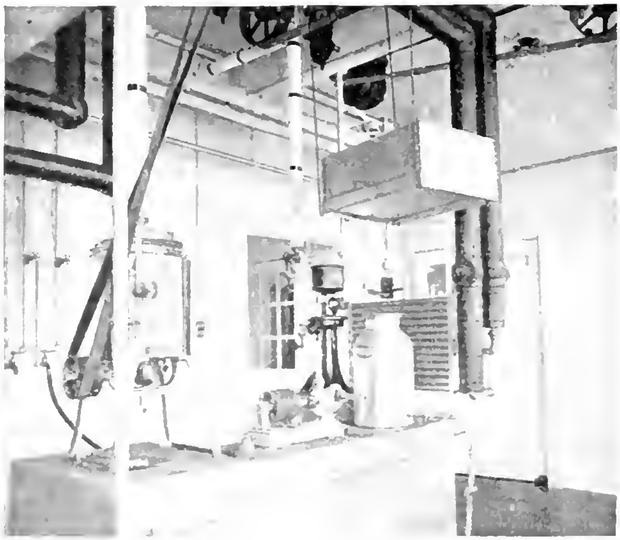


Fig. 2. 3 H.P., 220 Volt Induction Motor Driving Pasteurizer

In the dairy barn there are sixty fine imported Guernsey cows. The stable is a model of its kind, with every convenience for caring for the stock, and every sanitary arrangement necessary to preserve the health of the cattle and to assure a large supply of pure milk.

The milking is still being done by hand, although a vacuum milking system, driven by electric power, is being considered. The milk is carried across the intervening space between the dairy barn and the power house building and deposited in the milk room. This milk room is finished in white plaster with a concrete floor. A $\frac{3}{4}$ h.p. motor drives a countershaft from which is belted the pump that raises the milk to a tank in the loft. As the milk descends from the loft by gravity it is strained and cooled. Both sterilized and pasteurized milk are shipped, and when the proper quantities for this purpose have been prepared and bottled, the remainder is put through a De Laval separator driven by a tiny steam turbine; the cream being carried away to the ripening room where it is cured and soured by a special process. In this apartment a 3 h.p. General Electric motor drives the churn and other machinery.

In connection with the milk room there is a wash room where the cans, bottles, pails and other machinery are washed and sterilized. A 2 h.p. motor drives a countershaft from which is belted the machine for washing cans, the can being washed inside and out in one process. The bottle washer is driven by a small steam turbine. Every can, bottle and pail, as well as the parts of the separator and other machinery, are thoroughly sterilized with live steam as soon as the washing is done. Live steam is also used to sterilize the floors and walls of the milk rooms after the rooms have been carefully washed and flushed. The dairy attendants are provided with a wash room which is also equipped with suitable lockers and shower baths.

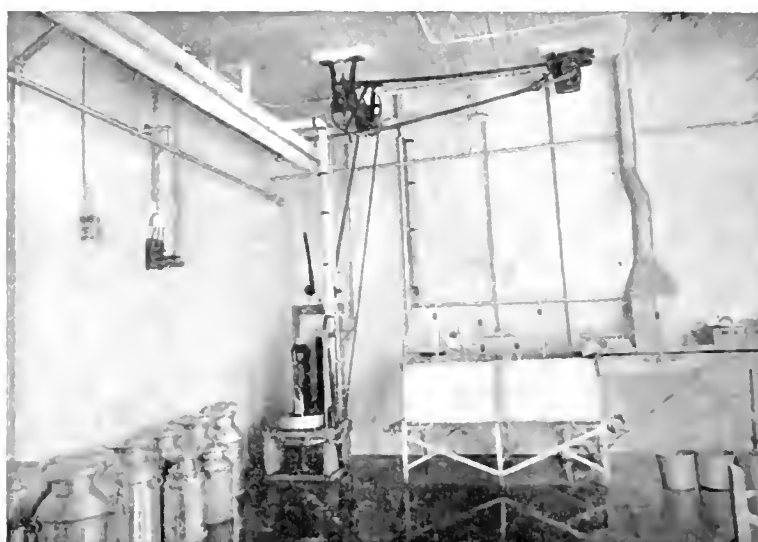


Fig. 3. 2 H.P., 220 Volt Induction Motor Driving Can Washer in Creamery

A novel feature of the dairy work is an up-to-date laundry where the white uniforms and other clothing of the dairymen are laundered. A 2 h.p. motor drives the washing machine. Another motor, rated at $\frac{1}{2}$ h.p., whirls the centrifugal dryer, the mangle being operated by a similar $\frac{1}{2}$ h.p. motor. The drum of this mangle is heated by electricity. Electric flatirons are also used.

Besides the blooded cattle on the plantation, there are nearly two hundred thoroughbred horses. To supply all these animals with ground feed a small flour mill is maintained, the waste from which is utilized for cattle feed. This mill has a capacity of fifty barrels of flour a day and handles a large portion of the wheat of that section. The mill is driven by a large electric motor.

Electricity plays no insignificant part in adding to the comfort of those who enjoy the hospitality of the Ryan homestead. The lighting current for the main residence is furnished by a storage battery located in the basement and charged from the main power plant. Every room in the large mansion is provided with an abundance of electric light, and electricity is also extensively used about the building for heating and power purposes. There are electric dish warmers in the kitchen, electric heaters in the chambers, and electric cooking devices for special service.

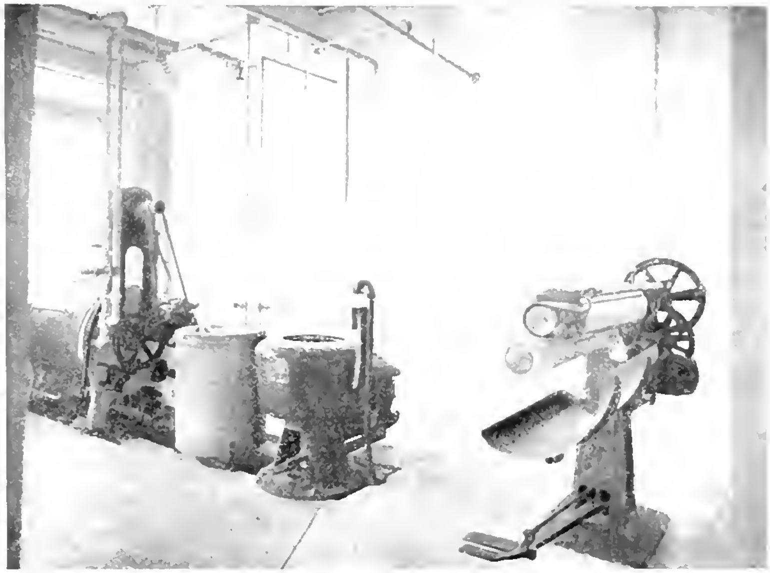


Fig. 4. Laundry From Left to Right. Washer Driven by 2 H.P., 220 Volt Induction Motor; Centrifugal Dryer Driven by $\frac{1}{2}$ H.P., 220 Volt Induction Motor; Mangle Driven by $\frac{1}{2}$ H.P., 220 Volt Induction Motor

In order that the electric service need not cease, even if the main power plant should meet with some unlooked for accident, an auxiliary plant is located about three hundred

Fig. 5. Farm of Thomas F. Ryan

yards from the main power station and arranged for parallel operation with the main plant. In this auxiliary power house, which was the initial electrical equipment on the estate, is located a 50 h.p. gas producing plant similar in operation to the one in the main power house. A 45 h.p., three cylinder Nash engine is belted to a 37½ kw. alternating current generator. This plant, though somewhat smaller, is operated in nearly the same manner as the main plant, and is held in readiness to be instantly started up in case of an emergency.

A mile away is still another gas producing plant where a 37 h.p. gas engine is direct connected to a powerful pump which forces water into a large reservoir having a capacity of 365,000 gallons. This reservoir is located on a hill, so that the water system for the entire place is operated by gravity, giving an abundant supply of water as well as ample fire protection.

This electrical plant has been in successful operation for nearly a year, and the foreman of Mr. Ryan's plantation speaks in the warmest terms of its conveniences, flexibility and safety. The apparatus was installed by Westerberg & Williams of New York City, and the electrical equipment is almost entirely General Electric apparatus. Already plans are under way for extensive improvements of the electrical apparatus and ultimately electricity will be employed wherever power is required about the plantation.

COMPENSATORS*

Part II

By W. W. Lewis

Compensators for Deriving Neutral of Three-Wire D.C. Lighting Systems

It is the standard practice to design three-wire generators up to 500 kw., with a three-wire generator, 8 poles, 150 kw., 110 r.p.m., 125/250 volts, 25 per cent unbalancing. A compensator rated H-7.3 cycles, 6.8 kw., 182/91 volts is suitable for the purpose.

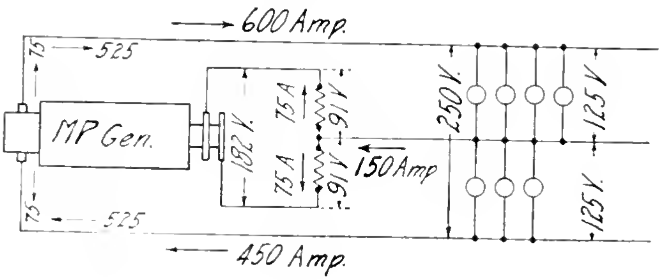


Fig. 17

single-phase collector rings; over 500 kw., with three-phase collectors. In this discussion we shall assume the following ratios of alternating current to direct current voltage at full load for three-wire generators:

	Full Load Ratio A.C. to D.C.
Single-phase collectors	73%
Two-phase collectors	73%
Three-phase collectors	62.5%

(*a*) For single-phase collector rings one compensator is used. Fig. 17 shows the connections and distribution of current for

The winding consists of four coils, two on each leg of the core, interconnected as shown in Fig. 18. The heavy inside arrows indicate the distribution of the direct current, and the light outside arrows the flow of the alternating current, which is exciting current only. The direct currents on each leg oppose each other, and thus cause no disturbance of the flux in the iron. The calculation of the rating is simple:

$$\frac{75\times 182}{2}=6.8 \text{ kw.}$$

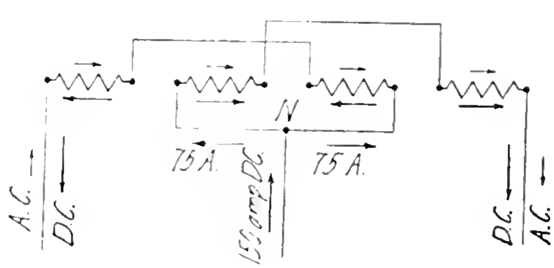


Fig. 18

(*b*) For two-phase collector rings two transformers similar to the above are used,

* Part I of this article was published in the Review for December, 1910

each one-half the capacity of the single-phase rating.

(*c*) Three-phase collector rings. If a Y-connected compensator, with the coils

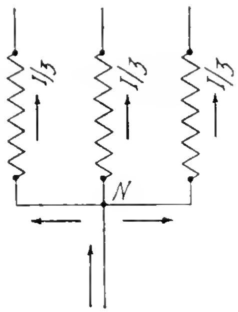


Fig. 19

of each phase on one leg were used, conditions similar to those illustrated in Fig. 19 would prevail. The unbalanced current

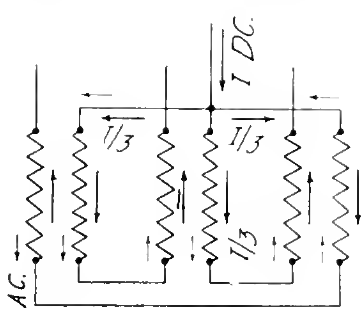


Fig. 20

flowing along the neutral splits in three equal parts at the "Y" point, one-third of the current flowing in each leg. The flux con-

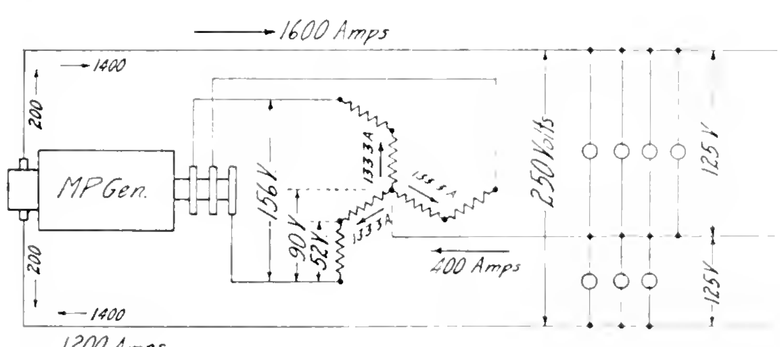


Fig. 21

ditions are as shown in Fig. 19-a. Equal fluxes are induced in the three legs. Two of them, say f_1 and f_3 will counteract each other, leaving the third, f_2, to send a flux around the core, tending to oversaturate.

To obviate this, the so-called "zigzag" winding is usually employed. This consists

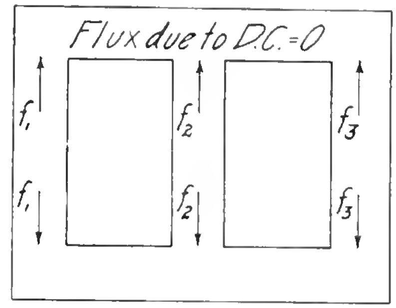


Fig. 19a

of two coils on each leg, cross-connected as shown in Fig. 20, and causing conditions in the core as shown in Fig. 20-a. The flux

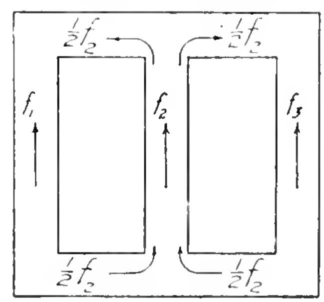


Fig. 20a

due to the outer coil in each leg will neutralize that due to the inner coil, and, as a result, the only flux in the core will be that due to the alternating magnetizing current. The heavy arrows in Fig. 20, as before, indicate direct current, the light arrows alternating current.

For a generator rated 10-poles, 400 kw., 110 r.p.m., 125/250 volts, 25 per cent unbalancing, a compensator rated 9.2 cycles, 20.8 kw., 156/90 volts will be required (Fig. 21). Following is a calculation of the capacity of the compensator:

$$\frac{133.3 \times 52 \times 6}{2} = 20.8 \text{ kw.}$$

Two compensators T connected are sometimes furnished for this service, but this is objectionable on account of the extra compensator required and on account of the difficulty in winding the teaser in order to prevent an unbalancing of the flux, or to maintain the same unbalancing in each leg. Fig. 22 illustrates this type.

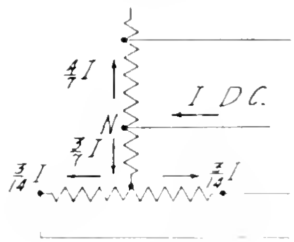


Fig. 22

Railway Compensators

Railway compensators are used for supplying current at proper voltages to the alternating current railway motors, compressor motors, fan motors, lights, heaters, etc., that form the electrical equipment of electric cars and locomotives. This type is an exception to the rule laid down in an early part of this paper, that compensators are not to be used when there is a wide difference between primary and secondary voltages. Compensators are used in this case because they are more convenient and somewhat cheaper than transformers for the same service. On account of the high voltages used and the fact that one side of the line is grounded, they must be highly insulated. As the conditions on railway lines using single-phase alternating current vary considerably, each type of compensator is special and adapted to the peculiar conditions of the particular railroad on which it is to serve. The compensators are rated arbitrarily as RK-512, RK-513, etc. Fig. 23 shows a typical compensator, RK-516, for operation on a 25 cycle,

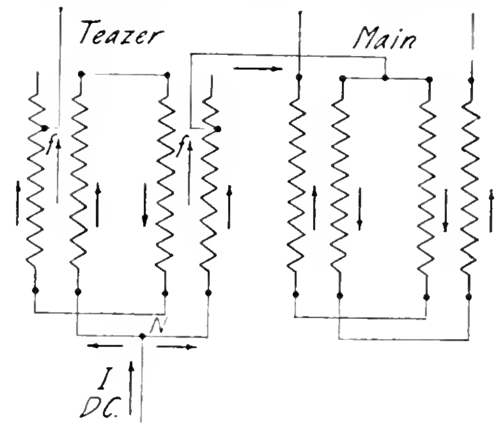


Fig. 22a

10,500 volt circuit; two compensators operating four GEA-603 motors in series-parallel. Two hundred seventy amperes may be taken from any tap with the exception of the 104 volt tap, which is good for 150 amperes. The

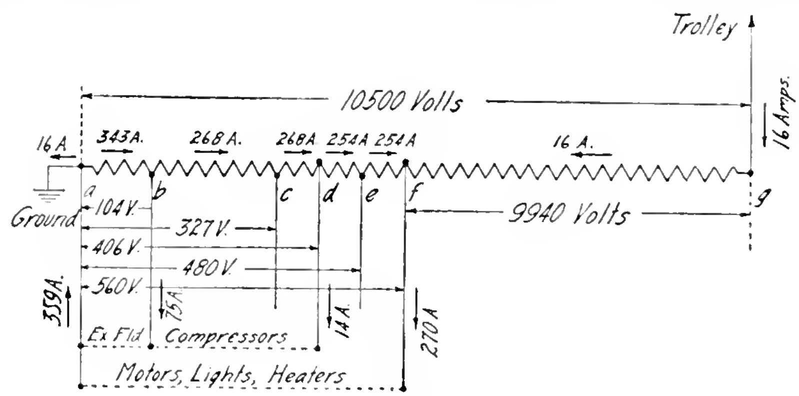


Fig. 23

output of the compensator is as indicated in the figure. The kilowatt rating is as follows:

Section	Current	Volts	Watts
ab	343	104	35672
bd	286	302	86936
df	254	154	39116
fg	16	9940	159040
			314764

$$\frac{314764}{2} = 157.4 \text{ kw.}$$

(To be Continued)

ENERGY LOSS THROUGH CORONA ON EXTRA HIGH VOLTAGE ALTERNATING CURRENT LINES

By Dr. C. P. Steinmetz

The subject on which I desire to say a few words is the phenomena of corona and the losses due to corona in high voltage electric circuits. This class of phenomena—luminous discharges, electrostatic glow, etc.—was really the first which was investigated when electricity was still a science and branch of physics and was dealt with theoretically but had no practical usefulness. Then, with the old high voltage, zero power electrostatic machines, all we could get were electrostatic sparks, glow discharges, brush discharges and corona effect. When electricity emerged from the theoretical stage into an industry—into electrical engineering—the electric circuits we had to deal with were of relatively low voltage, and all these phenomena of disruptive discharges, luminescent discharges, etc., did not appear and their investigation was of no practical value. It was only later on, when the alternating current had established its position as one of the methods of transmitting and distributing electric power, and when higher and higher voltages were required, that investigators and engineers became able to build transformers and apparatus producing voltages high enough to give appreciable electrostatic sparks and disruptive effects, and the glow effects as in corona—first from the surface of insulators which were in contact with the electric circuit, and then also in free air. Still later on progressive engineers realized that possibly sometime in the future electrical engineering might advance to voltages so high that these corona effects would really become of industrial importance. Investigations were made by Mr. C. F. Scott, of the Westinghouse Company, in observing and attempting to measure the power consumed by corona. That, I think, was in 1898. In 1904, Professor Ryan, at that time of Cornell University, published the most important paper that we have had thus far in this field, giving a review of the entire subject and formulating tentative laws on the appearance of corona effect which indicated the relation between the voltage at which the glow discharge begins in conductors, and the diameter and distance apart of the conductors, etc.

The first concern to realize that we were fast approaching the time when these phenomena might become of industrial importance was the Stanley Company of Pittsfield, Mass., our present friends, who indeed have been, as we know, the pioneers in very high voltage alternating current work. An extensive investigation for measuring losses by corona in conductors of various sizes was instituted by them in 1896, and they carried on this work not merely to the beginning of the phenomena where the glow appears but far beyond that, where the losses would be very formidable in any circuit of considerable extent. These investigations, the results of which were never published, were carried on by Mr. Hendricks. Transformers suitable for the work were designed and built, and in the investigations which we are now making, these very transformers, designed as the result of investigation of corona effect and allied phenomena, are being used.

Some years ago an attempt was made to corner the copper market and raise the price of copper out of sight. The result was that electrical engineering advanced very much faster than it would have done had copper been less expensive. We were forced to go to voltages very much higher than we would have otherwise dared to use; so 60,000 volts was brought up to 80,000 or 100,000 volts.

When the first 100,000 volt line was built (in Michigan) it was noticed that on quiet nights the line could be heard, and on very dark nights could even be faintly seen, and good pictures were made of the line wires in absolute darkness. The operating voltage was just approaching that point where luminosity begins to manifest itself. A number of tests were made on this line in measuring the losses, which, at 110,000 and 115,000 volts, amounted to something like 40 kw., this being an appreciable amount, yet not formidable in the seventy miles of line. Not long afterwards, on another 100,000 volt line in Colorado at high altitude, it was found that, when the line was opened at the step-down end, several thousand kilowatts of energy was delivered to it at the generator end—not kilovolt amperes but true power, which was dissipated from the line by corona—dissipated into the air as luminous discharge into space—true energy as measured by wattmeter and as shown by the opening of the water-gates on the wheels. At open circuit, therefore, the line ran far beyond the beginning of corona loss, and the voltage was high enough to give very formidable losses. When running under load these losses did not appear, because, for a 150 mile line, the voltage at the step-down end naturally was somewhat lower than at the step-up end and

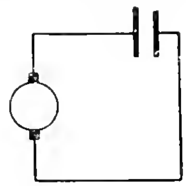


Fig. 1

was below the critical value at which losses occur. When there was no load on the line, the voltage rose in the line and was higher at the step-down end than at the step-up end, reaching a value above the corona critical voltage.

This instance naturally impressed upon everybody the fact that the corona loss in transmission lines is not merely of theoretical interest—not merely a thing to which electrical engineering may come—but that it is of immediate importance to find out where these losses occur and what they amount to, in order to avoid them in some other line that may be run under conditions where, even in normal operating voltages, we are beyond the critical corona voltage and are dissipating the power of our waterwheels and making the air luminous for 150 miles or so instead of delivering the power.

An experimental line long enough to measure the power dissipated from it has therefore been built, and in the last year we have made a large number of careful investigations to observe this phenomenon, determine where it lies and measure its amount.

First, let us consider what this phenomenon is. The air is an insulator. For instance, take an electric circuit terminating in two conducting plates separated by air (Fig. 1) and upon applying a low voltage no current passes. Increase the voltage between these plates, raising it higher and higher, and finally the air becomes a conductor there is a breakdown of insulation. The insulating character of air is limited by a certain voltage gradient—so many volts per inch. If we attempt to go beyond this value, the air ceases to be an insulator and breaks down, just as a column loaded mechanically beyond a certain critical point will be crushed, a wire will be pulled apart, or a beam will break. This critical value is probably between 70,000 and 80,000 volts per inch. If then, for instance, the distance between the two plates is two inches and we gradually raise the voltage, when we get to, say 150,000 volts or more, we find that the air ceases to insulate and the current which passes is a large current—a bright, noisy spark—the air becoming a conductor, and as a conductor, closes the circuit and permits a very large current to pass.

Take another instance: Suppose we have two conducting wires of a transmission line and gradually increase the voltage between them. In this case the distribution of voltage between the two conductors will not be uniform, but, as you can easily see, the voltage will be piled up more near the conductors. (Fig. 2). Near one conductor the voltage per inch will be high, it will go down to a low value midway between the conductors, and will get high again at the other conductor; so that the voltage distribution between two circular conductors is not uniform, but the voltage gradient—the voltage per inch—is a minimum midway between the conductors and a maximum at the surface of the conductors. If then we gradually raise the voltage higher and higher, we ultimately pass beyond that value where the air is an insulator. The volts per inch pass beyond the breakdown strength of air, first at that point—the conductor—where the volts per inch are highest. In short, if in the space surrounding the conductor the air is broken down and is conducting, the voltage per inch being higher than the air can withstand, then current flows from the conductor as far as the air is conducting.

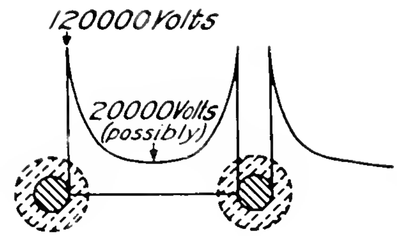


Fig. 2

Now when current flows through gas it produces luminosity, or light, the intensity of which depends on the value of the current. Where the current is very large it may be a very intense light, where small, the light is fainter. In this instance, where the space between the conductors breaks down and becomes conducting, the conducting air closes the circuit and we get the short-circuit current value; therefore, a very bright light and static spark.

In the case under consideration, the current will flow from the conductor across and into that air space which has become conducting, but the circuit between the two wires is not closed—it is open. The current cannot pass across because these two conducting air spaces which surround the two wires are separated from each other by non-conducting air; hence the amount of current which flows around the conductors is quite small—sufficient to show luminosity but not sufficient to appear as a burning, bright spark, nor as a rule to short-circuit the generating system or to lower the supply voltage. In one case, the current may be a very large current because the conducting air paths close the circuit; in another case a very small current because the circuit remains open and the current flowing is merely the current charging that volume of air.

Another way of looking at this phenomenon: Assume, for instance, that we have two conductors carrying current; there is then a magnetic field round the conductors, represented by lines of magnetic force that surround the conductors in circles somewhat eccentric, that is, crowded toward the outside. (Fig. 3). In the same manner there is a condition of electrostatic stress

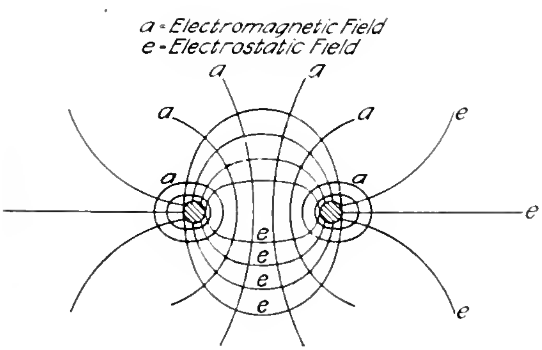


Fig 3

which is due to the voltage. We can also represent this stress by means of electrostatic lines of force, that is, by circles; not, however, by circles surrounding the conductor, but by circles passing from conductor to conductor across at right angles to the magnetic circles. Therefore, in the electric circuit we have lines of magnetic force surrounding the conductors, and at right angles to the lines of magnetic force, lines of electrostatic force issuing from the conductor and terminating at the return conductor. The density of the lines of electrostatic force will be proportional to the volts per centimeter length of electrostatic circuit. As there is a limiting breakdown voltage for air of 70,000 or 80,000 volts per inch, so also there is a limiting electrostatic density; that is, the number of lines of electrostatic force per inch in air cannot rise beyond a certain critical value. As soon as this critical value is reached, the air ceases to be an insulator and becomes conductive.

Consider two transmission wires: All the lines of electrostatic force converge towards the two wires, the electrostatic density being higher at the surface and decreasing outward therefrom. If now we gradually increase the voltage, the number of electrostatic lines of force increases proportionally thereto, the density increases, and at some voltage will reach the saturation density of the air at the conductor. At a higher voltage still, the saturation density spreads to further and further distances from the conductor. Saturation density here means that density of the lines of electrostatic force which is the maximum that air can carry, just as magnetic saturation density is the maximum that iron can carry. We therefore reach a saturation density at which air cannot carry any more static flux but becomes conducting, breaks down and becomes luminous. By increasing the voltage gradually this area of broken-down or conducting air spreads further and further from the conductor, enlarging the luminous zone of corona until from both conductors these areas have spread to such an extent that they merge into each other; there is a conducting path, the line short-circuits, and an electrostatic spark passes across.

For any given size of wire and distance apart of wires we find that there is a certain voltage at which the critical density or critical gradient is reached, where the air breaks down and luminosity begins the critical voltage where corona manifests itself. At still higher voltages corona spreads to further distances from the conductor and a greater volume of air becomes luminous. Incidentally, it produces noise. Now to produce light requires power and to produce noise requires power. Air is broken down and is heated in breaking down, and to heat it also requires power; therefore, as soon as corona forms, power is consumed or dissipated in its formation. When this phenomenon occurs on the conductors of an alternating current circuit a change takes place in relation to current and voltage. On the

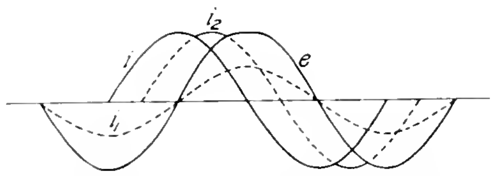


Fig. 4. e, Voltage Wave; i, Charging Current; i_1, Energy Current Due to Corona; i_2, Resultant Current

wires of an alternating current transmission line, at a voltage below that where corona forms—at a voltage where wires are not luminous—considerable current, more or less depending on voltage and length of wire, flows into the circuit as capacity current or charging current. That is, the two wires act as the two plates of a condenser and absorb the charging current—a current flowing into the line when the voltage rises and returning when the voltage decreases. This means that the wave of charging current is 90 degrees ahead of the voltage wave; or, showing this diagrammatically (Fig. 4), if e is the voltage wave and i the wave of the charging current, i will be ninety degrees ahead of e. For half the time we have each half waves in the same direction and the other half of the time in opposite directions. For one-fourth wave the line takes energy from the generating system and for the next one-fourth wave returns energy by the same amount. In other words, the charging current is a wattless, reactive current, consuming no energy. As soon as corona begins, energy is consumed in breaking down the air, etc., and there must be then a second current; a current in phase with the voltage or energy current, which combines with the charging or wattless current and gives a resulting current still ahead of the voltage wave, but less than ninety degrees, that is, not entirely wattless. Corona formation therefore results in a change of phase between voltage and current and a decrease in lead of the condenser current from ninety degrees to less than ninety degrees, so that the charging current is not wattless any more, but contains a power component.

As we have seen, we are now at such voltages industrially that in some instances the beginning of corona formation has been reached. It is therefore essential to investigate the laws under which this phenomenon occurs and the losses which may result from it—to measure the power consumed by the corona. It might be thought that this alternating current, leading the voltage by less than ninety degrees, could be measured by wattmeter. However, the problem is not so simple. First, it means measuring the power of extremely high voltages—100,000 or 200,000 volts—by wattmeter, and no wattmeter can be connected directly in a 100,000 volt circuit. Furthermore, where losses occur by corona, the current is still mostly condenser current or wattless current and we have to measure the power in a circuit of very low power factor, where the accuracy of the wattmeter is necessarily much impaired. This is especially the case with leading current—low power factor due to leading current. With leading current the reliability of the wattmeter is still less, so that there are difficulties in measuring on the instrumental side of the problem. Most investigations, therefore, have to be made by measuring the power, not at the high potential line but at the low tension side of the step-up transformer which feeds the high potential line. Measurements have been made and very accurate results derived in this manner, but the power loss measured at the primary terminal of the step-up transformer is not only the loss in the line by corona, but added thereto is loss by core loss. The core loss we can calculate, but when we have on the transformer the leading or charging current of the line, the core loss may be changed thereby—usually is changed—and is increased by an unknown amount. Consequently, when we measure the total loss by corona and core loss of transformer and get the actual corona loss by the difference between the measured total loss and the core loss, the accuracy is not very great—at least in the lower values. We subtract two moderately large quantities to get a relatively small quantity. It is important then to devise methods of measuring directly in the high potential line, and that we are doing by connecting the current coil of the wattmeter directly into the high potential transmission line at the neutral, which is grounded, and the potential coil of the wattmeter to the high potential transformer coil. That would be a direct measurement, but there is still a source of loss; that is, the corona loss and other electrostatic losses in the high potential winding of the transformer. When designing the testing transformer we always figure the losses by core loss, eddy currents, and I^2R loss, but do not assume, and are right in not assuming, that there may be electrostatic losses of the nature of electrostatic hysteresis, etc., in the insulating materials of the transformer; but they are there and become appreciable when we come to 200,000 volts. Therefore, these losses also have to be measured and subtracted, but they are relatively small.

(To be Continued)

NOTES ON ELECTRIC LIGHTING

Part V

By C. D. Haskins

We have come to that portion of our subject which deals with those devices commonly to be found on the premises of the consumer—as the store, the manufacturing establishment, or the domestic dwelling—and have to do with applications that make electricity useful to man.

The great impetus which was given to electric lighting came with the incandescent lamp. It is not generally realized that although electric lighting started with the arc lamp, its usefulness was very seriously curtailed, except for purposes of street illumination and the like so long as the problem of small lighting units remained unsolved. This was the great problem for several years, and to its solution one man addressed himself almost to the exclusion of everything else. This man was Mr. Thomas A. Edison. As you know, the first incandescent lamps consisted of a glass envelope enclosing a minute filament in a vacuum. The passing of electric current through that filament up to a point where the temperature of the filament would be destructive were it not in a vacuum, seems to us a perfectly obvious thing, but when first done it was a marvelous thing. In the earlier lamps, the filament consisted of platinum wire; this was not an entirely satisfactory material for this purpose, however, because of its cost, the inadequacy of the supply, and the high conductivity of the metals, various experiments were therefore made to determine more suitable material, and these finally led to the selection of carbon. There then followed a long period of research in connection with carbons of various kinds, with a view to increasing the efficiency of the lamp. In thinking about the incandescent lamp there are probably very few people who realize the fact that the amount of material that is active in giving illumination is exceedingly small. In the city of New York, for example, there are about three and one-half millions of electric lamps, and if all of these were burning at one time, there would be less than thirty pounds of material actually at work giving light, that is, the gross weight of these three and one-half million of filaments would be less than thirty pounds.

For a very long period the improvements in the incandescent lamp have been constant, though the individual steps have often been individually small. The efficiencies advanced from perhaps 4½ watts per candle, to 3½ watts, and then practically halted for some years. An efficiency of even 3$\frac{1}{10}$ watts was regarded as a very high standard of incandescence. In the early development of the lamp, efforts were directed more toward securing long life for the lamp than toward the obtaining of high efficiencies. This was due very largely to the fact that in the early days incandescent lamps were far more costly than now. It must be borne in mind that the candle-power of carbon filament lamps runs down with considerable rapidity during the first few hundred hours of use. In the United States, this led to the adoption of the so-called free renewal system, a system which has been highly instrumental in keeping our standards of illumination on a better basis than those obtaining in any other country. In Europe, incandescent lamps are almost always supplied on the basis of groceries. The person who wants one goes to the store and buys it, in the same way that he would purchase butter or sugar. Since the average European buyer of lamps is not a technical man, he does not exercise very careful judgment in the selection, nor is he likely to learn. The result of this has been that through competition the sale of lamps became entirely a matter of cost, rather than quality. In this country the lighting companies early recognized the fact that the prosperity of the industry was dependent upon the uniform maintenance of good lighting. It was realized that electric lighting as an industry could not be rapidly increased unless the quality of lighting could be kept up to a high standard. The result is that the standard of electric lighting in this country is very much higher than abroad, and is likely to remain so as long as the present methods obtain in Europe and here at home.

Under the free renewal system the lamps are furnished without specific charge by the same company that does the lighting. It is not universal in this country, but it is the common practice in large and progressive communities. This system does not contemplate permitting the lamps to burn out. They are installed and left at the point of installation for so long as they will give a good standard of lighting for the current consumed, after which they are renewed by the company. The lighting companies cannot, of course, do this for nothing, the charge for the lamps is included in the gross charge for the current. It is one of the elements that go to make up this charge.

The history of the last few years in incandescent lamps has been one of suddenly renewed and exceedingly rapid progress in the direction of efficiency. The first step was the so-called metalized filament lamp, in which, by chemical processes, the filament was so changed in its constituents as to permit it to run at a higher incandescence without rapid destruction. This resulted in a lamp with an efficiency of $2\frac{1}{2}$ watts per candle instead of 3.1 watts per candle—the highest efficiency to which carbon had been brought.

In the meantime scientists all over the world were working on metal filaments which gave promise of possible elements capable of withstanding a high density of current without deterioration. A little later than "metalized" filaments, the tantalum filament lamp appeared on the market. This was the first commercial lamp with a purely metal filament to be sold in any considerable quantity. These metal filament lamps presented new problems both electrically and mechanically. For example, the specific resistance of the filament was much lower than that of carbon. This condition involved mechanical problems which were difficult of solution. That of keeping apart the convolutions of this very much finer and more delicate filament within the glass envelope was a particularly troublesome one.

The tantalum lamp placed the art on the basis of 2 watts per candle, or about one-half the expenditure of energy that had been necessary for carbon filament lamps a few years before.

There has been remarkably rapid progress made in the incandescent lighting industry. Bear in mind that three years ago the country at large was on a basis of not much better than $3\frac{1}{2}$ watts per candle, and in the face of this condition a lamp has been introduced having an efficiency of $1\frac{1}{4}$ watts per candle or less. It can be easily appreciated that the result was radical. The moral as well as the economic effects were curious. The first tendency of the electrical managements was to become greatly alarmed. There was no price basis for the furnishing of current for these very much more efficient lamps, and the electric companies all asked themselves what they were coming to. "We shall be selling about three times as much light for the same money," they argued. "Therefore, our output and our bills will be cut down in the ratio of two to one or three to one, while our fixed charges will be no lower." They considered that their prosperity was seriously menaced, but they did not—in fact, could not do anything about it. The whole electrical industry viewed the matter with some anxiety. Curiously enough the greater part of the electrical industry seems to have failed to realize that the gas industry had just gone through an exactly similar situation through the introduction of the Welsbach burner. With the same amount of gas this burner gave as much more light, compared with the open burner, as does the tungsten filament compared with the carbon filament. This condition in the electrical field has now existed for about two years and it is extremely interesting to note how the matter has actually worked out. Consumers who yesterday were using quite an amount of light at 3.1 watts per candle, put in tungsten lamps, and at once noticed that their use effected a great saving in light bills; but these consumers did not continue to take advantage of that saving for the purpose of reducing bills, they used more light. Bills have in general been a trifle reduced, but the almost universal tendency has been to use more light as a luxury and keep the bills just about where they were before. In other words, the whole standard of electric illumination has been raised as the ratio between 3.1 watts and $1\frac{1}{4}$ watts.

The tungsten, like the tantalum filament, is of lower specific resistance than the carbon filament and consequently is materially longer, and the same mechanical difficulties are involved in this filament as in the tantalum, but to a greater degree. In Europe the difficulties have been more serious than here, as in many sections of Europe the ordinary service voltages are higher than in this country and the greater length of filament required for these voltages becomes very difficult to handle; as, for example, in the case of the 220 volt lamps in common use in England.

In connection with the tungsten lamp, the first tendency in the United States, among those who gave the matter careful thought, was towards voltage reduction. In the early nineties 50 volts was common, and many people whose opinions were worthy of consideration felt that we should go back to low voltages, and in fact, this may yet come. It is, however, less likely today than it was yesterday. It is probable that the low voltage tungsten lamp with its high efficiency will replace other lamps for certain kinds of lighting, as that of the farm house, the ranch house, the rural village, etc. Few of these have buildings that are wired, and in relation to fire risks, the wiring problem is a serious one even at 110 volts, as compared with, say, 15 volts. It seems entirely possible that for this class of work, which reaches about thirty millions of people, a very low voltage tungsten lamp may eventuate. I can readily conceive of a wide use of very small generating plants driven by internal combustion engines. With such a generating outfit and low voltage lamps the problem would be a relatively simple one. The wiring of such an installation would present no difficulties and could be put up with double pointed tacks.*

But against the advantages of low voltages we must set the fact that only in standard voltages (100 volts, plus) are most heating and power appliances obtainable.

In touching upon the subject of incandescent lamps earlier in this lecture, one very essential point was omitted, namely, the relation between life and efficiency. The same lamp that will live 500 hours when operated at x watts per candle-power, will live over 1000 hours when run at $2x$ watts. At the dictates of economy, the incandescent lamp specialist has done a vast amount of detail research work in this connection, to determine the point where the life curve and efficiency curve will cross.*

* The results of some of these investigations were given in the October, 1910, issue of the REVIEW.

CHARGES FOR DISPLAY LIGHTING WITH LUMINOUS ARC LAMPS

By Louis Friedmann

Central station men are already familiar with the luminous (magnetite) arc lamp, as it is now in general use throughout the country for street lighting. Having proven so successful for outdoor illumination, it is being rapidly adopted for special or display lighting.

It is hardly necessary to explain in detail the many advantages of display lighting, both to the business man and the central station.

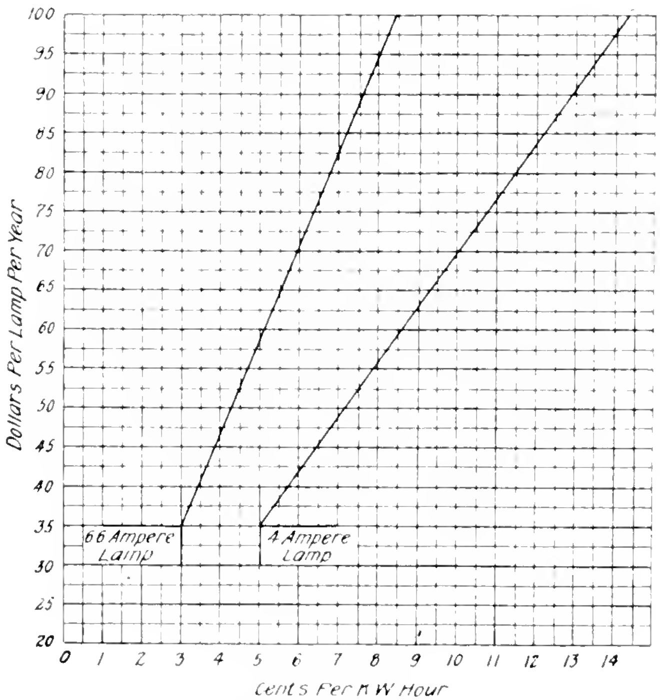
6.6 Ampere Series Luminous Arc Lamp

A high standard of street lighting naturally forces a high standard of indoor illumination, with the result that the business of the central station is materially increased by a load that is constant for a comparatively long period.

In order to add to the æsthetic value of display lighting, the lamps are usually suspended from ornamental poles. Luminous lamps on ornamental poles are now in use for display lighting in Toledo, Ohio, St. Louis, Mo., East St. Louis, Ills., Detroit, Mich. and Boston, Mass.

Following the usual method of charging for series arc lighting on a lamp-per-year basis, luminous lamps are furnished for display lighting by central stations at a definite amount per year; although the business men's associations usually divide the charge on a pro rata basis per front foot served.

In display lighting the lamps are usually burned from dusk until 12 p.m. every night



Cost per kilowatt-hour corresponding to various flat rates in dollars per lamp per year. Figures based on luminous lamps operated from series luminous rectifier system, with lamps in service from dusk until 12 p.m. daily

(approximately 2000 hours per year), and in order to assist the central station to readily determine the proper charge for this service on a lamp-per-year basis, or to determine at what price it is selling energy on a kilowatt-hour basis where the price per lamp per year is already fixed, the above curve will be of assistance.

This curve is based upon the use of series luminous arc lamps operated by means of the constant current transformer and mercury arc rectifier at approximately full load efficiency and 2000 hours per year.

Suppose that the central station desires to sell energy for this service at 6 cents per kilowatt-hour; by referring to the curve it is apparent that the price per lamp per year should be $71.50 for the 6.6 ampere lamp, and $42 for the 4 ampere lamp. On the other hand, if the price per lamp per year is fixed at $70, the central station would be selling energy at 5.9 cents per kilowatt-hour when using the 6.6 ampere lamp, and at 10 cents per kilowatt-hour when using the 4 ampere lamp.

It is very apparent that a greater charge should be made for the 6.6 ampere lamp, but the use of this lamp should be encouraged, as it is more efficient than the 4 ampere lamp and will therefore produce a higher standard of illumination for a given expenditure of energy.

The 6.6 ampere lamp consumes approximately 60 per cent more energy than the 4 ampere lamp and produces over 200 per cent more light; although, where display lighting is desired at a moderate cost, the 4 ampere luminous lamp is better suited than any other illuminant.

While the curve is based upon on a 2000 hour schedule, it is a simple matter to use it for any other schedule, inasmuch as the curve increases and decreases in direct proportion.

For instance: assuming a burning schedule of 1800 hours when using the 6.6 ampere lamp and a price per lamp per year of $70, by referring to the curve we find the price per kilowatt-hour is 5.9 cents (on a 2000 hour schedule). We then have the proportion:

1800 : 2000 : : 5.9 : x, or 6.5; this being the price in cents per kilowatt-hour at which energy would be furnished. Or, assuming that the central station desires to sell energy at 6 cents per kilowatt-hour on the 1800 hour schedule, using the 6.6 ampere lamp, we have:

$1800 \times 6 \div 2000 = 5.4$.

By referring to the curve we find that, at 5.4 cents per kilowatt-hour, the price per lamp per year is $64.20, or the price which should be charged for the 6.6 ampere lamp on an 1800 hour schedule in order to sell energy at 6 cents per kilowatt-hour.

The maintenance cost of this system of lighting varies with local conditions and is therefore not considered in this curve.

GENERAL ELECTRIC REVIEW

VOL. XIV, No. 3 MARCH, 1911

CONTENTS

Arc Drawn by Air-Break Disconnecting Switch in Rupturing a Current of 800 Amperes at 13,000 Volts

(See page 101)

GENERAL ELECTRIC REVIEW

SWITCHBOARDS

During the past fifteen years the switchboard with its accessories has rapidly progressed from a position of relatively small importance to one of receiving at least as much consideration and attention as generators, engines and boilers. From the control of the small machines of moderate capacity and low voltage that were in general use but a comparatively short time ago, to those of large capacity and high voltage which accompany the power developments of the present day, is certainly a large step.

In the early days of switchboard design an installation of 50 kw. at 250 volts was considered a rather stupendous undertaking while today a request for a switchboard to control the largest modern electric power development, with power transmitted at 140,000 volts, would perhaps excite but little comment.

Naturally, the first switchboards were of wood and were rather simple. As the capacities of generators and stations grew in size, and as operating voltages became higher, the wooden switchboard, because of its poor inherent qualities for such service, was superseded by slate and marble.

Then as time progressed, the panel system of building switchboards was developed; first for 500 volt railway work, then for direct current lighting and power, and last of all for alternating current systems.

As the amounts of power to be controlled increased, and as switching systems became more complex, the duties of the switchboard also grew. This made remote control apparatus necessary and caused the development of the benchboard—the latest type of switchboard for large stations.

Contemporaneously with the development of the switchboard itself, new detail apparatus necessary for the proper control of electrical energy was developed, and existing apparatus was improved to meet the more exacting conditions of service.

Thus the switchboard has gradually increased in effectiveness and importance until now it is to the power house what the human human nerve system is to the body, concentrating as it does all the energy of the plant and controlling the distribution of this energy from a single center. Were it not for the development of the extensive switchboard apparatus in modern use, large generating units and transmission systems involving high voltage would have no commercial value.

In order to take care of the many important details of switchboard design and manufacture it is necessary for the manufacturing company to have in its employ a well organized corps of engineering specialists and shops fully equipped to carry out engineering recommendations with speed and precision.

For these reasons the switchboard articles in this issue of the Review will no doubt prove interesting, as they in a measure indicate the wide scope embraced by that branch of the electrical industry known as switchboard design and manufacture. From these some idea can be gained of the great amount of engineering research, ingenuity, and skill which have been expended in the development of switchboard controlling apparatus, as well as a few details of the organization which the General Electric Company has developed to enable it to build its switchboards as perfect as the present state of the art will allow.

E. M. Hewlett

THE SWITCHBOARD NUMBER

The present number of the REVIEW is issued somewhat in advance of its regular date, in order to be distributed at the Midyear Convention of the American Institute of Electrical Engineers, which that body has decided to hold during the month of February, in Schenectady and Pittsfield — the cities where are located two of the largest plants of the General Electric Company.

In making this issue a switchboard number the editors have endeavored to select a subject that will be of direct interest to the majority of engineers. Such a topic the switchboard furnishes, it being a necessary and highly important component part of every electrical plant, whether it be high tension, low tension, water power or steam.

A few years ago, when the amounts of energy to be controlled were relatively small, the early oil switch—which has been described as "a knife blade in a tub"—was adequate to all switching requirements; and this with a few measuring instruments and one or two minor accessories was all that conditions demanded in a switchboard. The enormous loads of modern stations and the absolute necessity for continuity of service—which is easily understood when considered in connection with the serious results that may accrue from a shut-down of even ten minutes—have given birth to many valuable improvements and refinements that have made the switchboard of today a marvel of reliability, efficiency and convenience. Some of the factors that have brought about this result and on which the success of the modern switchboard depends are discussed in the articles appearing in this issue.

THE PITTSFIELD-SCHENECTADY MIDYEAR CONVENTION

This convention of the A. I. E. E. will be held on February 14, 15, 16, meeting at Schenectady on the first and last of these dates and at Pittsfield on the intermediate date. The following is a list of the papers to be presented:

High Tension Testing of Insulating Material, by A. B. HENDRICKS, Transformer Engineering Department, General Electric Company.

Hysteresis and Eddy Current Exponents of Silicon Steel, by W. J. WOOLDRIDGE, Transformer Engineering Department, General Electric Company.

Commercial Problems of Transformer Design, by H. R. WILSON, Transformer Engineering Department, General Electric Company.

Design, Construction and Tests of an Artificial Transmission Line, by J. H. CUNNINGHAM, Instructor Electrical Engineering, Union College.

Protection of Electrical Transmission Lines, by E. E. F. CREIGHTON, Consulting Professor of Electrical Engineering, Union College.

Tests of Grounded Phase Protector on the 44,000 Volt System of the Southern Power Company, by C. I. BURKHOLDER, Electrical Engineer, Southern Power Company and R. H. MARVIN, Power and Mining Engineering Department, General Electric Company.

Tests of Losses on High Tension Lines, by G. FACCIOLI, Ass't Engineer of the Transformer Department, General Electric Company.

Mechanical Forces in Magnetic Fields, by C. P. STEINMETZ, Consulting Engineer, General Electric Company.

Problems in the Operation of Transformers, by F. C. GREEN, Transformer Engineering Department, General Electric Company.

The Regulation of Distributing Transformers, by C. E. ALLEN, Westinghouse Electric & Mfg. Company.

Temperate Gradient in Oil-Immersed Transformers, by JAMES MURRAY WEED, Transformer Engineering Department, General Electric Company.

Dissipation of Heat from Self-Cooled, Oil-Filled Transformer Tanks, by J. J. FRANK and H. O. STEVENS, Transformer Engineering Department, General Electric Company.

Oil-Break Circuit Breakers, by E. B. MERRIAM, Switchboard Engineering Department, General Electric Company.

Proposed Applications of Electric Ship Propulsion, by W. L. R. EMMET, Engineer Lighting Department, General Electric Company.

Voltage Regulation of Generators, by H. A. LAYCOCK, Power and Mining Engineering Department, General Electric Company.

Briefs on Vector Rotation, by E. J. BERG, Professor of Electrical Engineering, University of Illinois, and W. S. FRANKLIN, Professor of Electrical Engineering, Lehigh University.

Several of these papers, either in full or in abstract, will be published in the GENERAL ELECTRIC REVIEW. Further elaborations of some of the subjects have been arranged for and will appear in early issues.

OIL-BREAK CIRCUIT BREAKERS*

By E. B. Merriam

Introduction

The problem of interrupting an electrical circuit which may be momentarily carrying millions of kilowatts is an exceedingly difficult one. The greater concentration of power that is at present under way and the obstacles to be overcome in controlling the huge electrical systems of these developments are matters which were foreseen by the manufacturers of electrical apparatus, who, keenly appreciative of the importance of such problems, are continually striving to fulfill the requirements imposed by the development of the art. Unfortunately, it is inconvenient and at times even hazardous to make tests to determine the ultimate rupturing capacity of heavy duty oil circuit breakers, since these tests require the use of the largest power plants now in existence, and the men responsible for these plants are rarely willing to loan their equipment for such purposes. Owing to the variable conditions of service, reports obtained are of limited value and manufacturers are forced to accept incomplete information on the action of oil circuit breakers under operating conditions. This state of affairs is greatly improved where the engineers of the large power companies co-operate with the designers and carefully recor ' and exchange data relating to all unusual disturbances.

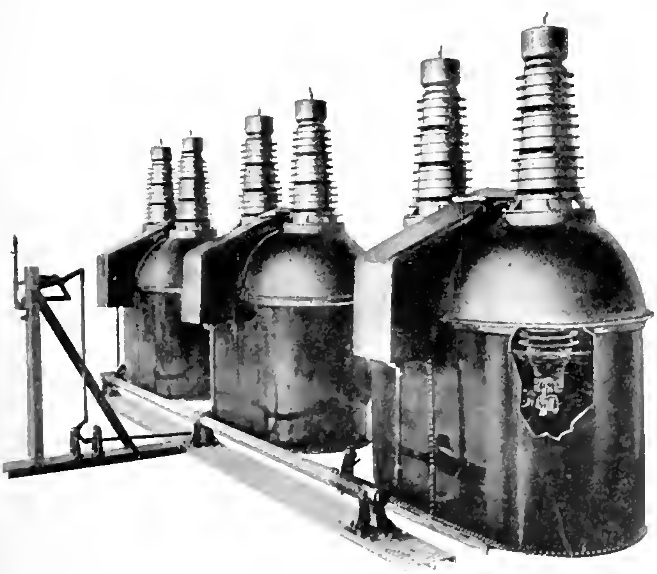


Fig. 2. Modern High Voltage, Large Capacity Oil-Break Circuit Breaker for Controlling Three-Phase Alternating Current Circuits

Development

From a small knife blade switch (Fig. 1) placed in a can containing oil of unknown quality, we have seen the oil circuit breaker rapidly pass through various forms, until today we have the efficient high voltage, large rupturing capacity devices with high quality oil. (Figs. 2 and 3.) These switches are the result of a natural evolution based upon the demands of the service and the results of much experimental work on the part of the manufacturers.

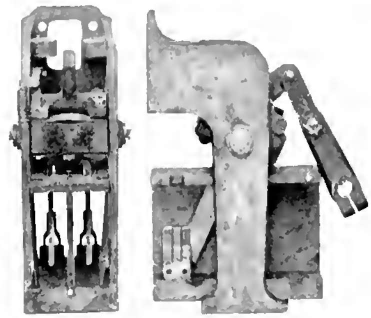


Fig. 1. Early Type of Oil-Break Circuit Breaker Consisting of a Knife Blade Switch Immersed in a Can of Insulating Oil

Function

The oil circuit breaker interrupts an electrical circuit in oil without producing abnormal disturbances in that circuit and also confines the destructive arc to a small volume, thereby preventing its spread to adjacent apparatus and enabling the oil circuit breaker to be safely placed in any convenient location on the switchboard or in the power station. Air break circuit breakers, owing to the large vicious arcs which they produce, are unsuited for general alternating current circuit breaking applications. The illustration on page 98 shows an arc drawn by one of these devices when opening a circuit carrying 800 amperes at 13,000 volts. This arc, one of many observed, was about 180 inches long and rose 140 inches in the air, while the same circuit ruptured in oil produced an arc only 9 inches long and with no external disturbance.

Action

A distinctive feature of the oil circuit breaker lies in the fact that when the alterna-

* Paper read before Pittsfield-Schenectady Midyear Convention of the A.I.E.E., Feb. 14-16, 1911.

ting current that is maintaining an arc in the oil, passes through zero (at which point the electro-magnetic energy is a minimum) the current is interrupted and remains so until the voltage rises to a sufficient value to puncture the oil insulation which has been established between the contacts. As soon as this occurs, the current re-establishes itself and flows for another half cycle. This successive going out of the arc and its re-establishment thus continues until sufficient insulation is interposed between the contacts to resist the maximum voltage of the circuit. (Fig. 1.) The insulating layer of oil may be introduced by the rapid parting of the contacts; by the confining of the oil to the immediate neighborhood of the disturbance, thus utilizing the pressure developed by the arc; or by the introduction of fresh oil under external pressure.

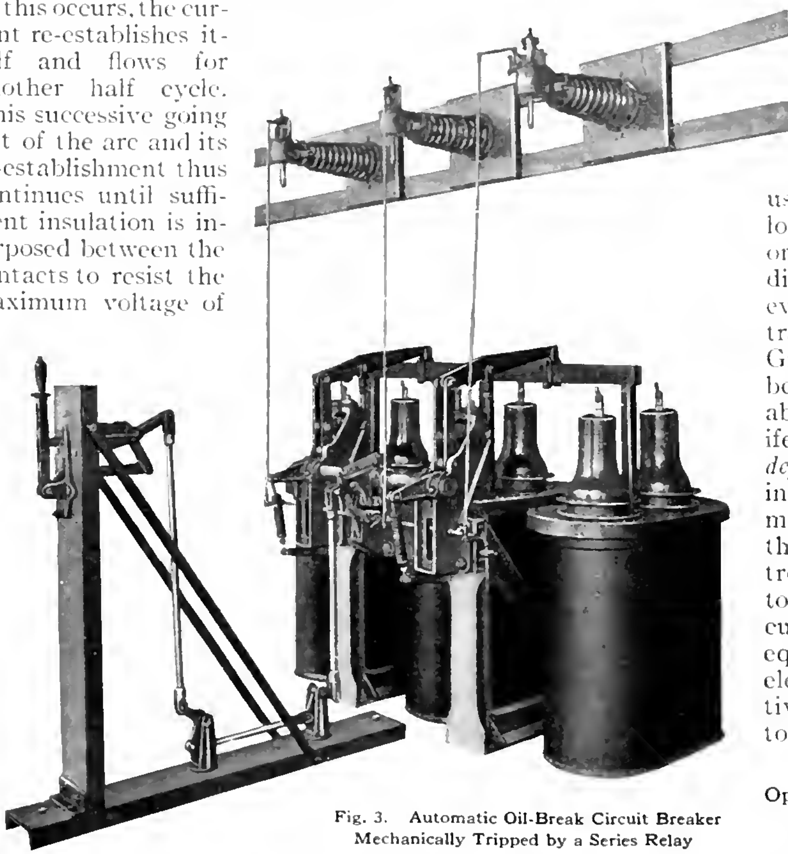


Fig. 3. Automatic Oil-Break Circuit Breaker Mechanically Tripped by a Series Relay

Application

While the duties of an oil circuit breaker are to connect, disconnect or isolate different parts of an electrical system, its most important function is to relieve the system of dangerous overloads or short circuits which would otherwise prove disastrous to the service. The oil circuit breaker may act instantaneously, or have its operation delayed by suitable time limiting devices. In this way, we are able to make them act selectively and thereby isolate faulty generators, transformers or feeders without disturbing the supply of energy. From these various applications, oil circuit breakers take the name of generator, transformer, group or feeder circuit breakers. (Fig. 5.) Generator circuit breakers are preferably *non-automatic*, as it would greatly disturb the system to have the generators continually disconnected therefrom. Transformer circuit breakers are usually equipped with overload inverse time limit relays, or sometimes instantaneous differential relays, so that in event of trouble the faulty transformer will be isolated. Group circuit breakers may be set to operate after an abnormal condition has manifested itself for a certain *definite* predetermined time, in order to protect the remainder of the system should the oil circuit breaker controlling the faulty feeder fail to operate. Feeder oil circuit breakers are generally equipped with an *inverse* time element relay so that selective action may be secured to isolate faults.

Operation

The method of operating an oil circuit breaker, whether by hand, electric motor, solenoid, or pneumatic mechanism, is largely a detail of construction, as any well designed circuit breaker may be interchangeably operated by any of these means, the circuit rupturing feature being independent of the operating mechanism. For convenience, economy, and safety, large circuit breakers are remotely controlled so that they may be placed in fire resisting compartments very near the station busbars. The control wiring should be installed in such a manner as to preclude its failure under *any condition*, as instances have occurred where adjacent circuit breakers have caused the destruction of control wiring, thus rendering other circuit breakers inoperative.

Inspection and Oil

The severe service to which these circuit breakers are subjected necessitates the regular inspection of oil, contacts and mechanism, with frequent attention to the general insulation. The oil may be carbonized considerably on a heavy short circuit, and should inspection indicate this, fresh oil should be supplied. Carbonized oil may be filtered and the moisture removed, after which it is again fit for use in oil circuit breakers. The quality of oil should also be given careful consideration: its flash and burning points should be as high as possible (not less than 180 degrees centigrade); also its dielectric strength (not less than 40,000 volts when measured between 0.50 inch discs placed 0.20 inches apart) to avoid leakage between contacts or from contacts to ground, and to increase its arc rupturing properties. It should be capable of extinguishing the arc sprung by opening the switch, and in doing this the carbon deposited should be a minimum. It should be free from acid, alkali, sulphur, or any other content likely to corrode the metal parts of the circuit breaker. It should be as fluid as is consistent with other requirements and remain fluid at low temperatures.

Insulation

The insulation of oil circuit breakers up to 60,000 volts is well taken care of by porcelain bushings and supports, but

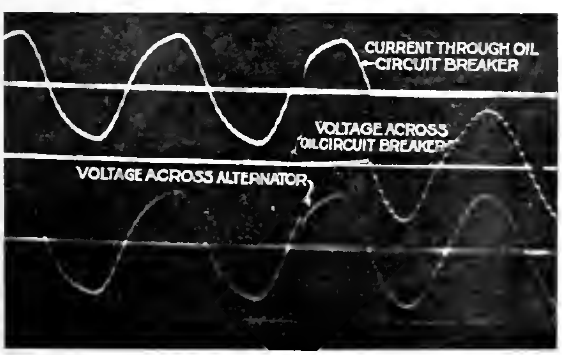


Fig. 4. Oscillogram Showing the Phenomena Occurring on Opening an Alternating Current Circuit by Means of an Oil Circuit Breaker Operating Under Test

above this point we have to resort to some other means. Here we begin to deal with very delicately balanced electrostatic forces whose peculiarities are only partially appreciated.

Time Factors

The total time interval between the instant the abnormal condition of the circuit is apparent and the instant the circuit breaker is completely opened, consists of the time element of the protective relay and the time characteristic of the circuit

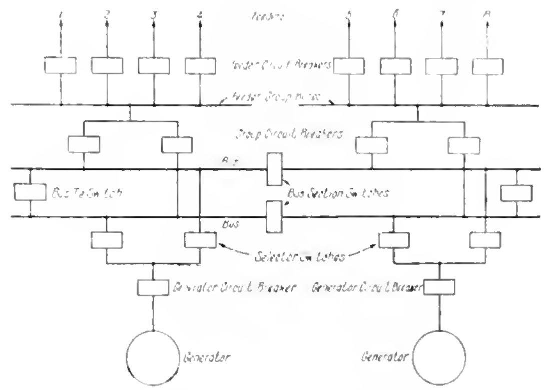


Fig. 5. Diagram Showing Possible Locations of Oil-Break Switches and Circuit Breakers in the Distributing System of the Modern Power Station

breaker. The time element of the protective relay is the time lapse from the instant the abnormal condition of the circuit is apparent to the instant the circuit breaker trip is energized. It may be variable or constant, depending upon whether the timing feature of the relay is inverse or definite, or it may be entirely absent.

The time characteristic of a circuit breaker is the time lapse between the instant the circuit breaker trip is energized and the instant the circuit breaker is completely opened. (Fig. 6.) This characteristic is influenced by the time which elapses from the instant the tripping mechanism is energized until the arcing contacts part, and the velocity with which this parting occurs. It should be remembered, however, that the arc is rarely, if ever, drawn the full travel of the arcing contacts of the circuit breaker.

Rupturing Capacity

The rupturing capacity of an oil circuit breaker is dependent upon a number of important elements, such as the velocity with which the contacts part, their size and shape, the quality of oil, the electrical characteristics of the circuit, the direction, length and number of breaks, and the type of smothering or arc "squelching" device employed. When we consider the velocity of the moving contacts, we see that if they move apart slowly, the arc formed has time to become very violent and destructive,

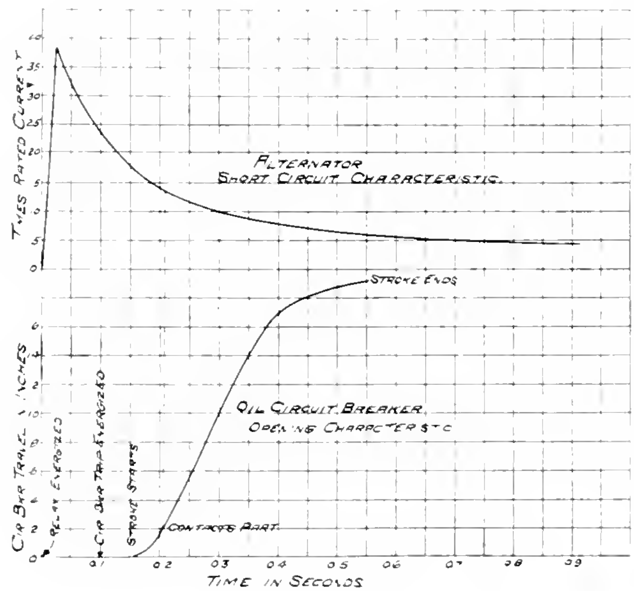


Fig. 6. Opening Characteristic of Oil Circuit Breaker on Short Circuit

while if we make this velocity sufficiently high we reduce the time during which the arc can act, thus diminishing its effects and increasing the capacity of our oil circuit breaker. The power-factor of the circuit to be opened greatly affects the rupturing capacity of an oil circuit breaker. If the power-factor is less than unity, the voltage is not in phase with the current and this permits the arc to be continued for a longer period. The amount of current also affects the rupturing capacity of an oil switch, since upon its magnitude depends the destructive effects of the arc. Hence anything which will reduce the current will diminish the work of the switch. Another feature which we have to consider as affecting the rupturing capacity is the arc "squelching" device employed. A number of these devices have been proposed and some are now being utilized, such as baffle plates (Fig. 7), directed oil jets, oil pressure systems, etc., and it is due to their efficiency that we are enabled to control high capacity circuits and reduce the amount of oil required in oil circuit breakers.

The characteristic of an abnormal load, such as a short circuit, against which the oil circuit breaker is relied upon to relieve the system without interfering with the operation of synchronous apparatus or interrupting the supply of energy, depends in a great measure upon the size and number of generators actively connected to the system, their internal impedance, and the impedance of the circuits between the generators and the point at which the abnormal load occurs. The enormous currents which have been encountered have led to the consideration of placing external reactances in the leads of the generator units in order to limit the amount of current which may be taken from them on short circuit. The present tendency is to design generators with larger internal impedance, even at the expense of regulation, in order to limit the maximum instantaneous value of the short circuit current. This practice will permit generators to be short circuited without material injury to themselves, and will greatly diminish the amount of current which the oil circuit breaker is called upon to interrupt. It will also permit the use of oil circuit breakers upon a system of larger capacity than possible heretofore, besides protecting the generators from injury.

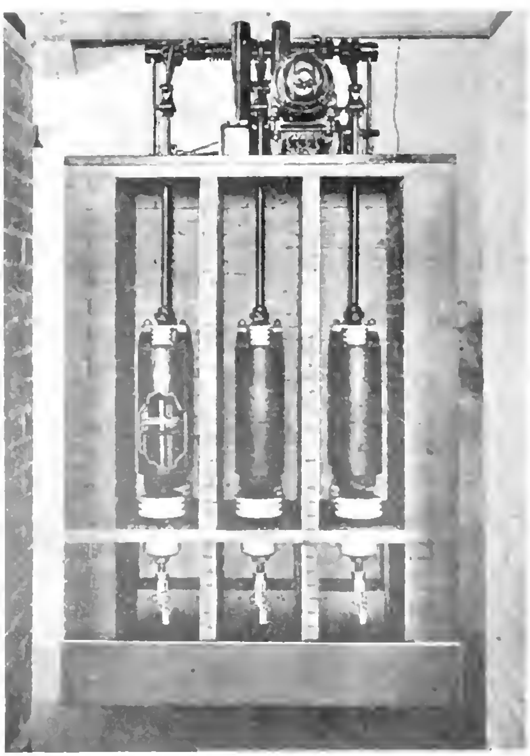


Fig. 7 Modern High Capacity, Moderate Voltage, Three-Phase Oil Circuit Breaker, Showing Baffle Plate for "Squelching" Arc

SOME NOTES RELATIVE TO BUSBAR CAPACITIES

By C. J. Barrow

In drawing up busbar specifications it is customary to state maximum current density of cross section and of contact surface at which the bus is to operate. The object of this is to secure a reasonable temperature rise, which in any layout is entirely dependent on the facility with which the heat generated can be dissipated. It is therefore insufficient to specify densities only (a feature of design) to determine performance as regards heating. The variations of current density with size of conductor in conductors operating at a temperature rise of 30° C. is illustrated by the density curves of Figs. 1 and 2, which apply respectively to cylindrical conductors and 5 in. by 1/4 in. copper bars arranged in the usual way.

The energy loss is, of course, a question of current density, but this is a consideration which rarely enters here. When the cost of power is high it may warrant

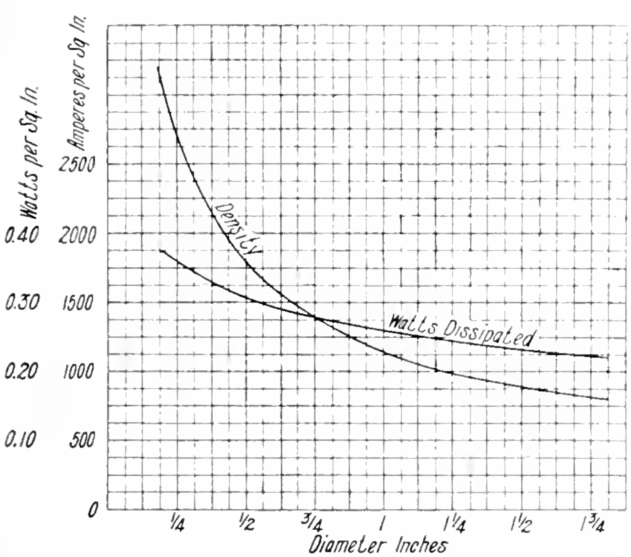


Fig. 1. Watt Dissipation and Corresponding Current Density at 30° C. Rise for Cylindrical Copper Conductors of Various Diameters

consideration: for example, a bus consisting of four 5 in. by 1/4 in. bars at 5000 amp. direct current shows a temperature rise of 30° C. and dissipates 46 watts per foot length. This loss figured flat represents 400 kw-hrs. per year. Assuming an average loss 20% of the maximum, we have 80 kw-hrs. at, say 0.5 cts. per kw-hr., or 40 cts. to balance against investment in copper, which, at 18 cts. per pound of busbar, is $3.45 per foot. Capitalized at 8%, this represents a fixed charge of 27.6 cts. per foot of bus; a showing which even at the moderate power cost assumed argues more bus copper and incidentally lower bus temperatures.

When power is cheap and the load intermittent there is no reason why buses should not be operated at higher temperatures than usual, particularly in electric furnace and similar work. Copper can be operated in air at 80° C. for an indefinite length of time without discoloring, and the nature of a bus is such that if properly insulated, much higher temperatures can do no harm. In switchboard work a precedence in favor of moderate temperatures is found in the limitation of 30° C. maximum rise imposed in rupturing devices. The heat from a high temperature bus adjacent to switchboard meters, etc., would also be objectionable.

Of the factors which determine temperature rise in a conductor dissipating energy, ratio of external surface to energy dissipated is evidently of first importance. In the case of cylindrical conductors of increasing size in which the density is maintained constant, the energy dissipated increases as the square of the diameter, while the dissipating surface increases only as the first power. Hence, with increasing size of conductor the temperature must increase; or, if a constant temperature rise is to be had, the current density must be decreased. Assuming at a given temperature rise a definite rate of dissipation per square inch external surface, the density for constant rise will vary inversely as the square root of the diameter and the capacity as the diameter squared, divided by the square root of the diameter; i.e., as the 1.5 power of the diameter.

That a fixed rate of dissipation per square inch external surface obtains for a given temperature rise is not borne out by experimental determinations. The rate is found to decrease with increasing size of conductor, and consequently the capacity of cylindrical conductors considered above increases at a lower rate than the 1.5 power of the diameter.

In Fig. 1 the watt dissipation per square in., at 30° C. rise, from cylindrical conductors of various diameters suspended in air and protected from draughts, is plotted against diameter along with the current density corresponding to this rate of dissipation.

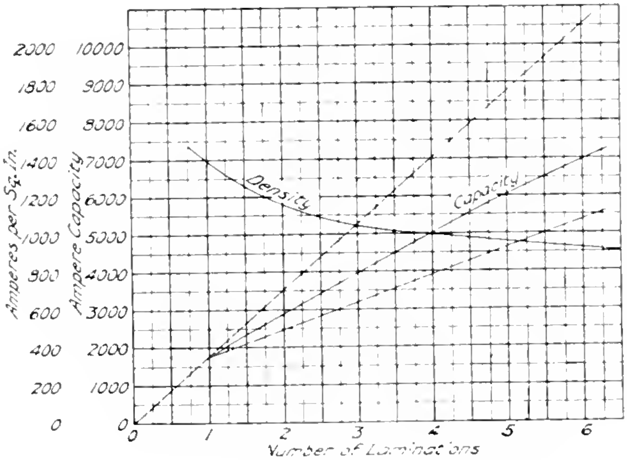


Fig. 2. Current Density and Ampere Capacity (Direct Current) for Various Numbers of 5 in. by ¼ in. Copper Bars; ¼ in. Vent Ducts; 30° C. Rise

Apparently very little heat from a conductor in air at the temperatures usually obtaining in practice is truly radiated, practically all being carried away by convection currents of air set circulating by the heated conductor. Obviously no theoretical method of arriving at the cooling effect of such air currents is possible and recourse must be had to experimental data, obtained on representative layouts under service conditions.

While considering the rate of dissipation from a heated surface it may be well to remark that the rate expressed in watts per square inch increases a little faster than the temperature rise. The increase is somewhat offset, as regards current carrying capacity, by increased resistance at the higher temperature.

In obtaining representative data on buses of rectangular copper bars grouped in the usual way, the following considerations assist in interpreting results and outlining tests to be made.

The heat carried away at a given temperature rise from two bars arranged side by side without vent ducts between will not be materially greater than in the case of one bar alone. The resistance of the combination being ½ that of one bar, its capacity will not be less than $\sqrt{2}$ times the capacity of the single bar. If the two bars are so far removed from one another that they do not handicap each other in getting rid of their heat, the capacity of the pair will evidently be twice that of a single bar. Hence the capacity of any two-bar bus should be between 1.41 and 2.0 times the capacity of a single bar. The capacity increase in amperes on the addition of a third bar will be between the capacity increment due to the addition of the second bar, as maximum, and 41 per cent of the capacity of a single busbar as minimum. In the process of adding bars or laminations, the capacity increment due to the addition of any bar cannot be greater than the increment which resulted on addition of the previous bar. Eventually an additional lamination will increase the capacity of the bus by a constant current which will be between 41 and 100 per cent of the capacity of a single lamination, depending on the effectiveness of the ventilation.

The direct current ampere capacity for 30° C. rise of a bus consisting of various laminations of 5 in. by ¼ in. copper spaced with ¼ in. vent ducts is shown by the capacity curve of Fig. 2. This and other curves submitted are based on data obtained on common drawn copper, and a room temperature of 25° C. The upper dotted line projected from the origin through the capacity of one lamination shows the capacity at constant current density, using as basis the density obtaining in a single lamination bus. The lower dotted line shows the increased capacity which results from increased conductivity only. The amperes per square inch corresponding to the capacity curve are plotted by the curve marked "density." An efficiency of 100 per cent for several lamination buses is represented by the upper dotted line. Such a value can hardly be realized in any practicable arrangement. A first hand consideration, however, will show that the width of vent ducts between bars should be a function of the duct length (width of bar) and the droop in the capacity curve. Fig. 2 indicates that wider vent ducts are desirable from the standpoint of copper efficiency in the case of 5 in. bars, and even more so in the case of bars 10 in. wide. The use of ducts wider than the lamination thickness involves complications in the way of special separators and connections, and in the case of alternating current buses the increased width of bus is objectionable. For heavy direct current work, the advantage to be derived from wider vent ducts offsets any objection to their use.

Fig. 3 shows the ampere capacity of single 1/4 in. thick copper bars of various widths, and also the watts dissipated per square inch external surface for 30° C. rise. Here again the dissipating rate is seen to fall with increasing size of bar, the upper sections of the wider bars apparently being handicapped in getting rid of their heat, by heat from the lower sections.

Of the two methods of increasing bus capacity indicated in Figs. 2 and 3, the more efficient for a given case will depend on the relative widths of bars and sizes of vent ducts. If adequate ducts are used the advantage (for direct current) lies with a group of several smaller bars, and this arrangement is generally preferable on the score of flexibility as regards additions and "tapering" of bus. For alternating current work, the advantage lies with the minimum number of bars.

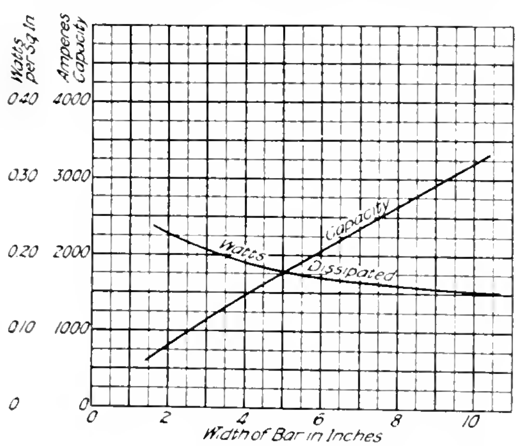


Fig. 3. Direct Current Ampere Capacity and Watt Dissipation at 30° C. Rise for Single Copper Bars of Varying Widths, 1/4 in. Thick

Having in mind the process of heat dissipation by convection, it is evident that the standard arrangement of buses grouped horizontally with laminations on edge will operate at a lower temperature than buses arranged with the width of laminations horizontal, or length vertical. Likewise a higher temperature must be expected in buses, the legs of which are grouped vertically one above the other.

In the foregoing discussion an attempt has been made to emphasize the importance of providing an arrangement properly disposed to permit free circulation of convection currents. It is equally important that proper ventilation of the bus structure as a whole be provided so that heated air does not pocket behind the switchboard or in bus compartments.

Contact Density at Joints and Connections

The first requirement to be fulfilled in any electrical joint is reliability. The joint must be so constructed as to preclude any possibility of the conductors parting company. When mechanical considerations are taken care of, the matter of contact density is usually amply provided for. Sometimes, however, very low specifications for contact densities are made, and to illustrate the nature of contact resistance, Fig. 4 is submitted. The curves show the drop across a lap joint (reduced to a one inch length basis) at varying pressures evenly distributed over 8 sq. in. and 16 sq. in. contact area, respectively. Joints were made between clean 4 in. by 1/4 in. copper bars, the surface skins of which were not removed by sanding as is usually done in making joints of this kind. Measurements made on similar sanded joints gave curves falling below and approaching those given at increasing pressures. Data on the higher resistance joints are used as representing worst conditions. The "drop" values plotted include resistance drop in the copper at joints, which cannot well be separated. In a perfect joint (copper resistance drop only), since there is double copper at joint, the drop per inch length will be 1/2 of that in the bar. For convenient reference this drop and the drop per inch of bar are indicated in the figure.

It will be noted that below a pressure of 200 lb. per square inch, pressure is quite as important a factor as contact area. Above 100 lb. per square inch the contact resistance was found to be constant independent of current density at which measurements were made. It will be noted also that on a "drop per inch of joint" basis of comparison, the 16 square inch contact has but little advantage over the 8 square inch contact at a pressure of 200 lb. per square in., and at the same total pressure the advantage is in favor of the smaller contact. The proper criterion of a good joint would seem to be a drop or energy loss per inch length of joint comparable with that in the bar jointed. There is no difficulty in keeping it below the value in the bar; it might exceed bar drop and have very little influence on the bus temperature. The real solution of the contact problem lies in the proper disposition of bolts, or their equivalent, so that the entire contact surface is put under pressure, rather than in providing a low nominal contact density without regard to pressure.

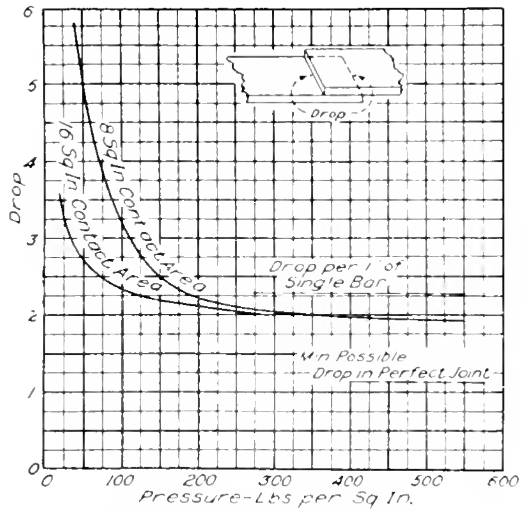


Fig. 4. Voltage Drop per Inch Length of Lap Joint Under Varying Pressure. Surface Clean but Not Ground

Tests made on soldered joints give drop values not more than 5 per cent in excess of the minimum drop possible in a perfect joint, which fact would indicate a very high permissible density for soldered joints. However, in a joint between flat bars there is but a small thickness of solder traversed by the current, while in the case of a round conductor soldered into a terminal there may be considerable thickness; in the latter case higher drops will be encountered. Ordinary solder has a conductivity of 10 to 12 per cent. To proportion the area of soldered contacts so that contact area is related to conductor section as the respective resistivities of solder and conductor material; i.e., as 9 to 1 (a proposition which results in the same drop for equal lengths), would be too conservative. Where soldered areas are not determined by mechanical considerations, a ratio in proportion to the square root of the resistivities; i.e., as 3 to 1, which, comparing equal sections, gives the same loss in solder and copper, would seem to be a good value for minimum permissible area of soldered contacts.

Alternating Current Buses

The preceding remarks relative to heat dissipation evidently apply alike to alternating current and direct current buses. In an alternating current bus, however, losses in excess of the usual resistance losses obtaining under direct current are encountered, which fact makes a distinction necessary, and the arrangement of copper in an alternating current bus is determined largely by considerations aiming to minimize these excess losses.

Losses in iron supports and fittings adjacent to alternating current buses will not be considered. They are the result of eddy currents, and to a less extent of hysteresis, which in the absence of material of high permeability would not require attention. The matter is one that must be considered in detail in connection with the particular arrangement of buses and feeders employed.

The excess copper losses are to be viewed not as eddy losses, but largely as losses resulting from uneven current distribution. Resistance loss varying with the square of current density any departure from uniform density results in increased losses. Eddy losses are no doubt present, but in a minor degree. An idle copper bar shows very little heating in a position in which a similar bar connected in circuit and carrying current shows marked "excess" heating.

An idea of the causes which alter current distribution in a conductor carrying alternating current may be had by assuming the conductor to be made up of a multitude of elemental conductors, constituting for purposes of anaylsis a group of conductors in parallel with common terminals at each end. An alternating current in dividing itself among the various elements will be influenced not by resistance only, but also by the inductance, self and mutual, of the individual elements. To avoid complications, the effect of resistance on current distribution will not be taken into account, only that due to reactance being considered. Resistance operates to offset the unbalance in current distribution which would result if inductance were the only factor entering. The current in establishing itself is opposed by a counter e.m.f. generated by the growth of flux accompanying the rise of current. That element which, when the same current flows in all elements, is enveloped by the least flux, will develop a minimum opposing e.m.f. and hence will pass a proportionally greater share of current than element enveloped by a greater flux. That is, the current passed by any element is determined by the opposition it meets—the reactance of the individual elements. It should be observed that variations of reactance and not the actual magnitude of the reactance determine the amount of unbalance of current.

A study of the magnetomotive forces and fluxes of the various elements of an isolated conductor will show the central elements to be enveloped by a greater flux than those nearer the surface. The result is a "crowding" of current towards the surface element, leaving a region of low density at the center—a result commonly known as skin effect.

For buses under service conditions, in addition to skin effect, the disturbing effect of return current in adjacent conductors is usually present, tending to further unbalance the distribution of current. Assume that return current acts as if it were concentrated at center of return conductor: a field whose polarity is opposite to that of the one we have been considering is introduced. In the space between the two currents the original flux exists as before, with the flux of return current acting in the same direction but superposed. Beyond the center of return conductor, however, the fields oppose each other, that of the return predominating. In this region the original field is overpowered and replaced by a reverse field; hence the entire flux about the first conductor must now pass "inside" the center of the return conductor, or between the two currents. Considering again the flux about the individual elements of the first conductor, it becomes evident that the flux which envelops those elements nearest the return must be less than that enveloping more distant elements, which have a greater space in which to propagate flux. The nearer elements, having less reactance, will therefore pass a more than proportional share of current; the result being a crowding of current towards the return conductor. In a similar way there is a corresponding crowding in the return conductor. In single-phase buses of several laminations, the effect manifests itself by increased heating of those laminations of opposite polarity nearest each other. The outer laminations operate at reduced current density in much the same way as would a single-phase transmission line operating in multiple with a similar line the wires of which are spaced on shorter centers.

In the case of three conductors arranged side by side and carrying three-phase current, the influences just considered are also present to offset the normal distribution of current. At first glance it would seem that the middle leg should be influenced equally and oppositely by the leg on either side, and therefore should show less heating than the outside legs. If we consider, however, that while current is reaching its maximum in the middle leg, in one outside leg it is just receding from a maximum in the reverse direction, and in the other leg is passing through zero, we can understand the tendency of current in middle leg to shift to one side. The side to which it shifts on this basis is dependent on the direction of phase rotation, as shown by test. Eddy currents in three-phase buses, particularly in the middle leg where a decreasing current on one side and an increasing current on the other introduce voltages in opposite sides of bus, are probably of appreciable magnitude. It should be observed that these voltages are only 30 deg. out of phase, or 30 deg. from opposition with the bus current on which they react, while in the case of single-phase buses the induced voltages are at a maximum when bus current is at zero.

By way of illustrating the magnitude of the excess losses under consideration, the temperature rise °C. obtaining on a three-phase bus at 10,000 amp. and 60 cycles, is submitted. The legs are designated A, B and C, B being the middle leg, and readings at outside and center of each leg are reported:

	A	B	C
Alternating current	29-88-100	100-80-77	108-65-25

With direct current such a bus approximates a rise of 40° C., with the maximum temperature at center and only 8° to 10° C. in excess of that of the outside lamination.

Each leg consists of four 10 in. by $\frac{1}{4}$ in. copper bars spaced with $\frac{1}{4}$ in. vent ducts and arranged horizontally on $5\frac{1}{4}$ in. centers. Owing to the transfer of heat between parts at different temperature, the degree of unbalancing is greater than indicated by the difference in temperature.

It is interesting to note when studying these current shifts in a conductor that they take place in a direction opposite that in which the conductor elements are urged mechanically by the magnetic forces present.

The foregoing is only intended to bring out in a general way the factors which influence the energy loss in alternating current buses. The laws of skin effect in an isolated cylindrical conductor have been formulated and are rather complex. It may be remarked that in copper conductors of 1 inch diameter at 60 cycles the excess loss becomes appreciable. For the more complicated case of rectangular bars arranged with vent ducts and carrying currents the distribution of which is far from uniform due to the reaction of adjacent conductors, no method of predetermining losses is available. The best that can be done is to provide a copper arrangement such that losses are minimized and to determine heating experimentally. In such an arrangement conductors will be separated as far as practicable and their thickness in line with the perpendicular between conductors will be a minimum. Extreme separation is not advisable as decrease in losses is not proportionate to increased separation and the increased reactance obtaining at the wider separation is objectionable. As regards skin effect, a wide flat bar—barring a hollow tubular conductor—is the most desirable conductor section, and therefore very good copper efficiency may be obtained with the usual bus construction if proper limitations are observed. The proper size of vent duct in a given layout will be determined by weighing increasing loss with increasing width of duct against increased dissipating ability.

Generally speaking, no marked difference in heating of buses under alternating and direct current is encountered at currents less than 3000 amp. At 4000 amp., 60 cycles and up, excess losses require attention, and with increasing current soon necessitate special design. Where very heavy currents are to be handled or where the high reactance of a bus arranged in the usual way is objectionable, "intermeshing" of the laminations of the various legs may be advisable. If reactance is not objectionable, a special construction in which a group of conducting elements are so disposed that self and mutual inductive effects are equalized seems to be the most efficient arrangement. Both expedients introduce mechanical complication and neither is well adapted to making other than terminal connections.

RELAYS AND THEIR USE WITH POWER CIRCUITS

By E. H. Jacobs

The successful controlling of electrical power circuits necessitates the use of various designs and capacities of air-break and oil-break switches and circuit breaking devices.

For some sections of the circuits, non-automatic switches, thrown in and out by the station attendant, are sufficient; but protection of the system from overloads and the cutting out of short circuits are obtained by the use of circuit breakers arranged to trip automatically under the abnormal conditions. Continuity of service being of prime importance, it is essential that the circuit breakers disconnect those circuits on which there is trouble without seriously affecting other parts of the system; consequently, they must act selectively.

To obtain the proper selective action of circuit breakers, it is necessary to control their automatic features by auxiliary devices. For this reason relays have been developed to meet the many requirements for automatic operation under conditions of overload, underload, reverse current, high or low voltage, reverse phase, and voltage or current unbalancing.

Fig. 1. Alternating Current Instantaneous Reverse Current Relay, For Use with Current and Potential Transformers

We may perhaps best describe the conditions for which relays have been designed for power circuits, by considering a one line diagram from the generator end to the substation auxiliary machines and feeders. (See Fig. 2.)

Considering first alternating current circuits: the prevailing practice is to make the circuit breakers by which the generators are connected to the low tension bus non-automatic, in order to insure minimum interruption of generator service. The chance of trouble in this part of the circuit is remote, but should it occur, the station attendant could generally open the circuit breaker before the machines would be injured.

Reverse current relays, of instantaneous or time limit types, are often connected to the secondaries of current and of potential transformers to indicate by lamp or bell any trouble that may occur in the generator circuit. These relays (see Fig. 1) operate with a low current reversal at full potential, and conversely with a proportionally greater current at potentials less than normal. At zero potential, the relay would act as an overload one set for high overload. At zero current, a voltage considerably in excess of normal would be required to operate it.

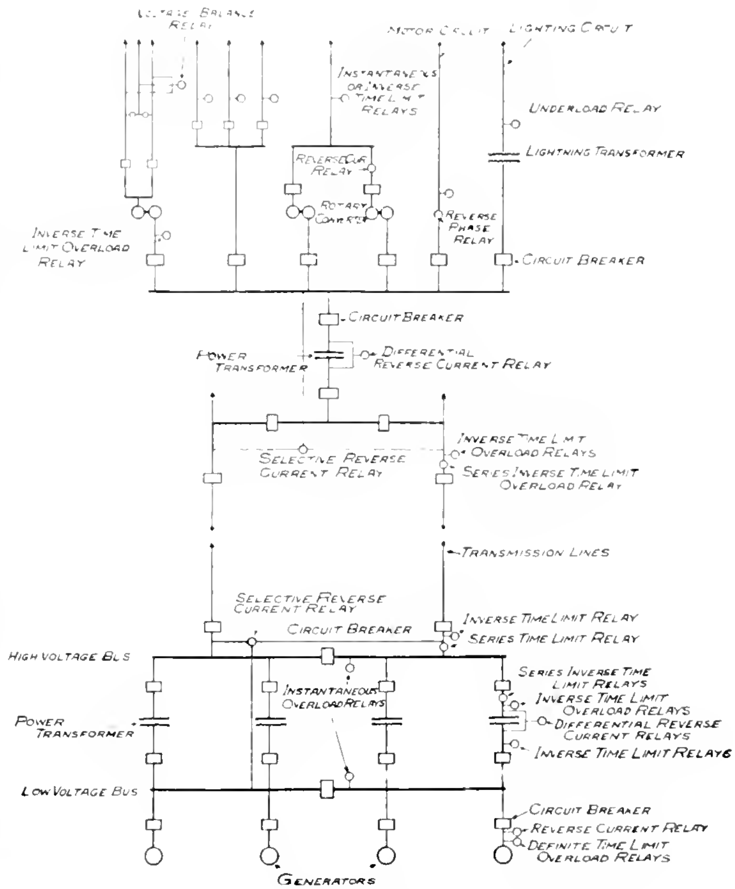


Fig. 2. Diagram of Modern Power House Wiring and Buses, Showing Location of Relays

Specifications sometimes call for automatic generator circuit breakers; in this case definite time limit overload relays are used (Fig. 3). They are connected in the secondaries of current transformers and are designed to give the same time delay for all trouble conditions; they allow the defective circuit to be opened, if possible, at a point more remote from the generator than the generator circuit breaker.

When the total generator capacity exceeds the rated rupturing capacity of the circuit breakers, one or more sectionalizing circuit breakers are placed in each bus. If operating conditions will admit, these devices are made non-automatic and are left disconnected except in case of emergency; but if it is necessary for them to be continually in service, they may be made automatic by means of instantaneous overload relays (Fig. 4) connected to current transformers in the low voltage bus; the relays being adjusted to trip the circuit breakers under short circuit conditions, confining the trouble to one section and preventing the circuit breakers from rupturing more than their rated capacity.

Installations with but one bank of power transformers, and without high voltage bus, are provided with automatic circuit breakers operated by an inverse time limit relay. The relay is connected to the secondaries of current transformers, which in turn are connected in the low voltage side of the power transformer.

The inverse time limit relay (illustrated in Fig. 3) is similar in design to the definite time relay, but is so arranged that the element of time varies in inverse proportion to the load; i.e., the relay will act much more quickly under short circuit than under overload conditions.

Stations with more than one bank of power transformers, a high voltage bus, and high and low voltage circuit breakers, may have both circuit breakers arranged to trip at the same time or one after the other. As in the former case, they are operated from the inverse time limit relay connected in the low voltage side.

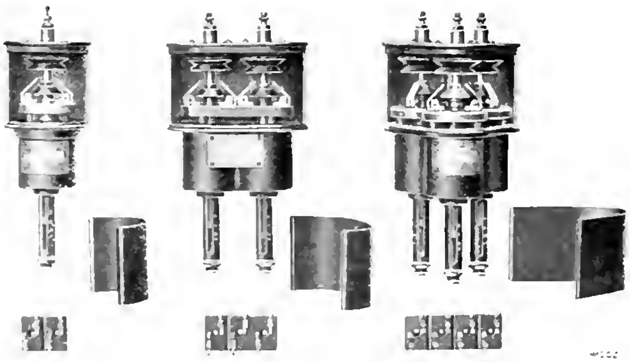


Fig. 3. Inverse or Definite Time Limit Overload Relays

With plants operating at voltages of 33,000 and above in which two or more banks of power transformers are in parallel between high and low voltage buses, it is desirable to open both the high and low voltage circuit breakers in case of any trouble in the transformers and this may be accomplished by means of an instantaneous differential relay connected in the secondaries of current transformers installed in both the high and low voltage sides and operating on a low current reversal in either winding of a power transformer. In case current transformers are not required in the high voltage side for use with instruments, inverse time limit relays may be used, connected to current transformers in the low voltage side; and high voltage series inverse time limit relays, connected directly in the leads of the high voltage side. Each relay may be arranged to trip one or both circuit breakers.

The differential relay arrangement is made instantaneous as it operates only in case of transformer trouble and is not affected by trouble in other parts of the system. The overload relays, however, not only operate for transformer trouble but also under fault conditions—involving an increase of direct or reverse current, remote from the transformers; they should, therefore, be equipped with the time limit feature.

When there are more than two banks of transformers in parallel, the inverse time limit relays also act selectively, isolating only that bank that is in the defective circuit.

The automatic circuit breakers in the outgoing line may be operated from inverse time limit relays connected in the secondaries of current transformers; or in case transformers are not necessary for use with instruments, series high voltage inverse time limit relays connected directly in the line may be used.

Whether to select current transformers with relays insulated for low potential, or to choose series relays, is a question of first cost and adaptability to service conditions. Below 33,000 volts, the commercial advantages in favor of the series relay is slight, and since it is somewhat difficult to design this device for the large current capacities met with at the lower voltages, it is generally the practice to use the relay with current transformer, because of its operating advantage. This practice, however, is not entirely followed, since some service conditions (described later) make the use of series relays very desirable and practical.

Inverse time limit relays are satisfactory for one or more than two outgoing lines in parallel, as they act selectively to disconnect the defective line only; but installations with only two outgoing lines in parallel have the same load conditions in both lines and selective tripping of the circuit breakers in

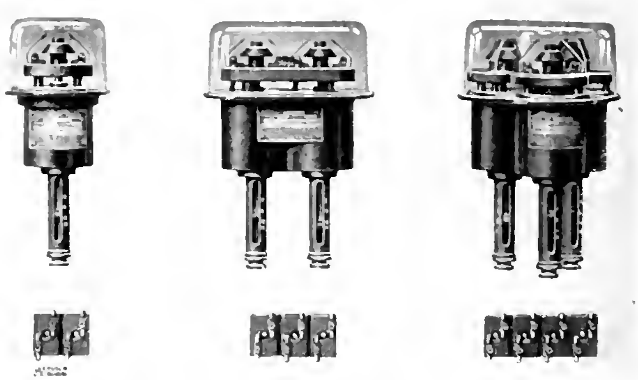


Fig. 4. Instantaneous Overload Relay and Differential Relay

the defective line is obtained by means of a relay acting instantaneously under short circuit conditions only. The relay design and action is similar to the reverse current relay previously mentioned, and is connected to the secondaries of current transformers in each high voltage line and potential transformers in the low voltage bus.

In the substation, the conditions are the reverse of those in the main station, the incoming lines becoming the source of power.

If there is only one incoming line and no high voltage bus, the line circuit breaker is generally non-automatic. With one incoming line and high voltage bus, the circuits from the service side of the bus are equipped with automatic circuit breakers and relays. These relays and those used for other arrangements of two or more incoming lines in parallel, as well as high and low voltage circuit breakers for power transformer circuits, are of the same design and are applied in the same manner as for the generating station.

Regarding the relay equipments for auxiliary machines, the same practice is followed with the generator end of alternating current

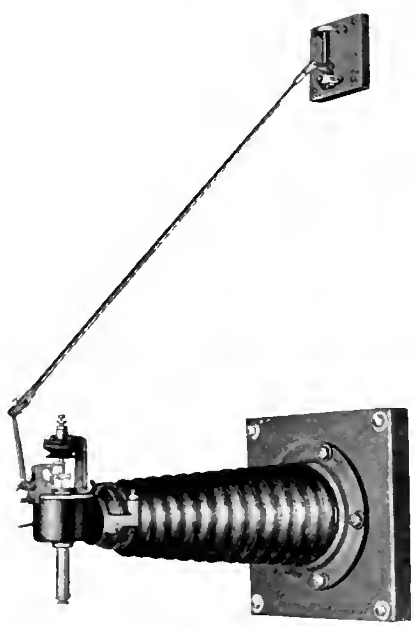


Fig. 5. High Potential Series Relay Mounted on Post Insulator

motor-generator sets as with the main generators, the outgoing feeder circuit breakers being tripped from inverse time limit or instantaneous relays.

With several synchronous machines in parallel, the relays are arranged to operate with the least time delay with which it is possible to get selective action, in order to prevent the machines from being thrown out of step in event of trouble conditions causing a decrease of voltage.

Fig. 6. Alternating Current and Direct Current Low Voltage Relay

The different types of induction motors and various conditions under which they are employed, have brought about the development of several types of relays to protect the motors and the apparatus with which they are used.

It is desirable to disconnect a large motor in case of voltage failure, and with conditions requiring either a motor-operated or a solenoid-operated circuit breaker, a low voltage relay is used to close the tripping circuit whenever the voltage decreases to, approximately, 50 per cent below normal. Up to 550 volts, these relays may be connected across the line, but for higher voltages they are connected to secondaries of potential transformers. (Fig. 6 shows one of these low voltage relays). Smaller motors with which hand-operated circuit breakers are used, are generally provided with low voltage release attachments that perform the same function as the relay.

Induction motors are sometimes subjected to high voltage conditions and to protect them from injury, high or excess voltage relays are employed to trip the automatic circuit breaker. These relays are of similar design and wired in the same manner as the low voltage relays.

For operating conditions under which a reversal of phase would cause trouble, as for example in the case of elevator motors, reverse phase relays have been developed. These are so designed that any phase reversal that would reverse an induction motor, would operate the relay and disconnect the automatic circuit breaker. The design is based on

Fig. 7. Reverse Phase Relay

the principle of the induction motor, and in the case of low voltage motors of limited capacity, the relay may be connected in series in the motor leads. If the voltage or capacity of the motor makes this arrangement inexpedient, the relay may be placed in the secondaries of current or potential transformers connected in the motor leads.

Underload relays are often used to trip the automatic circuit breaker that is placed in the primary of lighting circuits to prevent an abnormal rise of secondary voltage in case of a break in the secondary circuit. The underload relay is similar in design to the low voltage relay excepting that it acts on a decrease of current.

The problem of protecting induction motors from injury, that may result from running on single-phase, or from an overload, and at the same time permit the motor to be started with the necessarily high starting current that may be greatly in excess of the overload current, has caused the development of the series relay. This device may be connected in series with the motor leads for voltages up to 2500; it is designed with an inverse time limit device which may be adjusted to give the desired protection.

The field for relays is more extensive for alternating current than for direct current power circuits, the latter being generally confined to much smaller and simpler systems and areas of distribution, and generally sufficient selective action can be obtained by the use of fuses or circuit breakers arranged with instantaneous trip.

Operating conditions sometimes make it advisable for the generator circuit breakers to open only after the auxiliary and feeder circuit breakers have failed to isolate the trouble. This is accomplished by using direct current series inverse time limit relays to trip the generator circuit breakers.

Instantaneous reverse current relays are used to trip the machine circuit breaker of battery charging sets, rotaries and motor generator sets to prevent their running as a motor on the charging or direct current end. These relays can act only in case of current reversal.

To prevent serious unbalancing of voltages in Edison three-wire systems from causing trouble, differential balancer relays are used to trip the circuit breakers on a small percentage of unbalancing. (See Fig. 8.)

Fig. 8. Relay For Balancer Set

There are many conditions requiring modifications of standard relays and special designs, but it is the purpose of this paper to mention only those required to meet general specifications and practice.

ESSAYS ON SYNCHRONOUS MACHINERY

PART II

BY V. KARAPETOFF

ARMATURE REACTANCE IN ALTERNATORS AND IN SYNCHRONOUS MOTORS

In the preceding article the general vector diagram of a synchronous machine is deduced (Fig. 2) and expressions are given for the induced voltages E_1 and E_2. It remains to give values of the ohmic drop *ir* and of the inductive drop *ix*, in order that the diagram may be used for practical applications.

Armature Resistance. On account of the skin effect and eddy currents in conductors, the effective alternating current resistance, *r*, is considerably higher than the true ohmic resistance calculated or measured with direct current. E. Arnold recommends that the true ohmic resistance of the armature be multiplied by from 1.5 to 2.5 in single-phase machines, and from 1.3 to 2 in polyphase machines, in order to obtain the effective resistance to alternating current. (*Wechselstromtechnik*, Vol. IV, p. 40).* The actual amount of increase depends upon the character of the winding, the size of conductors, frequency, shape of the slots, etc., so that no definite rule can be given. Fortunately, the ohmic drop constitutes but a small percentage of the voltage of the machine, so that a considerable error committed in estimating the value of the drop affects the voltage relations but very little.

Armature Reactance. The reactive drop *ix* in the armature windings is the most difficult element to be determined theoretically. When using the methods given below for estimating *ix*, the designer must exercise his judgment in selecting one method or another, according to the conditions of the case and the accuracy required.

(a) In normal alternators the *ix* drop at the rated kilovolt-ampere load can be assumed to be from 5 to 10 per cent of the rated voltage of the machine. In synchronous motors it varies from 8 to 15 per cent. For 60-cycle machines and for machines with a comparatively large number of armature ampere-turns, values must be taken nearer the higher limit; for 25-cycle machines and for machines with a comparatively small number of armature ampere-turns, values must be taken nearer the lower limit. A considerable error in estimating the value of *ix* has but little effect upon the calculated performance at unity power-factor, because the vector *ix* is then perpendicular to *e*. (Fig. 2.) However, a considerable error may be introduced at lower values of power-factor if the reactive drop *ix* has not been estimated with a sufficient accuracy.

(b) If an accurate short-circuit test on the machine is available, the *ix* drop can be

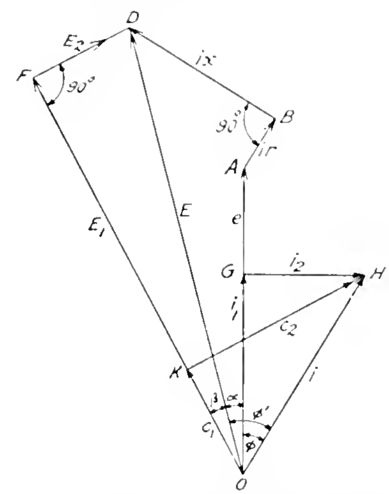


Fig 2. Vector Diagram of Voltages in an Alternator
(A Counter-Clockwise Rotation of Vectors is Understood)

calculated as follows: Take the point on the short-circuit curve corresponding to the rated current *i*, and assume the reactive component c_2 to be equal to about 98 per cent of *i*. Calculate the demagnetizing ampere-turns according to formula (5) and subtract them from the field ampere-turns which correspond to *i* on the short-circuit curve. The result will give the net excitation, which produces the actual flux on short-circuit. The voltage induced by this flux is just sufficient to overcome the *ix* drop in the armature (neglecting the ohmic drop *ir*). Hence, taking from the no-load saturation curve the value of the voltage which corresponds to the net excitation, we obtain the value of the *ix* drop.

The following example will make this clearer. For a certain 2300 volt, three-phase Y-connected alternator the rated current is 37.6 amp.; the number of turns per pole per phase, $T = 18$. There are two slots per pole per phase, and the winding pitch is

*See also A. B. Field, "Eddy Currents in Large Slot-wound Conductors", *Trans. Amer. Inst. Elect. Engrs.*, Vol. 24, p. 761.

100 per cent. Hence, the direct armature reaction per pole on short-circuit is equal, according to eq. (5), to $0.75\times0.966\times1\times3\times18\times37.6\times0.98=1440$ ampere-turns. From the short-circuit test the field ampere-turns corresponding to 37.6 amp. are found to be equal to 1818. The net excitation is $1818-1440=378$ ampere-turns. This excitation corresponds on the no-load saturation curve to 220 volts. Hence, for this machine, $ix=220$ volts, or about 9.5 per cent of the rated voltage. In some machines with a comparatively large armature resistance and considerable eddy currents we are led to assume the reactive component of the current on short-circuit to be only 96 per cent of the total current (instead of 98 given above) in order to make the calculated performance check with test results.

(c) The armature reactance can be measured directly by removing the revolving field and sending alternating currents through the armature from an outside source. High-frequency currents are particularly well adapted for this purpose, because then the influence of the armature resistance is reduced to a negligible amount. One must be careful, however, with windings of large cross-sections, because considerable eddy currents and skin effect at high frequencies may introduce inaccuracies into the result.

Such a reactance test is conveniently performed in the shop or in the power house before the machine is completely assembled for other tests or for regular operation. It is highly desirable that this test be specified on all machines of new design going through the shop. It costs but very little, and at the same time the results enable the designer to estimate the performance of future machines with much more accuracy. Moreover, having a reactance test, a no-load saturation curve, and a short-circuit test as a check on the armature reaction, the performance of the machine, whether as generator or as motor, can be predetermined to a considerable degree of accuracy, and the expensive load test may be dispensed with.

(d) The following method for calculating reactance of windings is due originally to H. M. Hobart. By definition, the coefficient of self-induction (inductance) of a coil is equal to the *average* permeance of the path times the square of the number of turns.* Let u_1 be the average permeance of the slot per inch of the embedded part, in maxwells per ampere-turn; let u_2 be the average permeance of the "free" parts of the coil, that is to say, of the end connections and of the parts in the air-ducts. Then the permeance of the winding *per slot* is $(u_1l_1+u_2l_2)$, where l_1 and l_2 are the lengths (in inches) of the embedded and of the free parts of the coil respectively; viz., l_1 is the active length (without air-ducts) of the armature core and l_2 is the length of one end connection plus the sum of the widths of the air-ducts.† If there are T turns per pole per phase and s slots per pole per phase the number of conductors per slot is $2T/s$. Consequently, the inductance of the winding *per slot* is

$$L_s=(u_1l_1+u_2l_2)(2T/s)^2\times10^{-8}\text{ henrys} \qquad (8)$$

The reactance of the total winding per phase is therefore

$$x=2\pi f.L_s.sp.10^{-8}\text{ ohms} \qquad (8a)$$

where f is the frequency in cycles per second and p is the number of poles of the machine. Substituting the value of L_s from eq. (8) into (8a) we obtain after reduction

$$x=25\,fT^2p(u_1l_1+u_2l_2)/(s.10^8) \qquad (9)$$

The value of permeance u_1 depends upon the size and the proportions of the slot; in ordinary machines it varies from 6 to 14 lines per ampere-turn per inch. The permeance u_2 depends upon the shape and the arrangement of the end connections; also upon the mutual proximity of the end connections belonging to different phases. Usually u_2 varies between 1.5 and 2.5 lines per ampere-turn, per inch of length. In preliminary calculations and for 100 per cent pitch windings, l_2 can be assumed equal to 1.5 times the pole pitch. In fractional pitch windings the reactance is smaller than that calculated according to the foregoing formula because the "belts" of currents belonging to different phases overlap. The designer has to use his judgment in assuming a smaller value than that given by eq. (9). For 67 per cent pitch Arnold recommends multiplying the preceding expression by 0.75 (*Wechselstromtechnik*, Vol. V. part 1, page 54).

For the above-mentioned alternator (which is a 60-cycle, 12-pole machine), assuming $u_1=12$ and $u_2=2$ we have, according to eq. (9):

$$x=25\times60\times(18)^2\times12\times(12\times8.1+2\times12.6)/(2\times10^8)=3.55\text{ ohm.}$$

The machine is Y-connected, so that the reactive drop, referred to the line voltage, is $ix\sqrt{3}=37.6\times3.55\times1.732=231$ volt. This value checks well with that obtained above from the short-circuit test.

The number of slots s enters into the denominator of formula (9); therefore, in order to

*See Heaviside, *Electromagnetic Theory*, Vol. I. p. 31.

† This method of calculating the reactance of armature windings is treated more in detail in the author's forthcoming book on *The Magnetic Circuit.*

reduce the reactive drop, it is of advantage to subdivide the winding into several slots per pole. This is recommended particularly for machines intended to operate at comparatively low values of power factor, in which case the reactive drop is especially objectionable. On the other hand, it would be wrong to conclude that the value of x is inversely proportional to the number of slots per pole per phase; with a larger number of slots per pole each slot becomes more narrow, its permeance increases, and a higher value of u_1 must be used in formula (9). This circumstance must not be lost sight of; besides, there are other disadvantages of too many slots, for instance, increased space occupied by insulation, higher current and flux densities, increased cost of manufacture, etc.

(e) The values of u_1 and u_2 used in eq. (9) can be calculated for a given machine by considering the actual paths of the stray flux in the slots and around the end connections. The necessary formulæ will be found in Arnold's *Wechselstromtechnik*, Vol. IV, pp. 41–52 and 298–299.* For more recent investigations, both theoretical and experimental, of the leakage reactance of armature windings see Rezelman, *Analysis of Leakage Reactance*, Electrician (London), Vol. 65, pp. 612 and 652; also in *La Lumiere Electrique* of August 13th, 1910. See also the appendix to R. Goldschmidt's book on *The Alternating-Current Commutator Motor*.

* * *

In the articles which follow, the theoretical considerations contained in the first two essays are applied to the following practical problems:

(a) Voltage Regulation of Alternators.

(b) Phase Characteristics of Synchronous Motors.

(c) Overload Capacity of Synchronous Motors.

*See also Hobart and Ellis, *High-Speed Dynamo-Electric Machinery*, p. 70.

OFFICE BUILDING SWITCHBOARDS*

By D. H. Plank

In designing office building switchboards, it is necessary to consider details that are of no importance in switchboards for ordinary power plant service. The former is usually designed to control certain definite amounts of power, and it is seldom necessary to provide for future extensions. It is possible, therefore, to arrange the various controlling devices symmetrically and compactly, which is not always the case when extensions are to be provided for.

When a switchboard is being designed for office building service, it is frequently necessary to match certain architectural features, thereby adding somewhat to the elaborate nature of the design; at the same time the main objects, utility and convenience of operation, must always be kept in mind and the artistic arrangements should not be allowed to interfere with properly locating the controlling apparatus to obtain these ends.

In order to match the finish usually met with in office building plants, the lever switches, instruments and circuit breakers used on the panels are often given a somewhat higher finish than is usual in ordinary power plant boards.

Usually the electrical connections are arranged for operating generators and feeders in multiple on one set of busbars, although sometimes it is desirable to separate the power and the lighting service, in which case two sets of buses—with double-throw switches for the generators—become necessary.

Figure 1 illustrates a board with one set of busbars, and Fig. 2, one in which two sets have been provided. These illustrations clearly show the type of instruments, switches, and fittings commonly employed.

Knife blade switches of ample proportions for the required service should be used for all capacities. Contact nuts should be of composition metal, to prevent binding on the copper studs, and of such shape and size as to permit the use of a standard wrench for tightening them. Their contact surfaces should be of ample area and carefully finished so as to avoid heating. When laminated bars are used, each lamination should be separated by a contact nut, as with this form of construction they are found to heat less than when separated by washers only.

Circuit breakers should be of the carbon break type and arranged to open both legs of the circuit. Their arms should operate

* This is the first of a series of articles on Office Building Switchboards, the next one will appear in an early issue.

independently, in order to prevent the possibility of their being held in if closed on short circuit. When the device is of this

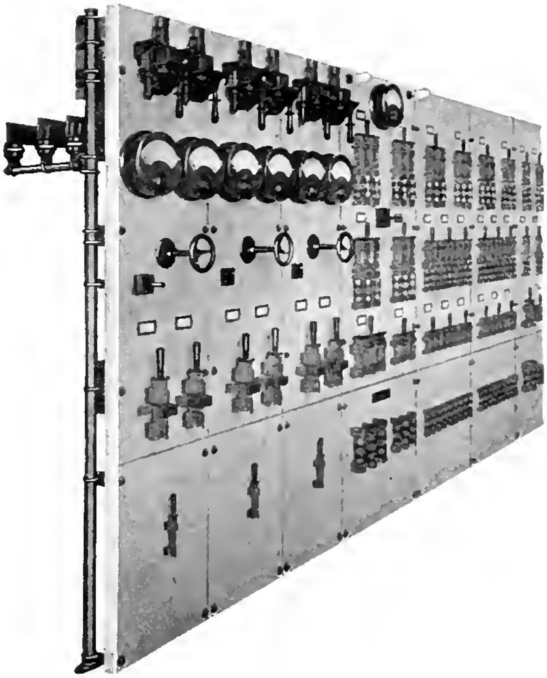


Fig. 1. Switchboard with One Set of Busbars

design, it is unnecessary to have a switch in series with it. In selecting circuit breakers, those should be chosen to which low voltage or shunt trip attachments may be added if desired. This selection avoids the purchase of a new breaker in case it becomes expedient to provide a means for tripping it from a distant point. Also with such breakers attachments can be added at any time for tripping the circuits in connection with time limit or reverse current relays.

The instruments generally used on office building switchboards are constructed on the permanent magnet dynamometer principle. They are high grade, and not being frequently subjected to short circuits, retain their accuracy indefinitely. In cases where instruments may be exposed to stray fields resulting from frequent short circuits, it may be advisable to select a type in which the action does not depend on a permanent magnet.

Two types of voltmeter switches are in general use. Figure 3 shows a radial type of switch with contact similar in construction to the brushes on a circuit breaker. The contacts of this switch are mounted behind the board, and the handle and numbered dial plate on the front. From the illustration it will be seen that for a large number of points the diameter of this switch becomes undesirably large. In Fig. 4 a type of voltmeter switch is shown which is more compact and an improvement in design over the rotary type just described. This switch consists of a number of small knife switches operated by push buttons and therefore is not dependent on the pressure of a spring for contact. The push buttons are interlocked, permitting only one circuit to be thrown on the voltmeter at a time. Each button is also provided with a holding-in device, so that in operation

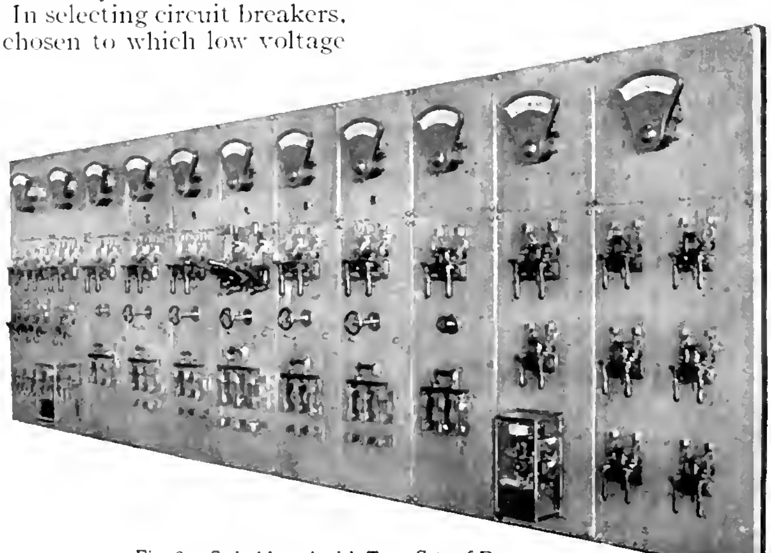


Fig. 2. Switchboard with Two Sets of Buses

the voltmeter can be left on any circuit continuously, or a number of readings can be rapidly taken by simply pressing successive buttons. The compact design of this switch is evident when it is considered that the push buttons are spaced on $\frac{7}{8}$ in. centers.

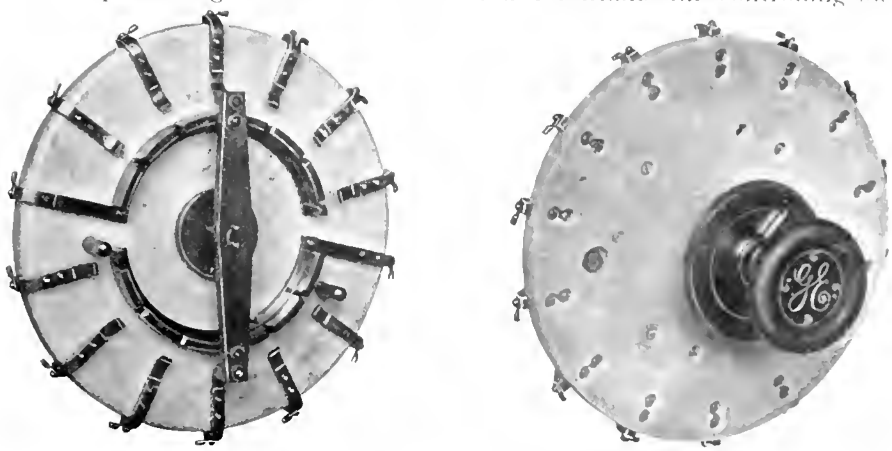


Fig. 3. Radial Type of Voltmeter Switch

Where circuits of high current capacity are to be controlled, or where the most desirable location for the switchboard is not sufficiently near the center of distribution, electrically-operated switches, located at the most economical or desirable points, can be used for opening and closing the circuits. With this arrangement the switchboard contains the controlling switches and the indicating instruments for the several circuits, while the main switches are mounted on a separate board at some distance from the main control board.

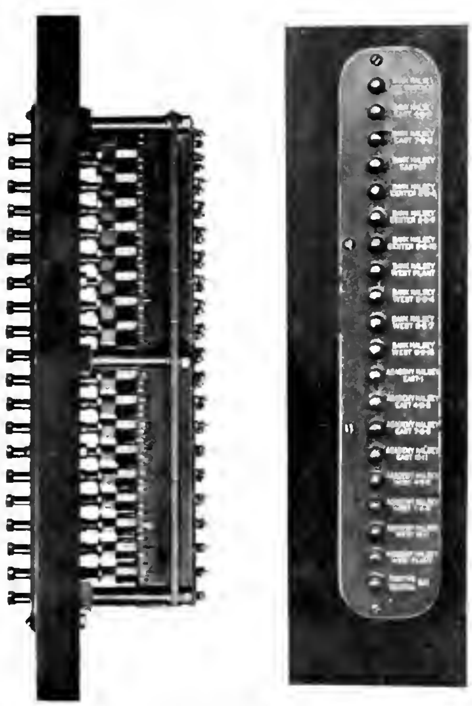


Fig. 4. Push Button Voltmeter Switch

Fig. 5 shows the type of solenoid operated switch or circuit breaker used on such an arrangement. The control switches for these breakers are of the pull button type.

Circuit breakers of this type are frequently used for controlling three-wire generators with double series fields. By locating the circuit breakers at the generator and connecting them between the armature and the series fields, it is possible to reduce the number of main cables going to the switchboard. For large machines the saving in cable and ducts effected by this arrangement is an item worth considering.

By using solenoid-operated circuit breakers, it becomes possible to contract the controlling switchboard into a very small space, as it is only necessary to provide room for comparatively small control switches and the indicating instruments for the several circuits. Such switchboards are usually of the benchboard type and consist of an inclined panel or bench on which the control switches and indicating lamps are mounted and a vertical section, on which instruments for the various circuits are located. This type of switchboard is very compact, and makes it possible for an operator to control and regulate conveniently a much greater number of circuits than would be possible if a vertical type of board were used.

Most office building installations are of sufficient size to make it economical and desirable to provide low voltage service for operating bells and annunciators throughout the building. The construction of switchboards for controlling such circuits should be of the same high class as the main power boards.

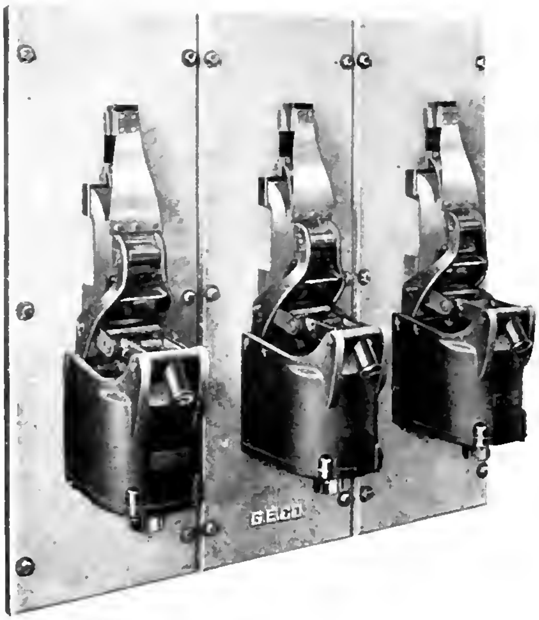


Fig. 5. Solenoid-Operated Circuit Breakers

It is frequently the practice to end all cables in a pull box at the top or bottom of the board, the connections from switch studs to the cables being made with copper bars ending in suitable terminals in the pull box.

A symmetrical arrangement of buses, connections and wiring on the back of the panel is usually met with in these installations. Fig. 6 shows a board on which all switch studs are extended so that the connecting cables can be brought straight down to the switch terminals without bending. This makes a very neat arrangement, but from a manufacturing standpoint it is undesirable inasmuch as it is necessary to make all studs of special lengths, and for this reason it is not possible to use standard switches taken from stock.

Another arrangement consists in using switches with standard length studs and bending the connection bars where necessary. Formerly there were serious objections to such an arrangement as it entailed the employment of bolted or soldered joints; these have now been entirely removed by the introduction of machine-made edgewise bends and twists, which make it possible to manufacture extremely complicated connection bars in a single piece. This is a new feature in switchboard construction and does away with objectionable bolted contacts, which should be avoided for electrical reasons as well as for the sake of appearance.

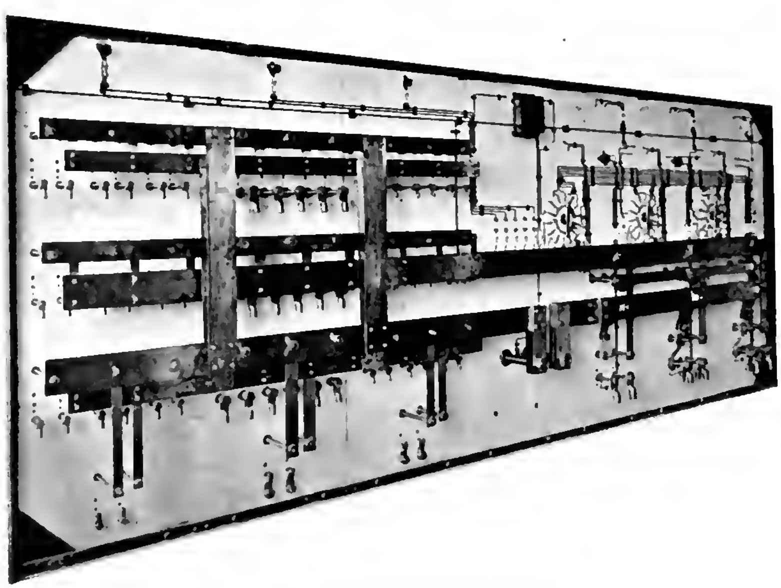


Fig. 6. Rear of Switchboard with Extended Switch Studs Showing Straight and Usual Method of Running Small Wiring

STORAGE BATTERIES IN SWITCHBOARD WORK

PART I

BY D. BASCH

General

Secondary or storage batteries are devices which transform chemical energy into electrical, and whose energy can be restored again after having been exhausted. The unit of batteries is the cell containing positive and negative electrodes and an electrolyte. The voltage of the cell is a function of the electrochemical properties of the materials used for electrodes and electrolytes, and is independent of the size of the cell; the current capacity on the contrary, is approximately proportional to the surface of the electrodes that is submerged in the electrolyte.

Lead Batteries

The commercial storage battery mostly used is the lead type, containing as the positive electrode lead peroxide—a dark brown, chocolate-colored material, about as hard as soap stone; and as the negative electrode, sponge lead—which is gray in color, and so soft that it can be cut with a fingernail. As electrolyte diluted sulphuric acid is employed. The positive electrode is the portion of the battery from which the electric current passes into the load circuit; it returns to the cell through the negative. Inside of the cell the current starts from the negative electrode towards the positive, so that the negative electrode really has a higher potential than the positive. When a battery is connected to an outside load circuit, it will give out, as the result of an electrochemical action between electrodes and electrolyte, a certain current, depending upon battery voltage and load resistance and limited only by the internal resistance of the battery.

This process is known as discharging the battery. When discharging, both electrodes are changed in part to lead sulphate (white—hard and brittle—non-conductive) by taking the sulphuric acid component, or radical, out of the electrolyte. As more and more of this sulphuric acid radical is removed from the electrolyte, its conductivity is reduced, and as the electrodes are covered more and more with lead sulphate, the e.m.f. of the battery decreases. During the discharge, hydrogen is freed in the electrolyte and forms an electro-positive element around the negative electrode, causing an internal counter e.m.f. opposing the voltaic e.m.f. of the battery and decreasing the discharge voltage.

When after discharge an external source of current is connected to the battery and current is sent through it in the opposite direction to that taken by the discharge current, the electrochemical process of the discharge is reversed the lead sulphate formed on the electrodes is changed back to lead peroxide on the positive and reduced to sponge lead on the negative. The acid that during the discharge was taken out of the electrolyte for the formation of the lead sulphate, is returned to it and the battery is restored to the same state as before the discharge took place; i.e., it is charged. During the process of charging, the lead sulphate on the plates is changed to active lead and lead peroxide, the density of the electrolyte is also increased as the acid is returned to it and the battery e.m.f. increases. The added acid also decreases the internal resistance.

The input during charge must be somewhat higher than the output available at discharge—the efficiency of a battery, on account of heating and gassing, being between 85 and 95 per cent. Furthermore, the internal counter e.m.f. due to hydrogen does not oppose the passage of the current during charge as it does during discharge—the charging voltage must therefore be correspondingly higher than the required discharge voltage, in order to bring the latter up to a point sufficient to compensate for this counter e.m.f.

Storage batteries are rated in ampere hours discharge. The rated capacity varies with the duration of the discharge, being greater for slow discharge and smaller for a fast one. The slower the discharge the better the opportunity for circulation of the electrolyte, and consequently the better the opportunity for the stronger acid to come into intimate contact with every particle of active material. There is also better dispersion of the polarizing gas.

Electrodes

The electrodes of lead batteries are made in two different types, one the so-called "formed" or "Planté" plate and the other the "pasted" or "Faure" plate. In both the body consists of pure lead, but in the formed plate, the active material (lead peroxide and sponge lead) is formed electrochemically on the surface of the plate body; while in the pasted plate the active material is first deposited mechanically and afterwards subjected to the forming process.

The distinguishing operating features of the two types are the following:

The formed plates have an exceedingly long life when not subjected to a state of partial or complete discharge over a great length of time; they may be charged and discharged several thousand times and retain their capacity and mechanical strength. The life of pasted plates is limited to a considerable extent by the number of charges they receive; they will give more capacity for the same weight than the formed plate, however.

Aside from the characteristics resulting from the method of obtaining the active material, the positive plate in a cell has a much shorter life than the negative.

During the latter part of the discharge especially a local action is set up between the active material and the underlying lead of the positive plate, changing both the active material and the support lead to lead sulphate. This results in a "growth" of the plate and in distortion, which dislodges active material. The average life of a positive plate that is regularly charged and discharged is about four years. With negatives plate there is little local action, but there is a shrinkage of the material and a capacity decrease due to a gradual loss of porosity in the sponge lead.

Electrolyte

The conductivity of the electrolyte is dependent upon the amount of acid present, decreasing as the battery is discharged and increasing during the charge. It also is influenced by temperature, increasing as the latter rises.

The specific gravity of the electrolyte depends upon the amount of acid present, and on the temperature; it is therefore a function of the conductivity of the electrolyte, and, aside from temperature variation, is a direct indication of the state of charge and discharge.

Installation in Station

Batteries must be installed in rooms which are well ventilated, dry and of moderate temperature.

The individual cells are placed in sand trays; one tray per cell for the larger type, and one tray for five or six cells for the so-called "two plate" cells, those having one positive and one negative plate. These trays are mounted on insulators and then placed on wooden racks, in one or more tiers, according to the size of the battery and space available. Plates, spacers or separators and the electrolyte are then put in the cells, care being taken to see that the elements, with separators and plates in place, are not exposed to air without electrolyte any longer than absolutely necessary. When the electrolyte is in all the cells, glass covers are to be placed on top of the plates to prevent impurities et cetera from dropping into the cells. Adjoining cells are then connected together (the positive terminal of one to the negative terminal of the next) by means of bolt connectors, each consisting of two lead covered nuts and one brass stud. Where connections must be made from one tier to another, or between cell groups that

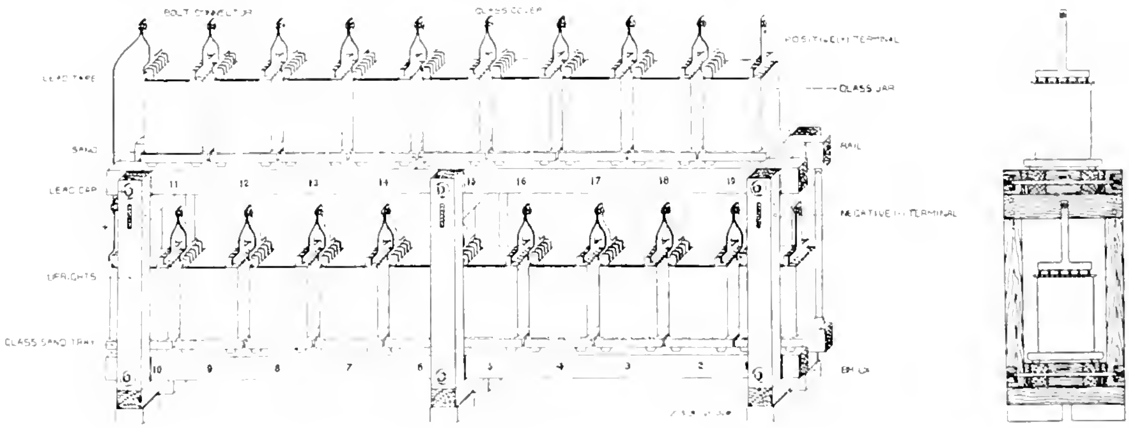


Fig. 1. Typical Installation of Storage Battery on Wood Rack

are separated from each other by a space, lead tape of suitable dimensions should be used in preference to copper cable.

At the two ends of the battery, end terminals are furnished for the connections to the switchboard. Terminals should also be provided for any intermediate taps.

Fig. 1 shows a common form of battery installation with all the individual parts. In general the racks should be so placed that they are easily accessible, but not where direct sunlight will fall on the cells; if this cannot be avoided the windows must be painted or whitewashed. No bare iron or copper should be installed near the battery; where the use of these metals cannot be avoided, they should be painted with asphalt paint, as should also all woodwork.

Initial Charge

After completing the installation, the battery must receive an initial charge before it can be put into regular service. The duration of this charge should be approximately 45 to 55 hours at the normal charging rate, or its equivalent in ampere hours. The charge should be continuous, until, with all cells "gassing" freely, the specific gravity and the voltage show no rise over a period of 10 hours. If, however, the temperature in any one cell reaches 100 degrees Fahr., the charging rate must be reduced or the charge temporarily stopped.

The specific gravity method for determining the condition of cells in course of charge or discharge is recommended as being superior to the voltage method, as the cell voltage varies with the charging rate as well with temperature and with the age and condition of the plates, whereas the specific gravity is nearly independent of the rate of charge and is, in fact, an accurate ampere-hour meter. This method, however, has the disadvantage that the hydrometer which is used to determine the specific gravity, is not always easy to read, and that it is necessary to make a trip to the battery when readings are to be taken.

Where batteries are inaccessible or the cells very small, the specific gravity method is often impracticable, and voltage readings are relied on solely; but in general it is strongly recommended that both methods be used as mutual checks, with the specific gravity method as the principle indication. Even where conditions are such that this method cannot be used regularly, occasional specific gravity readings should be taken as a check.

As has been said the specific gravity is affected by temperature, and allowances must be made for temperature variations. With the help of a thermometer this correction is taken care of without difficulty, all readings being reduced to a standard temperature of 70 degrees Fahr. by adding one point to the specific gravity reading for every three degrees above this temperature, and subtracting one point for every three degrees below it.

Operation

The most important feature during regular operation is the charge. There are two kinds of charges the regular charge and the overcharge. The former is intended to restore the capacity of a battery after discharge; the latter is given at regular intervals, about every two weeks, and carried to a complete maximum for the purpose of equalizing all cells (some of which may have fallen behind the others due to loss of active material etc.) reducing all sulphate, and keeping the plates in general good condition. For the regular operation of a battery, it is not necessary to take readings on all of the cells; it is sufficient to select a so-called pilot cell on which readings are taken to represent the rest. When batteries are charged or discharged in more than one series, a pilot cell should be selected in each, as the various series are apt to work differently and thus need separate watching. Charging should, wherever possible, be done at or near the normal rate; i.e., equal to discharge current for 8 hour discharge. If it is necessary to shorten the time of charge, the rate may be increased to an amount not over 40 per cent above the normal rate, but in this case the rate should be reduced to normal towards the end of the charge, as otherwise gassing would be excessive. Lower rates than normal are objectionable, because the indications of the completion of charge are not nearly so well defined and the battery is more liable to overcharge or undercharge.

Overcharge

The overcharge is continued until specific gravity and the voltage do not show any rise for five consecutive readings 15 minutes apart. All cells will then gas freely.

Regular Charge

The battery is charged until it has come within three to five points of the previous overcharge maximum, or until the voltage is from 0.05 to 0.1 volts per cell below the maximum. After the completion of the charge and with current off, the voltage will fall rapidly to about 2.05 volts per cell, falling to 2 volts when the discharge is started.

This decrease is due to the counter e.m.f. of the hydrogen.

Discharge

It is not advisable to discharge a battery too far, as the coating of non-conducting lead sulphate formed on the electrode plates during discharge would grow very thick and oppose a considerable resistance to electrochemical reduction during charge. In general, the voltage should not be allowed to fall below 1.75 volts per cell with current at normal rate, and the specific gravity should not decrease more than 35 points during whole discharge.

Withdrawal from Service

If a battery is to be shut down for any considerable length of time, e.g., for several months, it is recommended that the battery be taken out of service. For this purpose, after a thorough charge, the electrolyte must be syphoned out of the cells; the jars are then filled immediately with fresh pure water which is allowed to stand from 12 to 15 hours and then drawn off again. The cells can then stand idle indefinitely.

(To be Continued)

ENERGY LOST THROUGH CORONA ON EXTRA HIGH VOLTAGE ALTERNATING CURRENT LINES

Part II

By Dr. C. P. Steinmetz

Measurements of corona losses, or losses by the glow discharge from a high voltage conductor, give a curve of about the shape shown in Fig. 5.

Up to a certain voltage there is practically no loss, but above this voltage the curve turns very sharply, forming a "knee" and continuing with increasing steepness. This is the critical voltage at which the loss begins and beyond this point the loss increases very rapidly. The problem is to find out the value of the critical voltage and what the loss is beyond it. The simplest method of determining the critical voltage—the voltage where corona formation begins—is to gradually raise the voltage between the wires in perfect darkness and watch for the beginning of luminescence. At first sight this appears to be a rather crude method, but in trying it we find that the point where luminosity begins is marked extremely sharp, and we can measure that point between where the wire is perfectly dark and where it is luminescent, within a fraction of one per cent.

There is one method which is really most convenient for measuring the critical voltage of the beginning of luminosity; as soon as the critical voltage is reached—as soon as the insulating air begins to break down—the air is conducting. Now the air retains its conductivity, at least to a slight extent, for quite an appreciable time. If, therefore, the conductor is enclosed and air passed slowly by the conductor and over the electroscope (a gold leaf suspended against a metal plate, which, when electrified, moves away from the plate), the critical point can be determined. Such an electroscope is charged, and the air from the conductor in passing over the electroscope discharges it, because the air is slightly conducting. By this method we can measure very accurately the critical voltage where corona begins, and the values obtained

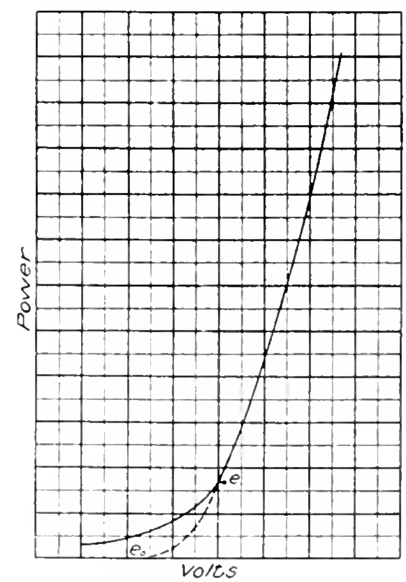


Fig. 5

in this manner check very closely with those obtained by watching the line for luminosity.

In measuring the losses by wattmeter and plotting the values against voltage as abscissæ, we get the full line curve of Fig. 5. We should expect, from observation of the wire, that the curve would go directly down to zero, from the very sharp point where air begins to conduct; but, as is shown, the curve slopes for a considerable distance at very low values of loss. To measure the critical voltage the point where the curve bends up abruptly must be determined. Take the point e on the curve where the bend is: this point does not correspond to the correct value of the voltage, theoretically, but to obtain this value we should produce the curve downward until it intersects the axis of abscissæ at e_0. This we could do if we knew the law of the curve, and this method of obtaining the value of the critical voltage would therefore be rationally correct. Now suppose we plot the curve in a slightly different manner; plotting voltage between lines as abscissæ, but not the power in watts or kilowatts as ordinates but the square root of the power. Then we get a curve like that of Fig. 6, the upper part of which is a straight line. Where we have a straight line we can produce it to zero and thus get the critical voltage.

Now it appears, from the tests made so far, as very probable that the curve plotted between the voltage and the square root of the power loss by corona is a straight line going through the zero line at some critical voltage—the critical voltage where corona begins. The

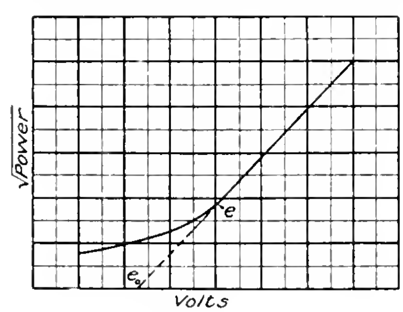


Fig. 6

square root of the power is proportional to the excess voltage over the critical voltage: the power, P, consumed by the corona is proportional to $(e-e_0)^2$, e being the voltage of the line and e_0 the critical voltage; or $P = c(e-e_0)^2$. This brings the determination of corona loss back to the determination of two constants, the constant c, and e_0, the voltage at the beginning of corona. Now the factor c is, or seems to be proportional to the frequency within a wide range; so that by writing $P = af\ (e-e_0)^2$, we eliminate the frequency. How the constant a varies with the different conditions we do not know, but it is quite probable that it does not vary much, and is at least approximately constant. It does not depend for its value on barometric pressure, altitude, size of wire nor distance apart of wires, though it does seem to vary with the degree of purity of air. If there is dust, smoke, fog, snow or any other foreign material in the air which could absorb energy by charge and discharge, constant a is increased more or less; but with air free of dust or other matter it is quite probably constant. However, the truth of this assumption requires further investigation. Quite likely we have enough experimental data to decide this question, but we have not reduced it to a definite conclusion.

The critical voltage depends upon the size of the wire, the distance between the wires, and also upon temperature and barometric pressure; at least barometric pressure enters as a proportionality factor; that is, the disruptive strength of air—the electrostatic or saturation density—is proportional to the air pressure.

All tests check with extreme closeness in so far as they show that the beginning of the corona formation gives $\Psi = Ce_0$ for same size of conductors at various distances; which means that e_0 (critical voltage) $= \dfrac{\Psi\ (\text{constant})}{C\ (\text{capacity})}$.

The electrostatic gradient, or the voltage per inch at the conductor at which the breakdown begins, is the same regardless of the distance between the wires; consequently, if we know the critical voltage e_0 for a given size of wire at a given distance from the return wire, we can calculate the critical voltage for other distances. The voltage varies as the capacity in such a manner as to give the same potential gradient g at the conductor as before. Following this matter further, we get $g = \dfrac{e}{r\lg\frac{s}{r}}$, where s is the distance between conductors and r the diameter of the conductor.

The law of variation of the critical voltage with variation in distance between conductors is the same law as that by which the capacity or the reactance of the circuit varies as the distance between conductors.

Now then, the next question is to determine the variation in the critical voltage e_0 with the variation in size of wire. If we have the size of the wire and know the potential gradient, the breakdown strength of air can be calculated from the observation of the critical voltage at a given distance between the wires. We can then calculate the critical voltage for other distances between the same wires.

We say air has a definite breakdown strength or saturation density; that is, at an electrostatic stress of 70,000 volts per inch, air breaks down. This fact should give us the gradient g as 70,000 volts per inch, and if this value were correct for all cases it would be very easy to calculate e_0, the corona voltage. This would then be simply $e_0 = 2\ rg\,lg\frac{s}{r}$. However, if we determine this value experimentally for conductors of different diameters we find that with decreasing size of conductor, g apparently increases and the disruptive strength of air for smaller conductors is greater than for larger conductors. If we calculate the disruptive strength of air in volts per inch for different sizes of wires from the observation of corona formation, we get values as low as 70 kilovolts for very large conductors, and as high as 200 kilovolts for very small wires—probably higher for still smaller wires. This means that either the disruptive strength of air is not constant or that in our premises we are wrong in some manner.

Now it is not really rational to assume that air should have a different breakdown strength in one place from that in another. It is not so with mechanical breakdowns; the material is always of the same strength, no matter whether of large or small section. The reason why very small conductors give an abnormally high apparent disruptive strength of air is a point which is not yet sufficiently clear. One explanation for this phenomenon, which originated from observation of striking distances between a pair of plates and the voltage required to jump a spark between them, is as follows: We find that where the electrostatic field is uniform, the voltage is proportional to the distance, as we should expect; twice the distance requires twice the voltage to strike. If it requires 70,000 volts for one inch, one-half of 70,000 volts, or 35,000 volts, is necessary for one-half inch; but when we come to extremely small distances we find that it takes a higher voltage proportionally to strike across—that apparently the disruptive strength of air is higher for very small gaps. This is accounted for by assuming that the air in immediate contact with a solid body is not at ordinary pressure but at a higher pressure—the body is surrounded by an atmosphere of condensed air. The disruptive strength of air is proportional to pressure, and consequently, if the body is surrounded by a layer of air at higher pressure we should expect that a higher voltage would be required to break it down. When we come to a short distance where practically the entire gap consists of air at a higher pressure, caused by this atmosphere of condensed air, a voltage corresponding to the disruptive strength of air and the higher pressure which exists in immediate contact with the surface would be required. Assume this to be the case with the conductor of a transmission line: then picture that conductor surrounded by a layer of air at higher pressure than normal. If now the rise of voltage reached the critical potential gradient of 70,000 volts per inch at the surface of the conductor, there would be no breakdown—not until we had the critical density of 70,000 volts per inch at some distance away from the conductor. From this reasoning we could expect that the point where breakdown occurs when the critical density is reached is not at the surface of the conductor but at some finite small distance from it.

The formula corrected for this condition was given by Professor Ryan in his paper, to which I have already referred. It is

$$g = \frac{e}{2(r+d)lg\frac{s}{r}}$$

This equation checks very well with observations; that is, it gives a constant gradient g, or constant voltage per inch at which the corona begins, for all diameters of conductors down to about 1/4 inch. For still smaller conductors, this formula does not hold good, for the gradient rises higher and higher. While a 1/2 inch conductor gives, when corrected for this atmosphere, 40,000 to 70,000 volts per inch, a conductor of 1/10 inch diameter will increase the potential gradient at the beginning of corona to about 150,000 volts.

We can apply still another reasoning: Assume a thickness of air of 1/10000 inch surrounding the conductor, and a gradual rise of voltage between conductors until the breakdown gradient of the air is reached (approximately 70,000 volts per inch at the surface of the conductor); the air will be broken down—will be in a conducting state—but that does not mean that current will flow. Gas subject to high enough voltage will conduct, but it requires a certain critical voltage before conduction begins, and the law of conduction does not follow Ohm's law.

The effective resistance of a gas is a function of the current density, so that when very low current densities are reached in gas conduction, the resistance of the gas becomes extremely high, approaching infinity for zero

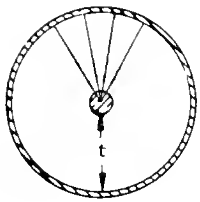


Fig. 7

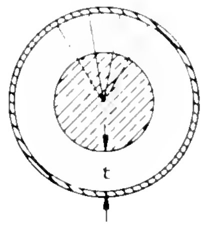


Fig. 8

current density. With this principle in mind, we will again assume a conductor surrounded by a thin layer of air; this air is broken down and is conducting, which means that current would tend to flow rapidly through this layer of air from the conductor, discharging it, and equalizing the potential gradient in this layer; but since the layer of air is extremely small, the actual voltage across it is also very low. The resistance, however, is extremely high—nearly infinite—with the result that no current flows. It probably requires a finite volume of gas before conduction can take place—before current can flow—and it is quite likely that with rising voltage the air breaks down electrostatically at the conductor when the voltage passes its breakdown strength; but nothing happens, no luminosity occurs, no current flows, until the broken down area has reached a certain distance from the conductor—a distance large enough so that the current density of the discharge across the conducting area is sufficient to make the current flow with the limited available voltage.

From this point of view, which appears reasonable from a consideration of gas conduction, it would seem that corona formation begins, not when the disruptive strength of air has been reached at the surface of the conductor, but when the disruptive strength of air has been exceeded over a finite volume up to a finite distance from the conductor; in other words, not that the voltage gradient at the conductor must be beyond 70,000 volts per inch, but that the average voltage gradient within a small area must exceed the critical voltage.

From the relations between the diameter of the conductor, the distance between the return conductor, and the average voltage gradient in a zone t surrounding the conductor, we get another expression, $g = \frac{e \lg(1 + \frac{t}{r})}{2t \lg \frac{s}{r}}$

We find that we get a constant gradient g, or one that is very nearly constant, for all sizes of wire, with the exception of the very smallest. For extremely small sizes of wire—less than one millimeter or so in diameter—we get a variation.

This formula checks with constant potential gradient of air and constant saturation density down to the very smallest size of wire. For very small sizes of wire we find that the saturation density where breakdown begins gets lower, not higher. For wires down to one or two millimeters in diameter, the value is 70,000 volts per inch; for smaller wires the breakdown gradient drops to 60,000, 50,000 or 40,000 volts per inch—possibly down to zero for infinitely small wires.

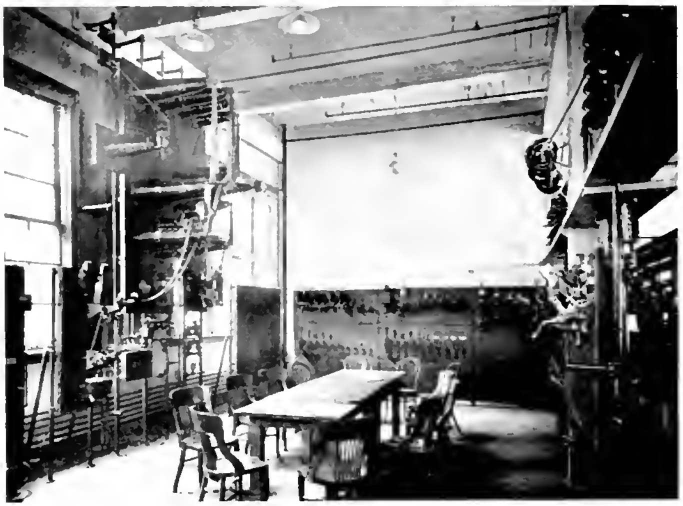
I believe that this variation in the value of the breakdown voltage can be explained by going back to the reasoning which led to this formula. The formula is based on the nature of gas conduction; that is, the rising resistance of the gas with decreasing current density, which statement means that a finite volume of gas has to be broken down. Take the example of current between two concentric cylinders (Fig. 7): the elements are conical and when corona finally begins the current density is not uniform in the broken down space, but becomes very high near the conductor. With the conical section it is reasonable to assume that, since resistance goes down with current density, the current will be lower within the space of uniform section. If this is the case, we should expect that, as soon as the variation in that space becomes very extreme, those laws would fail to hold—that the distance t would have to be decreased for very small conductors. t is constant only so long as the outer and inner values of current are nearly the same; when these values are very different t gets smaller.

In the investigation of corona losses we have so far reached the constant by which loss is measured, although further investigation is necessary to find out the extent of variation of the different factors.

THE SWITCHBOARD DEPARTMENT

By D. S. Morgan

Although until comparatively recent years the switchboard did not receive anything like the attention its importance warranted, it has now come to be regarded as a very vital point in almost every electrical installation. This is necessarily so because it is actually the key to the operation of the whole station. In fact, one cannot imagine how the great quantities of electrical energy now being constantly developed and concentrated at central points could be applied to commercial use without a switchboard and its control and switching apparatus.



Portion of Conference and Exhibit Room

The switchboard industry, therefore, not only occupies a very important position in the field of electrical activity, but its proper development calls for the same high degree of engineering knowledge and manufacturing ability that obtain in other branches of the art. For obviously, to design a switchboard to control effectively and with safety all manner of generators and receivers of current under their diversified conditions of operation, it is first necessary to know the behavior of such machinery in actual service and the characteristics of the circuits to which it is connected.

The Switchboard Department of the General Electric Company is by far the largest organization of its kind in the world. Its present form is the result of the experiences of many years, so combined as to perfect an organization to accomplish its purpose with the highest possible efficiency.

Owing to its great size and numerous ramifications it would be impracticable to try to give anything like a detailed description within the limits of a single article. No attempt, therefore, will be made to do more than touch upon a few features which seem of interest.

The Department employs over one thousand men and occupies four entire buildings having a floor area of over 190,000 square feet. With the exception of meters, instruments, and current and potential transformers, which are built at the Lynn Works of the Company, everything that goes on the switchboard is designed, manufactured and inspected in this single department; that is to say, the switchboards are actually manufactured and not merely assembled.

The Switchboard Department is organized according to the general plan of segregation or decentralization carried out by the General Electric Company; that is, it is a complete institution in itself. Although separate and distinct from the other departments of the works, yet it keeps in close touch with all of them, because, in order to provide adequate switchboard control under changed or entirely new conditions, it must know what improvements are being made in apparatus and what new developments are under way.

The Switchboard Department is in charge of a manager and is divided into groups of specialists, each group being responsible to a head, who is in turn responsible to the manager.

To give some idea of the organization and its scope, brief mention will be made in the following order of the four engineering groups: research, designing, commercial and requisition engineers.

Research Engineer

The research engineer devotes his time particularly to the discovery of new facts pertaining to switchboard apparatus actually built or in contemplation, his business being mainly experimenting. Apparatus is subjected to endurance tests to reveal faults or merits in mechanical design and construction, and electrical tests are made under as nearly actual operating conditions as possible or practicable. Thus by observation, study and comparison, information is procured which when placed before the designing engineer, materially assists him in the development of new and the improvement of existing types of apparatus.

This procedure benefits the manufacturer as well as the purchaser; the manufacturer knows his apparatus will do what is expected of it, while the purchaser is secured against a product still in its experimental stage.

The long continued success of the General Electric Company as a builder of switchboards is perhaps due to the industry of these research engineers more than to any other cause, for their work means that every element of a switchboard has been subjected to tests corresponding to the most severe emergency conditions which may be met with in operation. Based on these tests the ratings of this apparatus are always very conservative when used under normal conditions.

Designing Engineer

Electrical engineering is continually progressing and what is satisfactory now may in but a short time be entirely discarded. There is no need to confirm this fact. The capacities of stations are annually becoming greater, and control and switching systems become more and more intricate with this increase in size. Besides, since in modern stations continuity of service is a feature of the utmost importance, the entire switchboard must always be above a reasonable chance of failure.

This means that for the designing engineer there is no standing still. He must ever strive to improve in every possible way the apparatus in production and to bring out new types in order to keep apace of development in other lines and to take advantage of the opportunities created by new sources of application.

Therefore, to keep in touch with these varying conditions, the switchboard designing engineer, who is directly responsible for the actual design of switchboard apparatus, works in conjunction with the switchboard research engineers and the experts from the other departments of the company. This opportunity to obtain from the designer, first hand and without delay, full information concerning the action and purpose of machines is very important in switchboard work. Too much stress cannot be laid on the fact that the availability of this expert advice concerning the machinery that the devices are to control and protect, very materially helps the switchboard designing engineer to do his work effectively. He acts also in a consulting capacity and advises the commercial and requisition engineers as to the use of apparatus,

Correspondence and Mailing Room

its location under standard or unusual conditions, and whether in certain specific cases it is advisable to furnish the purchaser with standard apparatus or something special to meet his requirements.

Commercial Engineer

When the prospective switchboard purchaser requests a quotation from the General Electric Company, the commercial engineer makes up a proposal conforming to the specifications, always including sufficient information to show without question just what it is proposed to furnish. The entire proposed equipment, with types, forms and capacities of meters, instruments, fuses, circuit breakers, oil switches, etc., is specified.

When necessary or advisable, drawings made up for this particular proposal are furnished to show the location of apparatus or the wiring arrangement, and sometimes photographs of switchboards more or less similar to the one being quoted on are included. These help the prospective purchaser to form an idea of what his switchboard will look like if furnished by the General Electric Company.

Sometimes, however, it happens that the commercial engineer believes that the proposal made up in accordance with the wishes of the prospective purchaser is not the best arrangement under the circumstances. In that case the commercial engineer also makes up an alternative proposal, which is forwarded

Portion of Proposal Division of Commercial Engineering Section

with the original one, recommending the equipment that seems better suited to meet the conditions of the service. In doing this the commercial engineer explains why he suggests certain changes and how, if adopted, they would benefit the purchaser. Here again, if necessary, drawings or photographs are included to make his points clear.

It may seem unwarrantable to suggest to a purchaser that he does not best know what he needs. This is rather a delicate point. It should, however, be understood that such an intimation is never intended. It is not unfair to assume that, however good the engineer who drew up the switchboard specifications may be and however well acquainted with conditions at large, he positively cannot be informed of all the developments of a large manufacturing company. He may, therefore, occasionally omit some item which it is advisable to include, or call for special equipment to accomplish a certain result when standard apparatus will do the work just as well and at less cost to the purchaser. The wide experience of the General Electric Company in this line of work, gained through handling an enormous number of highly diversified transactions, is always at the purchaser's service and can often be applied to his benefit. For this purpose only are alternate switchboard proposals submitted. The aim is always to make the switchboard as simple as possible and to quote the lowest price comparable with the quality of the product.

Requisition Engineer

Immediately after a switchboard order is received, it is turned over to the requisition engineer. He assumes full charge of the design of the board, issues engineering instructions to the factory concerning it, and thenceforth handles all correspondence, except the matter of shipment, which is taken care of by the production department.

Since it is his responsibility that all material furnished is properly designed to meet the particular conditions involved, and is in accordance with the conditions of the contract, in interpreting requisitions it is often necessary for him to consult with the designing engineer, the commercial engineer who drew up the proposal, and the engineer of the

Portion of Designing and Requisition Engineering Section district office through which the board was sold. In the preliminary instructions to the factory, which are issued within a few days after receiving the requisition, the engineer orders all oil switches, instruments, current and potential transformers, and all other standard material which is not carried in stock in quantities, so that the production of the parts going to make up the switchboard can proceed at once.

The next step is the preparation of drawings showing the assembly of the material ordered on the preliminary notice and the design of special parts, such as connection bars, pipe framework, etc., which may be required. These drawings are made up by the drafting department, following standard practice for the type of installation involved, and before completion are examined and approved by the engineer. As soon as drawings are complete, the factory is advised by additional engineering notices that they should be used in building the switchboard. On the engineering notice is also given a list of drawings to be mailed to the purchaser to be followed in installing the switchboard.

During the construction of the switchboard in the factory, the engineer makes frequent inspections of the work to see that it meets with engineering approval. When completed, the factory foreman is required to obtain the engineer's approval of the board in writing before turning it over for inspection and listing of material for shipment by the shipping department.

Conclusion

Although it cannot as a rule be said that the size of a business determines the quality of the output, it is nevertheless true that when the personnel of an organization comprises the best talent that can be acquired, and devotes itself conscientiously to an improvement in whatever comes under its jurisdiction, the manufactured product must steadily improve. It cannot do otherwise. This will invariably cause an increased demand, with increasing sales, necessitating increased manufacturing facilities and a greater working force.

It must be clearly evident that a continuance of the painstaking and accurate methods now employed will maintain this department in the front rank of switchboard manufacture, where it will continue to give to the purchaser switchboards in their very highest development.

AUTOMATIC CARBON BREAK CIRCUIT BREAKERS

By Charles Hubbard Hill

A device for making and breaking circuit, known as the switch, or perhaps more commonly as the lever switch, has been in use since dynamic electricity has been known.

As the amount of current and the value of the apparatus employed was increased, the necessity for a protecting device against overloads and short circuit became apparent, and although the fuse was introduced for this purpose, it was soon realized that a switch that would automatically open the circuit when the current reached a dangerous value, would be desirable. This undoubtedly accounts for the fact that the earlier forms of automatic circuit breakers were nothing more than lever switches, each provided with an electromagnet to release the latch that held it in the closed position, and some means for throwing it out of contact.

Although the lever switch type of circuit breaker was somewhat unreliable and inefficient, it served to demonstrate the fact that such a device was practicable. It also suggested the lines along which the experiments and investigations were made which have resulted in the perfection of the modern device.

The lever and clip form of contact had the objection that it offered a great deal of mechanical resistance to the opening of the circuit breaker. The efforts to overcome this objection resulted in the development of the laminated brush. This form of contact offers no mechanical resistance to the opening of the breaker and is a most efficient type. The perfection of its design required many months of careful study, not only to work out the various details, but to design tools and machinery for its production. Without doubt, the most efficient form of laminated brush in use today is the one employed with the circuit breaker, as shown in Fig. 1. This brush, while permitting a maximum uniform pressure over its entire surface and a positive contact on each lamination, will not deteriorate even when used for years under the most severe service conditions.

In the earlier forms of automatic circuit breakers, the provisions for protecting the main contacts from the injurious effect of the arc when rupturing the circuit, were very meager indeed; but it soon became apparent that some effective means must be devised for doing this or the life and efficiency of the device could not be depended upon. Perhaps one of the most effective methods for accom-

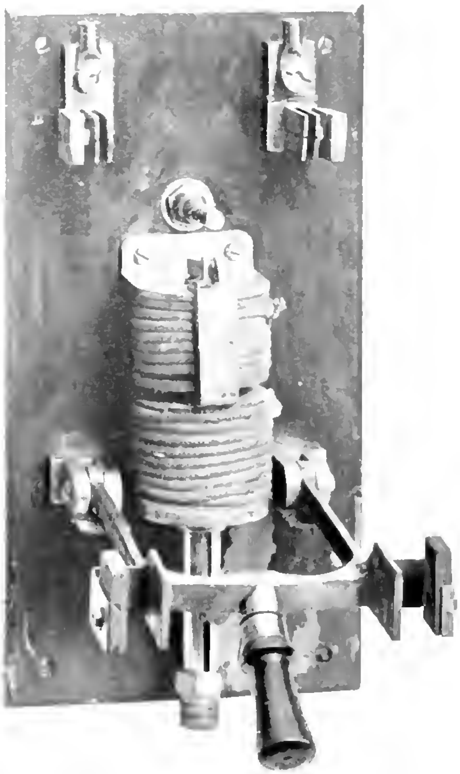


Fig. 1. The Early Lever Switch Type of Automatic Circuit Breaker

plishing this end was the use of the magnetic blowout, the principles of which we are all familiar with. Automatic circuit breakers equipped with this arrangement have been in successful use for years in power stations throughout the world, and this type of breaker will, without doubt, be used for years to come. It offers the only reliable means for opening large amounts of direct current in confined places, such as water-tight boxes for submerged service, or air-tight compartments for service where the arc would cause explosion or ignite inflammable material. Today, however, when the above mentioned conditions do not prevail, the open arc or carbon break circuit breaker is used almost entirely, because its construction is less complicated, it requires less attention, and the amount of energy which it will rupture at moderate voltage is almost unlimited.

Carbon is the only substance now known which is suitable for use in the construction of secondary contacts for the open arc circuit breaker, as it is not easily destroyed by the arc and when properly selected has sufficient mechanical strength to meet the demands of service. However, it has one drawback—its relatively high resistance. The drop due to this resistance would make it necessary to open a portion of the current on the main contact, if it were not for the fact that a third or arcing contact is introduced, which, if properly designed and located, will insure complete protection to the main brush. As is well known, the arrangement of the main and secondary contacts should be such that, in closing the circuit breaker, the carbon secondary makes contact first, then the arcing contact, and last the main contact. In opening the circuit breaker, this sequence is reversed.

While we frequently see circuit breakers mounted low on the switchboard, if we take into consideration the danger to the operator and to the apparatus mounted above the breakers, we cannot but conclude that the proper location is at the top of the panel.

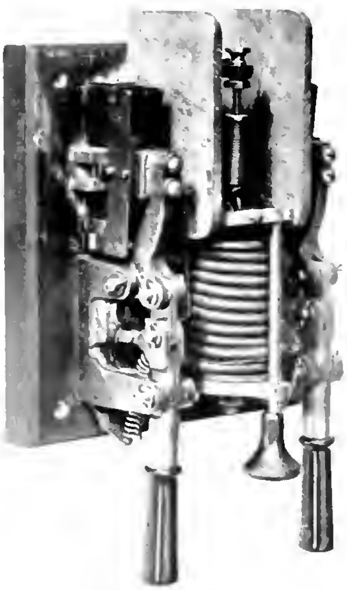


Fig. 2. An Early Type of Carbon Break Automatic Circuit Breaker

This location requires that the circuit breaker be so designed that it will take but a small amount of power to close it, which result is best accomplished by the use of the toggle joint. This joint affords a maximum pressure at the brush with a minimum effort at the operating handle, and also has the advantage

Fig. 3. A Modern Magnetic Blowout Automatic Circuit Breaker

that when the breaker is closed, the pressure on the retaining latch is very small and the power required to trip the circuit breaker is correspondingly small.

The automatic circuit breaker was at first made to take care of overloads or short circuits only, but its scope has been increased to include underload, reverse current, low voltage, high voltage, etc.; also combinations of these conditions, so that now it can best be described as a device which will automatically open the circuit when a predetermined condition exists in the circuit or system in which it is connected.

The modern circuit breaker, like any well designed apparatus, must be properly proportioned in every detail, with allowance for a reasonable factor of safety; therefore, the amount of material in the circuit breaker is by no means a measure of its efficiency. Specifications often call for a certain number of amperes per square inch of cross section; but as this is only one factor in the make up of a proper contact, while others such as pressure, workmanship, etc., may be left out, it means but little. If, however, the specifications called for a certain temperature rise, comparable with that of other apparatus with which the circuit breaker is to be used, a standard would be had which would not only include the proper amount of material, but also the proper adjustment and workmanship.

Present day circuit breakers are called upon to meet a wide range of conditions. They are used on all voltages up to 1200 volts direct current and 650 volts alternating current, with current capacities as high as 12,000 to 14,000 amp., and in addition to the more common hand-operated device, are designed to be operated by solenoids, motors, compressed air mechanisms, etc.

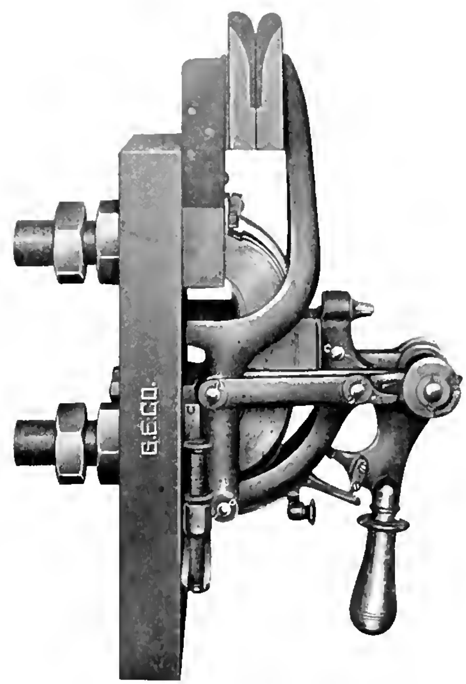


Fig. 4. The Most Up-to-Date Type of Carbon Break Automatic Circuit Breaker

While we may conclude that the fundamental principles of circuit breaker design are more or less well established, nevertheless it is safe to predict that each year will see a marked improvement in the method of their application.

MANUFACTURE OF SWITCHBOARDS, SWITCHES AND SWITCHBOARD APPLIANCES

By T. E. Drohan

To manufacture the immense product of the Switchboard Department of the General Electric Company, an organization of sub-departments has been perfected, wherein every part which enters into the construction of a General Electric switchboard is made and inspected by men particularly skilled in their respective branches of mechanics.

Partial View of One of the Switchboard Assembly Floors

The construction is altogether different from what it used to be in the old days, when a switchboard, so called, consisted of a few switches and instruments fastened to a slate or marble base mounted on a wooden board, with possibly insulated wire or bare copper rod connections on the front.

There has been a gradual change to keep pace with the development of other electrical apparatus until to meet the requirements of the present day, refinements in manufacture have been introduced which are probably not surpassed in any line.

That this statement is not an exaggeration can perhaps be understood only by those who are familiar with General Electric installations, or who have visited the works and seen the numerous processes connected with switchboard manufacture carried on in detail in the various manufacturing sections.

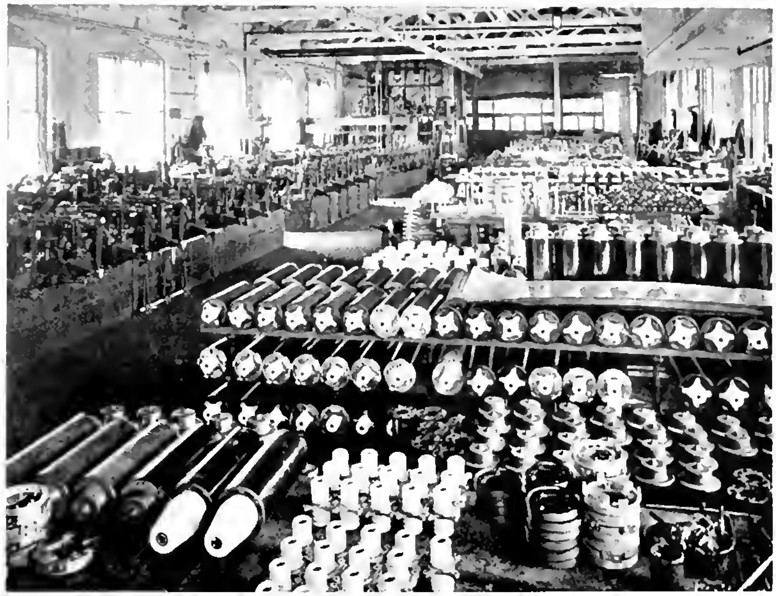
The constant application of new methods has demanded ever increasing facilities, until at the present time the floor space given up to switchboard manufacture covers an area of more than four and one-half acres. The magnitude of the output can be realized when it is considered that in the last year over 11,000 switchboard panels were produced.

In this article the shop equipment and the processes of manufacture are outlined briefly to indicate the degree of specialization applied to the manufacture of the various parts entering into the construction of this class of apparatus.

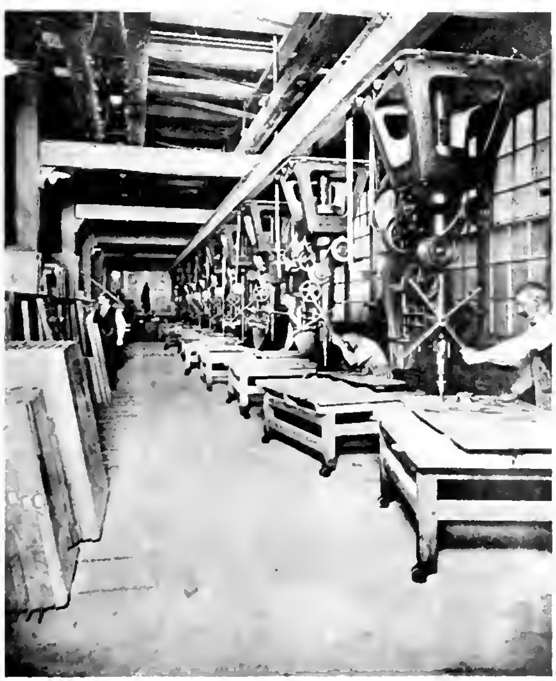
The making of switches, circuit breakers, oil switches, relays, expulsion fuses, entrance bushings, arc deflectors, low voltage releases, shunt trips, tripping magnets, interlocks, as well as indicating and other apparatus, is carried on from the raw material through various founderies (brass, iron and steel) and manufacturing sections, such as drop forge, porcelain, punch press, screw machine, machine tool, acid dip, plating, polishing, japanning, lacquering, instrument, test, and calibration, all of which sections are fully equipped with the most advanced tools and devices, many of which have been specially designed by the General Electric Company. All machinery is driven by individual motors. Every modern appliance is used for the guarding of machine tools and for the transportation of materials between the different sections. Besides, the conditions for workmen are good and the quarters are commodious, well ventilated and well lighted.

In each section there is a store-room in which the component parts of each piece of standard apparatus made in that section, with all or part of the machine work completed, is carried in stock.

The amount of stock so carried, is regulated by a card record system of maximum and minimum amounts. These amounts are scheduled by the switchboard production section, based on sales of a previous period and a forecast of probable sales for a like period in advance. There is also one main store room, which contains integral switchboard units, on the same card record system as that in the other manufacturing department store rooms, from which the panel assembly section draws finished parts to build the switchboards and to make up supply shipments as well. Daily or weekly reports are made to show the condition of stocks, so that when they have reached the minimum figure designated on the cards, the section making the facts is automatically notified to proceed to manufacture integral units again to bring stocks to the maximum authorized. This keeps the manufacturing departments at all times in touch with sales, and is a continual record of the activity of the various articles. Work is authorized by shop orders to which all labor and material is charged, so that accurate costs are arrived at on every piece of apparatus.

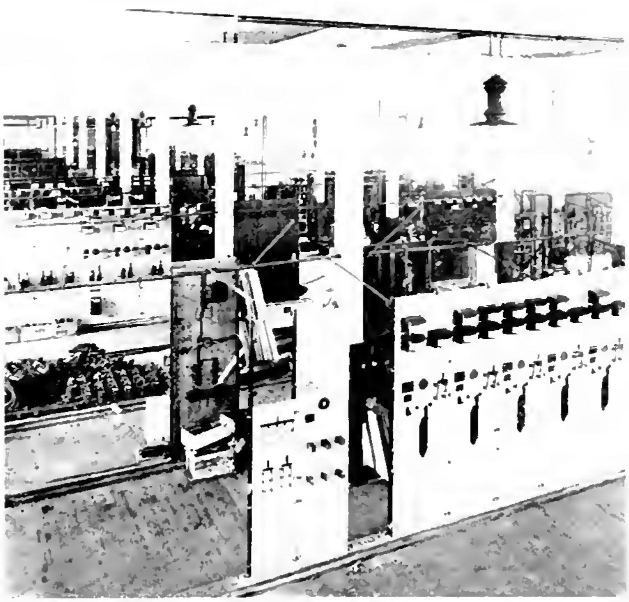


Oil Switch Assembling Floor



Panel Drilling

All the mechanical work in the factory is carried on under the instructions and with the co-operation of the engineers so that each piece of apparatus is the result of the practical ideas of both. Suggestions for the use of new materials, and new combinations of materials, as well as new methods of machining are continually being made to facilitate manufacture and to improve the output. These require and are given a great amount of study and practical demonstration and when of value are adopted. Machining operations are made in special fixtures and jigs to insure accuracy, interchangeability and ease of duplication. Parts are thoroughly inspected by mechanical inspectors and must conform to standard gauge or are rejected. Finished apparatus is inspected by both electrical and mechanical inspectors. All materials used in the manufacture of switchboards is made to specifications giving limits of requirements that must be met, samples of



A Portion of the Switchboard Assembly Floor

which are submitted to the testing laboratory for chemical and physical analyses.

Detailed drawings are made of connection bars. The bars are then made in machines specially fitted for bending, twisting, offsetting, forming, drilling etc. The time-honored custom has been to make flat-wise bends in connection bars at right angles and with short radius. These, however, have a tendency to rupture at the bends and their manufacture has been discontinued. Machines have been designed to make large radius bends in connection with obtuse angles, as well as edgewise bends and twists which eliminate lapping and splicing and make it possible for even intricate connection bars to be made in one piece.

For switchboard construction, slate or marble is now universally used, although marble of pleasing and prominent markings and harmonious shades is very difficult to obtain in slabs of any considerable size, because of the uneven running of the strata in the quarries. For architectural purposes, contrasts are often considered desirable, but in switchboard work this does not obtain. Switchboard panels should match as nearly as possible in shade and marking. Certain shades of marble, however, can be selected to make a large board fairly uniform in color. White marble is very easily soiled. At the present time blue Vermont marble is most in vogue. Marble of any kind is subject to discoloration from dust, acids or oil, and requires a very careful handling during manufacture and great care during and after installation.

Natural black slate is now used to a greater extent than marble. One great advantage of slate is that oil improves its appearance. Slight scratches or abrasions can be smoothed over and made to look as good as ever. Only the best selections from the quarries are used, as it is important that it be of even grain, good structural strength, and high dielectric quality.

Panels are drilled by suspension drill presses, using drills of special form. To insure accurate and rapidity of drilling, steel frame jigs are used to a large extent. When special drilling arrangements are wanted, the drilling layout is first made on paper templates and then transferred to the panels. The slate and marble section contains an elaborate equipment of drill presses as well as sawing and polishing machinery. The work employs a large number of slate workers, marble cutters and polishers.

After drilling, polishing, etc., the panels are delivered to the switchboard assembly floors and mounted on the necessary pipe or angle iron framework. Pipe framework is usually used. This has now been so standardized that a great many combinations of pipes and fittings can be made up from standard parts. Many installations, however, call for other arrangements to suit the local conditions, and these are met by combining standard parts and special fittings to make up the required forms. In pipe framework, welded iron pipe is used with cast malleable iron fittings. A prominent feature of these fittings is that they can be applied without the use of threads, most fastenings being made by special clamping arrangements.

After the panels have been mounted, switches, instruments, etc., are then assembled on the various sections, all small wiring is neatly arranged and held on the back by cleats fastened by screws, screwed into leaded holes. Rheostat mechanisms and insulated busbar supports are put into place. Busbars are mounted and connections are completely made, insuring that all parts are correct, and allowing clearances and alignments to be checked so that after shipment the board can be readily reassembled in its permanent location. The assembling of switchboards in the factory is done by men skilled in this branch of the work.

When the assembly is finished and approved by the engineer, the board is turned over to the switchboard inspectors, who make a detailed inspection and itemized report covering every item required to make the complete permanent installation. A copy of this report is placed in the hands of the shipping department, which systematically checks all the parts listed when packing for shipment.

EQUIPMENT OF A THREE-WIRE GENERATOR PANEL

By G. A. Elder

Panels for controlling compound wound direct current generators operating in parallel must be equipped with automatic protective devices so connected as to instantly and effectively disconnect the machine in the event of any injurious overloads, and should have a switching equipment such that any machine may be connected to live busbars in a manner that will cause the least possible voltage disturbances on the system. It may be said that these principles have been almost universally adopted in the design of panels for two-wire machines, the usual equipment of which is illustrated in Fig. 2. In the case of three-wire generators, however, there still exists considerable diversity of opinion regarding the proper panel equipment to insure thorough protection and successful control of the generators under all operating conditions.

Since a compound wound three-wire generator has one series field connected to each terminal of the armature, two equalizer connections are necessary for parallel operation. The connections existing between two such machines operating in parallel are shown in Fig. 3 and a careful study of this diagram will reveal the following facts, all of which have a direct bearing on the question as to what equipment should be used for controlling the machines.

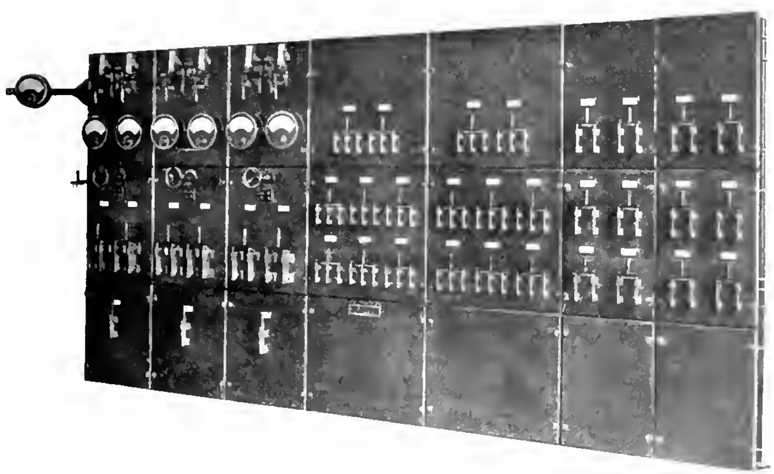


Fig. 1. Modern Direct Current Switchboard for Controlling Three Wire Generators and Feeders

(1) The automatic protective device must be connected between the machine brushes and the equalizers in order that its tripping elements may be actuated by the full armature current and thus fulfill the functions of the device. If placed between the series fields

and the busbars, the device would be actuated by a current sometimes greater and at other times less than the armature current, depending upon the direction in which the equalizing current is being exchanged between the machines.

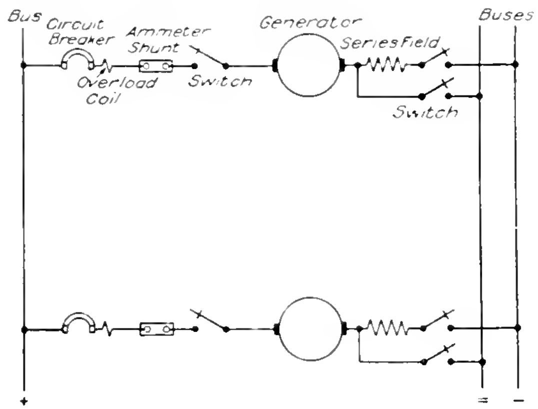


Fig. 2

(2) Owing to the neutral connections, a protective device is required on each side of the armature and the two devices must be interlocked. If the interlock were omitted the compensator for deriving the neutral would be injuriously overloaded due to the opening of the device on only one side, imposing on the compensator the full current of the opposite side of the circuit.

(3) The equalizers are at the full terminal potential, hence, unless the voltage of an incoming machine is fully built up before it is paralleled, all machines running may be short-circuited through the armature of the incoming machine. The series fields should therefore be connected in circuit before the machine is paralleled. The ability to throw in the series field before paralleling not only minimizes the possibility of short circuits from the cause just mentioned, but results in minimum voltage disturbances on the system, and furthermore provides a convenient method for correcting the polarity of a machine if for any reason it has become reversed.

(4) With two overload devices in the main circuit, none is necessary in the neutral lead. Commercial machines are designed to regulate for at least 25 per cent unbalanced current, which is the maximum condition for most well designed plants. In the few cases where unbalancing is anticipated in excess of the limits for which the machines are designed, the compensators may be most economically protected by installing in the neutral lead of each generator an overload relay arranged either for tripping the main circuit breakers or for operating an alarm device. An overload circuit breaker should never be used in the neutral busbar for the reason that the operation of such a breaker at times of severe unbalancing might result disastrously to the connected three-wire load.

(5) It will be seen that two ammeters are required in order to indicate the current on each leg of the machine and also that these instruments must be connected between the brushes and the equalizer connections in order that they may register the total load on the machine. The two ammeters afford a ready means of determining at any time the degree of unbalancing which may exist. The practice of using but one ammeter connected in the neutral is objectionable, as it gives no indication of the load on the machine.

In view of the facts just mentioned, no doubt should remain as to the equipment required for the three-wire generator panel; the simplest one that will afford adequate protection and proper switching facilities being as follows:

Two ammeters.

One double-pole double-coil overload circuit breaker with independent operating arms.

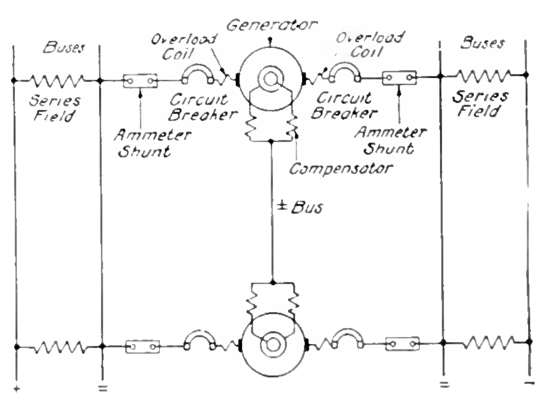


Fig 3

Two double-pole single-throw lever switches (main and equalizer.)

One single-pole single-throw lever switch (neutral.)

One single-throw potential switch for connecting the machine to a station voltmeter.

One field rheostat operating mechanism.

Since three-wire machines maintain equal voltages on both legs within the limits of unbalancing for which they are designed, it is not necessary to provide any means for measuring the voltage between outside leads and neutral. The potential switch may, therefore, be single-throw.

Figs. 1 and 4 show respectively a front view and a wiring diagram of a panel equipped as above. The sequence of operations in paralleling a machine would be: (a) start with all switches and breakers open; (b) throw in the series fields by closing the two double-pole switches and adjust the machine voltage; (c) close the circuit breaker one pole at a time so that in the event of closing on trouble one pole will be free to trip when the armature circuit has been completed; (d) close the neutral switch.

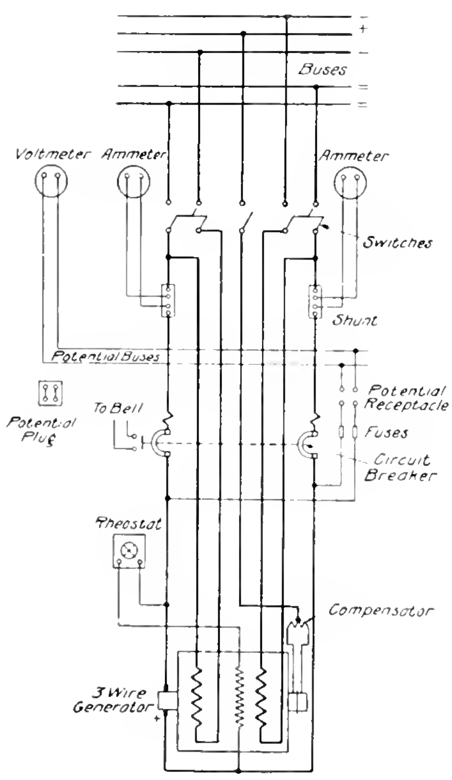


Fig. 4.

It will be noted that the circuit breaker in the above equipment does not have any auxiliary device for automatically breaking the equalizer connections at the same time that the main circuit is broken. It is true that without such a device a small voltage disturbance is caused by the opening of a generator breaker, owing to the series fields

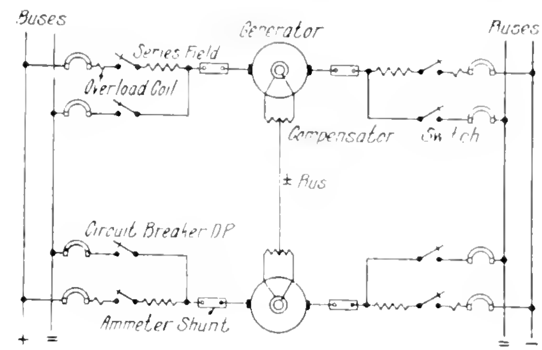


Fig. 5.

of the disconnected machine remaining in multiple with those of the machines running. For several reasons, however, the added complication and expense of such a device is seldom justified. These reasons are as follows:

(1) The voltage variation is small and of short duration, lasting only for the time consumed by the operator in opening the equalizer switches.

(2) Short circuits and similar troubles usually occur on the feeders and are taken care of by the fuses or breakers on those feeders. When trouble is severe enough to trip out the generator breakers also, it will generally trip all the breakers. The possibility of one set of generator breakers opening is therefore very remote.

(3) Such a device has never been considered necessary for two-wire generators, the operating conditions of which are exactly analogous.

It will be noted from Fig. 1 that seven leads are required between the generator and the panel, provided that all of the equipment is mounted on the panel. The consequent expense of the cable required may therefore be raised as an objection to the above equipment. Other equipments which require only five leads to the panel are possible (Figs. 5 and 6), but the saving accomplished is very small in comparsion to the cost of the entire installation, and by no means compensates for the risk of damage incurred in using an inadequate equipment. Due to the fact that in order to use less than seven cables it is necessary to have the circuit breakers for the main leads connected outside of the series fields, any such equipment is inadequate for the reasons stated below.

(1) At those times when a machine is furnishing equalizing current to other machines the total armature current does not

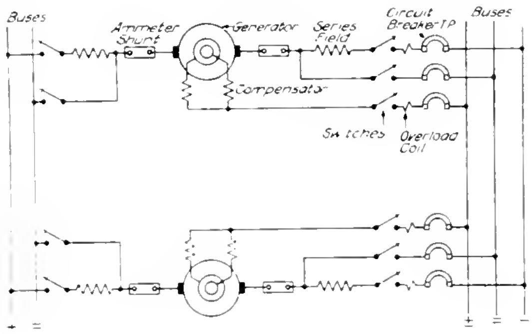


Fig. 6

pass through the overload device and the machine is, therefore, inadequately protected.

(2) If a machine is drawing equalizing current from the other machines the overload device is actuated by a current in excess of the armature current, so that the machine is liable to be thrown out of service when its armature is not overloaded and when equalization is most needed.

(3) The series fields cannot be thrown in circuit before a machine is paralleled.

The economical results of using such equipments are not as great as would appear at first sight, for the reason that the saving in cable is considerably offset by: (a) the more expensive circuit breaker equipments required; (b) the long and therefore expensive ammeter leads necessary; and (c) the expense involved in installing the ammeter shunts and their connections on the frames of the machines.

It is evident that when the entire equipment is to be mounted on the panel no less than seven cables are possible if adequate protection and proper operating facilities are to be secured. However, the cost of certain installations may be materially reduced by using remote control circuit breakers, together with the ammeter shunts and equalizer switches, mounted on an auxiliary panel close to the machine. With equipments of this kind the equalizer buses may be installed near the machines and only three cables run to the switchboard. Estimates show that in those cases where the cables would exceed 30 ft. in length and 1200 amp. capacity, or in any case where the capacity would exceed 3000 amperes the consequent saving in cable would more than counterbalance the increased cost of a panel with such an equipment.

The question of the switching device for the neutral has not been discussed. However, it will be seen from the various illustrations, that one single-pole switch is sufficient for this purpose, it being unnecessary to interpose any switches between the collector rings and the compensator in case the latter is external to the machine. The most economical arrangement is to locate the compensator near the machine so that only one lead to the panel is required.

The above remarks apply to panels for controlling generators operating in parallel. If a single machine forms the ultimate installation, no equalizing connections would ever be necessary; hence only a triple-pole switch with either fuses or circuit breakers is required, and the fuses, circuit breakers, switches and ammeters may all be connected outside of the series fields. If fuses are used

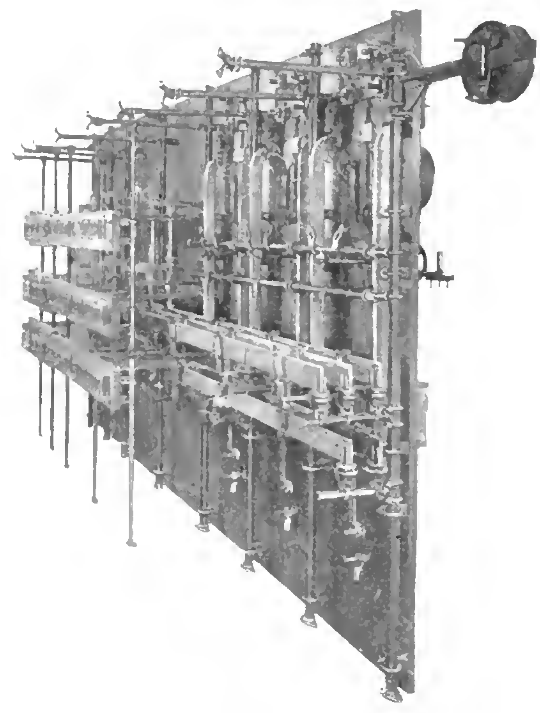


Fig. 7. Back View of Board Shown in Fig. 1

the neutral fuses should be approximately one-fourth to one third of the capacity of the fuses of the outside leads, in order to protect the compensator in case only one of the outside fuses should blow.

COMMERCIAL ELECTRICAL TESTING

PART XVII

BY E. F. COLLINS

STARTING COMPENSATORS

Compensators for starting squirrel-cage induction motors, synchronous motors, and rotary converters are built for voltages from 110 to 13,200 volts. The switching mechanisms constitute the chief difference between the various types. One of the principal types has a double-throw oil switch and is so connected that when the motor is thrown on the line, the fuses are in circuit. Figs. 76 and 77 show the wiring for quarter-phase and three-phase compensators of this design.

Complete tests on compensators consist of commercial tests, heat runs, impedance, and insulation tests. Commercial tests consist of ratio of taps, exciting current at normal voltage, and insulation tests. Insulation tests consist in applying high potential between windings and ground for one minute, operating the compensator at double potential for one minute, and also at 50 per cent above normal potential for five minutes.

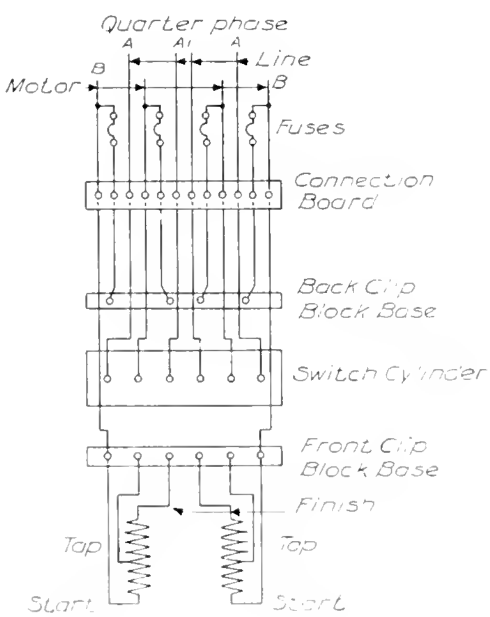


Fig. 76. Quarter-Phase Compensator

Ratio

Connect the leads to the line terminals of the compensator and apply about 100 volts to the lines, throwing the switch on the compensator to "starting" position and leaving all others in the "off" position. On the three-phase compensator read the voltages between the taps; the lowest voltage tap is

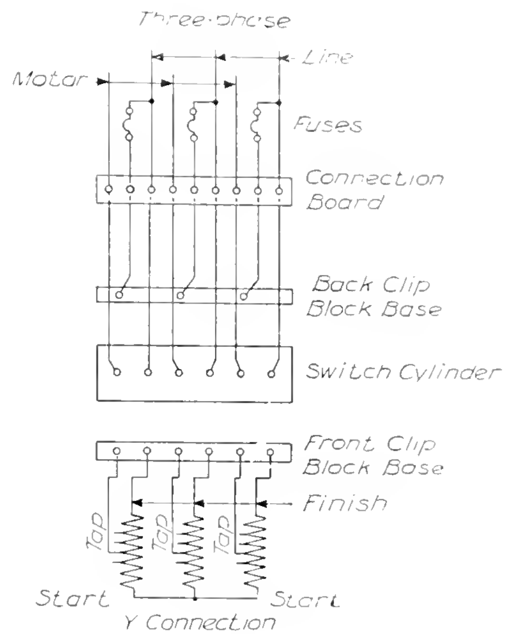


Fig. 77. Three-Phase Compensator

next to the core. Standard compensators for motors up to and including 15 h.p. have 40, 60 and 80 per cent taps; those for motors above 15 h.p. have 40, 58, 70 and 85 per cent taps. The ratios obtained should agree to within 3 per cent of the above values.

In determining ratios see that both the primary and secondary meters are on the same phase. In checking the ratio of quarter phase compensators, apply 100 volts to lines A and A_1 (Fig. 76) and read the voltage on the taps between the motor A and B and the taps. These compensators are tested single-phase.

Magnetizing Current

Magnetizing current is measured at normal primary voltage and normal frequency. The alternator used should operate at about its normal voltage. On 60 cycle compensators, the magnetizing current should not exceed 20 per cent, on 40 cycle compensators it should not exceed 25 per cent, and on 25 cycle compensators it should not exceed 30 per cent of the full load current of the motor, assuming the latter to operate at 80 per cent *apparent* efficiency.

On compensators that are not standard, the magnetizing current should be measured at 20 per cent above the normal potential, as well as at normal. In making this test, hold the volts constant across one phase and read the current in all three legs; then hold the current constant in one leg and read the three-phase voltage. Instead of holding the current in one leg, two voltmeters may be used, one to hold the volts constant and the other to read the three-phase voltage. Since a high magnetic density obtains in the core, see that the voltage and frequency are correct, as a slight change in either will change the magnetizing current considerably. Quarter-phase compensators are tested as though they were single-phase.

Heat Runs

Short circuit the leads to the motor and apply sufficient voltage to the line leads to force the required current through the coils for one minute. Place a thermometer on the coils to obtain the temperature. Thirty minutes should elapse between successive heat runs on the same compensator and after each heat run the tap leads should be changed to the next tap. On very large compensators it is often necessary to wait several hours between heat runs, otherwise the compensator will run hot and smoke. The heat run cannot always be taken on all legs at the same time on account of insufficient power. In such cases bare the Y connection, short circuiting the tap to the Y.

On compensators not standard, or those covered by special instructions, the impedance volts should be measured. See that frequency is correct for this test. When the heat runs have been finished, inspect the oil boxes for leaks; if they are tight, empty the oil out and turn them upside down to drain. Connect the top leads on the first tap, replace the oil boxes, tape and insulate all the connections, and replace the covers. All cast iron oil boxes are tested for leaks by filling with oil for ten hours. Pressed steel boxes are not tested and therefore need not be removed from the compensator.

Insulation Test

Double potential should always be applied after the compensator has been completely assembled and the taps insulated with tape. Double voltage is applied to the line terminals for one minute, followed by 150 per cent normal potential for five minutes; the frequency being high in order to keep the magnetizing current below the normal current of the compensator.

If the compensator is designed for high voltage, double potential may be applied on the taps for one minute. The high potential test is made in the usual way, with all leads connected together. Compensators up to and including 550 volts are tested at 2500 volts.

Reactances are generally used in compounding rotary converters. They are placed between the secondary of the step-down transformer and the collector rings of the rotary.

ROTARY CONVERTER REACTANCES

The ratio of conversion of rotary converters, except those of the split pole type, is practically constant for all field strengths. Therefore, to increase the continuous current voltage, the alternating current voltage must also be increased. In large systems, with a number of substations receiving current from the same generating station, any given substation voltage must be varied independently of that of the others. Several methods are possible: for lighting systems an induction regulator is often employed, or the step-down transformers may be provided with a dial switch to vary the ratio of transformation. These devices do not operate automatically, whereas the compounding of a rotary converter is automatic.

The excitation of the shunt field is adjusted at no load to a value which causes the machine to take a small lagging current. This lagging current, flowing in the reactive coil, reduces the voltage at the collector rings below that at the transformer terminals. As the rotary takes load the current through the series field first reduces the wattless current through the reactive coils and at higher loads forces a leading wattless current through them. When the current becomes leading, the voltage at the collector rings is higher than at the terminals of the transformers.

Rotaries may be made to over compound; that is, increase the continuous current voltage as the load increases.

Reactive coils are often placed in multiple with long distance, high voltage transmission lines to compensate for capacity; they are also used as dimmers, for the lighting of theaters, etc.

Complete tests on reactive coils for rotaries consist of measurements of resistance, reactive drop, and heat runs at normal and overload, polarity and insulation tests. Reactive drop is usually taken during the heat run. These coils have the same heating guarantees as the transformers with which they operate.

For the heat run, connect the coils in Y and supply full current at proper frequency, taking precautions to see that the meters are protected from stray fields. The transformer cables should be kept close together, to prevent high impedance and unbalancing. Heat runs on air blast reactances should be started without air at normal load for about thirty minutes before the air blast is put on. Oil cooled reactances should be started at overload to shorten the heat run as much as possible.

In making heat runs on reactances designed for six-phase circuits, connect the coils in series and make the heat run on three-phase circuit. Reactive coils cannot be tested by the motor-generator method (Hopkinson method), hence, the test must be run from an alternator capable of supplying full kilovolt-amperes. If an alternator of sufficient capacity is not available, use two in multiple. They can be run as generators, but after the alternators have been synchronized, it is better to pull the breaker of the driving motor of one of them. By proper adjustment of the field current, the one running light will operate as a rotary condenser.

In measuring reactive drop, take the volts across each coil, holding full load current in one leg; then hold the volts across one coil constant and read the current in all three legs; after which take the drop across each leg, holding full load current on all legs. This test must also be made at 50 per cent overload. The frequency must be held constant while the drop is being taken, as the reactance depends directly on the frequency. When the reactive coil has reached constant temperature at normal load, run for two hours at 50 per cent overload.

When the heat run is finished take air readings and test the insulation. The insulation tests consist of double potential for one minute, and one and one-half potential for five minutes, and high potential tests. The high potential test must be applied between the winding and core, between the winding and frame, and between the phases.

Polarity Test

The polarity test is made by supplying direct current to the middle phase and so connecting a voltmeter to the terminals as to get a positive deflection; the drop lines are then transferred to the corresponding terminals of the other phases and the direction of kick on breaking the current in the middle phase is noted.

THE SWITCHBOARD DRAFTING DEPARTMENT

While from the engineer emanate the ideas that are embodied in a salable article, which the mechanic produces from raw material, and the salesman places on the market; the draftsman, on the contrary, produces nothing of market value, for he but transmits to the mechanic the idea of the engineer, and does that in what many times seems a slow and expensive way. Thus managers are sometimes led to begrudge the cost of drafting, and well they might if a drawing accomplished no more than that.

Properly made, a drawing is by no means so limited in its utility. Among other things, it has long been recognized that in the drawings an idea receives its first real test, for there it is first visible in all its detail and in its correct proportions. This makes good drawings serve in the place of costly experiments. Indeed much may be gained, if the drawings are made by men capable of working out simple ideas themselves, by referring most of the details of design to these men and leaving the engineer free to spend his whole time on the broader phases of the work. Then too a drawing may be of great value to a salesman in placing before his prospective purchaser a definite idea of what might otherwise be an obscure proposal and in preserving an accurate memorandum of what has been furnished to a purchaser, so that he need not be harassed with questions should he wish to repeat his order or to purchase additional equipment.

Realizing these facts, the General Electric Company has countenanced the expense required to build up a drafting force perhaps as effective as any of its kind to be found in the switchboard field.

Such development depends upon the following four essentials:

1. Good men.
2. Thorough organization.
3. Reliable sources of data.
4. Good working quarters.

The switchboard drawing room is sixty feet wide and two hundred feet long; is comfortably heated by steam and lighted by a continuous row of nine-foot windows, placed along each side and across the end; while the ceiling and walls are treated with white paint to diffuse the light. All the windows are supplied with pale green shades to cut off any direct light from the sun. For artificial light, a row of enclosed arc lamps, fitted with diffusing reflectors, is placed over each row of drawing tables.

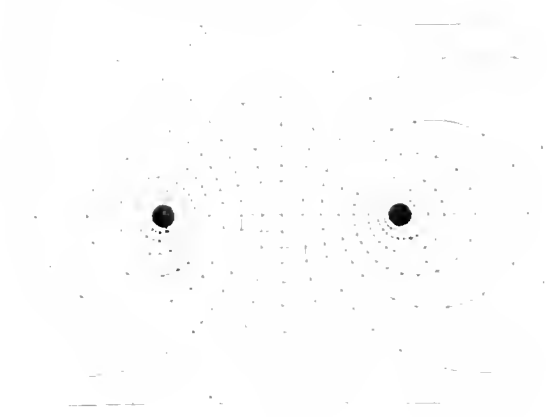
The organization is patterned in part after the general organization of the switchboard department, and consists of expert groups which specialize respectively in switches and circuit breakers, electrical connections, the location of devices on panels, drilling and templates, miscellaneous, and general supervision of work.

To provide reliable data an information bureau is maintained containing lists and card catalogues of all the devices made or used in the switchboard work; prints showing their dimensions, lists of material carried in the several stock rooms of the works, sketches showing proper methods of connecting all kinds of apparatus needed, technical reference books, lists and dimensions of commercial hardware, etc.; together with copies of all standing instructions issued in the works.

The most important factor in any working force, is, of course, the men. Careful search is made for those of the proper qualifications, and when found, they are trained to the special needs of switchboard work; then as fast as they show themselves able to cope with it, they are given more and more responsible work. In this way a working force is built up which is loyal and capable.

NOTES

In Part I of the article by Dr. C. P. Steinmetz, which was published in the February number of the REVIEW, a diagram was shown (Fig. 3, page 91) which gave an incorrect idea of the electromagnetic and electrostatic fields surrounding the conductors of a transmission line. The following cut is a correct representation of the distribution of these fields.



* * *

Editor G. E. REVIEW,

Dear Sir:

In the issue of the GENERAL ELECTRIC REVIEW of December, 1910, on page 563, Mr. E. F. Collins gives a formula for calculating regulation of transformers which is not used by the General Electric Company as stated in the article, and which is inconsistent with the definition of "regulation" given by the American Institute of Electrical Engineers.

The formula in question was developed many years ago when regulation had a different definition, and was obtained by comparing the conditions of the transformer at full load with the conditions of an ideal transformer, with no resistance and no leakage reactance.

The formula which is actually used by the General Electric Company, and which corresponds to the accepted definition of "regulation" nowadays is:—

Per cent Regulation =

$$(\%IR)p + (\%IX)w + \frac{[(\%IX)p - (\%IR)w]^2}{200}$$

where

$\%IR$ = total resistance drop due to load current expressed in per cent of rated voltage.

$\%IX$ total reactance drop due to load current expressed in per cent of rated voltage.

p = power factor ($\cos\theta$).

w = wattless factor ($\sin\theta$).

This formula is only approximate, but is satisfactory in all practical cases.

General Electric Company, Pittsfield, Mass., Feb. 1, 1911.

G. FACCIOLI, Asst. Eng. Transformer Dept.

GENERAL ELECTRIC REVIEW

VOL. XIV, No. 4 APRIL, 1911

CONTENTS

Rainbow Falls of the Missouri River

(See page 149)

GENERAL ELECTRIC REVIEW

FLUORESCENCE AND PHOSPHORESCENCE

The problem of obtaining improved efficiency in lighting production is one that has continually confronted the modern scientist. It has been touched upon several times in these pages and is mentioned briefly by Mr. W. S. Andrews in his article on fluorescence and phosphorescence. Great strides have been made in this direction of recent years; both through the attainment of higher temperatures in the radiating material, as in the case of the metal filament lamps, and through the utilization of the property of luminescence, as with the Welsbach mantle and the flaming arc lamps.

As regards further progress in the direction of simple temperature radiation, many authorities are inclined to the belief that any *great* step in advance is doubtful, seeming to think that we are unlikely to secure substances that will be sufficiently refractory to withstand a material increase over the temperatures now employed.

Along the line of luminescence, however, it is possible that much may be accomplished, and in connection with the phenomena of phosphorescence and fluorescence the outlook is not hopeless, though from time immemorial the firefly as the exponent of light without heat has been held up to the illuminating engineer as a (literally) shining example of what can be.

The first steps toward a realization of this goal consists in a study of these phenomena of fluorescence and phosphorescence. In this field much interesting work has been done by Prof. Wilder D. Bancroft, who has arrived at many suggestive results.

Inasmuch as there is no known way by which light of one wave length can be converted into light of another wave length, it is Prof. Bancroft's theory that in these phenomena the ether waves are not changed directly into waves of different lengths—that it is not a matter of frequency changing *per sec*, as is maintained by Koblentz, but rather that the ether waves produce a chemical change or changes, which, in turn, cause the emission of light. In the demonstration of this hypothesis, experiments were made with phosphorescent materials, these being less complicated chemically and the reactions that might produce the light being fewer in number. In the first experiments substances were selected with which but one reaction could take place. Briefly, it was found that by chemical means it was possible to produce the same light as by phosphorescence. For example, under the action of the cathode ray mercury bromide phosphoresces with an orange glow: by causing bromine vapor to impinge upon hot mercury, a red flash of light may actually be obtained, which, examined through a spectroscope, gives a more or less continuous band of light, much more intense in the orange.

Again when exposed to the cathode ray cupric iodide gives a violet red light, which can be reproduced by dropping iodine crystals on molten copper. Similar results are obtainable with sodium iodide, potassium iodide, etc.

Entering upon the sulphates, the investigation becomes more complex, for while with substances like $HgBr_2$ or KI, etc., there is but one chemical reaction, with the sulphates, e.g. $PbSO_4$, any one of several reactions may be the light producing one; thus it may be the combination of the metal with the SO_4 radical, or of the metallic oxide PbO with SO_3, or it may be the reaction of the metal with oxygen $Pb+O$; the further combination with the SO_3 being a reaction without light-producing properties.

In point of fact, by subjecting the substance to the action of the cathode ray, pumping off the gaseous dissociation products, and examining the residual material, the light producing reactions were determined. Thus, $PbSO_4$ under the cathode ray phosphoresces with a blue light, and after a time metallic lead is found in the residuum,

SO_4 being removed by the pump. To reproduce this phosphorescence chemically the following reactions were tried, with the results noted:

$Pb+O=$ nothing

$PbO+SO_3=$ white light

$Pb+SO_4$ (by $[NH_4]_2S_2O_8$) = blue light

The last duplicates the cathode ray reaction.

The next step was the study of fluorescence, and for this purpose anthracene was selected. Briefly, it was shown by some remarkable experimentation and reasoning that the fluorescence is seemingly due to a non-electrical dissociation or reassociation of the double bended hydrogen atoms of the central nucleus.

These investigations constitute a real advance in the study of phosphoresence and fluorescence; they indicate that these phenomena are due to perfectly definite chemical reactions, and place the study of the subject upon a scientific basis on which to build toward a really efficient production of light—one that will successfully compete with the performance of the glowworm or firefly. Such a result, indeed, is no more Utopian or remote than was electric light in the days of kerosene.

WATER POWER DEVELOPMENT OF THE GREAT FALLS POWER COMPANY

About the time of the consummation of the Louisiana Purchase, President Thomas Jefferson was desirous of determining whether the Missouri and the Columbia rivers, of which nothing certain was known, would afford a practicable route for commerce with the Pacific. To this end an expedition was arranged which constituted the first step taken, under national auspices, to open a road across the continent. The region was practically untraversed, save for some aimless wanderings of migratory trappers. For this arduous exploration Jefferson selected Capt. Meriwether Lewis, who, in turn, requested that Capt. William Clarke might accompany him.

The expedition reached the mouth of the Missouri in the fall of 1803 and the ascent of the river was begun the following May. By October the explorers had reached a point 1600 miles from the Mississippi and here among the Mandan villages camped for the winter. Above this point, which they left early in 1805, their difficulties rapidly increased. Slowly and laboriously they forged their way up stream, sometimes forced to drag their canoes with tow lines, or push them through dangerous rapids by means of poles, or again to carry them over long and difficult portages.

On June 13, 1805 Capt. Lewis, who was scouting in advance of his party, descried in the distance a thin misty cloud "that arose above the plain like a column of smoke," and that showed him he was approaching the great Falls of the Missouri, tales of which had come to him through the Indians. Traversing the intervening seven miles, he reached the Falls about noon and enjoyed the sublime spectacle of this stupendous object, which since the creation had been lavishing its magnificence upon the desert, unknown to civilization.

These Falls that a hundred years ago were discovered by Capt. Lewis in an unexplored region containing buffalo herds of a thousand heads, are now the site of a modern hydro-electric development that has harnessed a portion of their energy, transmitting it one hundred and fifty miles or more across the territory over which Clarke and Lewis toiled through many weary months.

The article by Mr. M. Hebgen, begun in this issue of the REVIEW, is a description of this development, which possesses a number of unusual features that furnish additional interest to the author's otherwise attractive description.

THE REAL THEORY OF REAL ELECTRIC RATES

Through the courtesy of the author, we are able to publish in this issue of the REVIEW an unusually interesting monograph on the theory of electric rate making, by Mr. R. S. Hale—a paper which was read at a meeting of the New York Section of the National Electric Light Association, recently held in Schenectady. Mr. Hale is accorded the distinction of being one of the foremost students of the broad rate question, and we feel certain that his views on this subject will prove of much interest to the readers of the REVIEW.

The nature of the industry in which the General Electric Company is engaged does not carry it into matters of rate making, and on such questions the REVIEW voices no opinions. The paper is therefore presented in the REVIEW as an important contribution to the rather scant literature on the subject of rates, because of its interest and the manner in which the subject is presented.

WATER POWER DEVELOPMENT OF THE GREAT FALLS POWER COMPANY, MONTANA

By M. Hebgen, General Manager

INTRODUCTION

From the tower of the courthouse in the city of Great Falls you can see the spot, hardly three miles away, where in 1805 the intrepid members of the Lewis and Clark expedition celebrated the Fourth of July. In the journal of that famous tramp it is recited that game was not then abundant, and the quaint record is: "We contrived, however, to spread not a very sumptuous but a comfortable table in honor of the day, and in the evening * * * as is usual among the men in all festivals, the fiddle was produced and the dance began which lasted till nine o'clock, when it was interrupted by a heavy shower of rain."

On their way up the Missouri the explorers had heard from the Indians about the great falls. They were eager to reach the scene. The story of what happened, as a part of their experience for June 13, says that Captain Lewis "had gone about two miles when his ears were saluted with the agreeable sound of a fall of water." Toward the place whence the sound came he directed his steps, and the noise increasing as he approached soon became too tremendous to be mistaken for anything but the great falls of the Missouri.

During this sojourn and, a year later, when the expedition was on its return from the coast, Captain Lewis made a careful study of this water power and its environs. This he did with a far-distant future in view; if he did not realize what the century dating from his activities was to achieve in the way of our country's development, he apprehended, at least, the inestimable value of the industrial energy concerning which he and his companions were soon to inform the civilized world. The carefully treasured report then prepared, with its maps and charts, attest the extreme care with which he observed every aspect of the region, and is made the more interesting by the fact that the surveys of recent times establish the surprising accuracy of the data Captain Lewis set down for all the distance from the point where the waters take their first plunge to the place, miles below, where the river resumes its placid course.

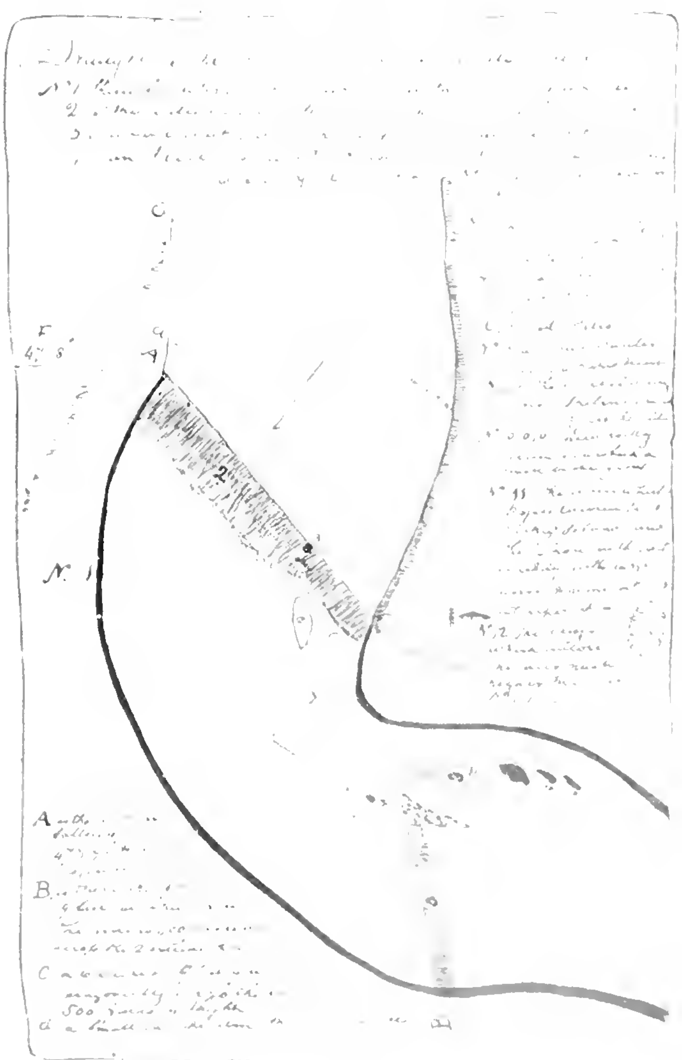


Fig. 1 Reproduction of Original Drawing by Clark, of Lewis & Clark Expedition, Showing Rainbow, Crooked and Coulter's Falls

Those whom local coloring interests, in connection with scenic wonders, are gratified to know that even with respect to a good many minor items the imprint of the old expedition has not been disturbed. When they were trudging across Dakota and Eastern Montana the explorers were told by Indians that at one of the falls an eagle's nest would attract their notice. They found it. The journal says: "Just below these falls is a little island in the middle of the river, well covered with timber. Here on a cottonwood tree an eagle had fixed its nest and seemed the undisputed mistress of a spot to contest whose dominion neither man nor beast would venture across the gulfs that surrounded it." They christened this cataract Black Eagle Falls; they gave the name of Coulter, one of their comrades, to another falls; they applied the stream's course to the naming of Crooked Falls; the Rainbow Falls recall the lines in which the journal speaks of "the masses of white foam upon which the sun impresses the brightest colors of the rainbow."

Fig. 2. Old Tree Near Big Falls, Mentioned in Lewis & Clark Journals

At a distance of three hours by railway from the city of Great Falls, the Missouri River gets its start from the mingling, at Three Forks, of the waters of the Gallatin, the Jefferson and the Madison. Near Great Falls, in traversing a distance of eight miles the river's drop is four hundred feet. It makes the descent over a series of cataracts, with intervening rapids, in a volume of water so great that when translated into an economic force it means more than 130,000 horse power. Majestic power this; exhaustless in resource, limitless, almost, in its possibilities! Unknown till Lewis and Clark told about it. During uncounted centuries it ran on and on, the waste of stupendous energies. Indeed, for decades after the finding of it by the men who explored this region it was a useless treasure.

The time is within the memory of men now at manhood's prime when Great Falls power was first applied to industries in Montana—an insignificant draft was made then upon the available total. In fact, the present day is witnessing the first efforts, under Mr. John D. Ryan's discerning guidance, to adapt this splendid force to a fair measure of its ability and its opportunities. In this progressive commonwealth there is need for every drop of this water converted into an industrial agency. For the uses of the mammoth copper-making plant at Anaconda, five thousand horse power is under constant transmission over a distance of 152 miles. The quota furnished to mines in the Amalgamated and Anaconda group is 15,000 horse power, conveyed 130 miles.

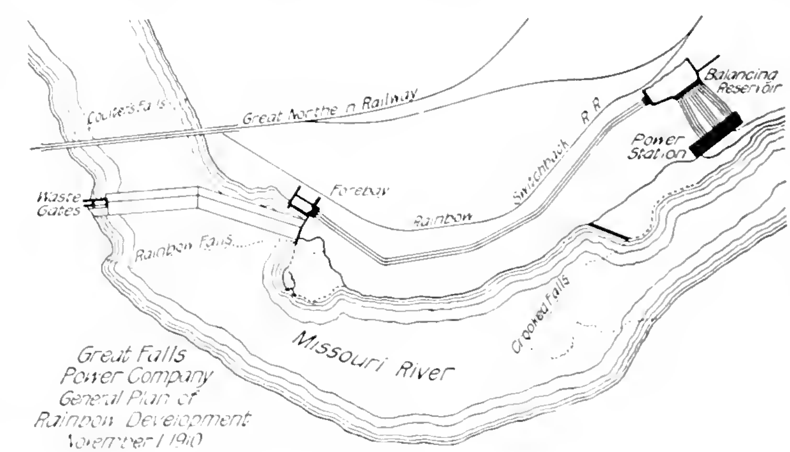


Fig. 2. Map of Power Development, Rainbow Falls

These paragraphs are the preface to pages that tell of the power at Great Falls; of the dams and stations and equipment; of con-

Fig. 4. Cross Section of Dam at Rainbow Falls

venient sites for industrial plants; of transmission lines; of present service and available field; of the aggregate of power compared with that of other famous cascades; of the millions spent and spending; of relative economy in generating electricity; of the enormous conservation involved in the displacing of coal; of the economies assured and the commercial opportunities afforded.

Power Development at Great Falls, Montana

The completion of the Rainbow Falls Power Development with a plant capacity of 36,000 h.p. marks the first step in the development of power on a large scale from the Missouri River at Great Falls, Montana.

As has been said, the river in this locality falls 400 feet in a distance of 8 miles, making possible a total development of 76,000 electrical horse power continuously at the lowest stages of the river. With an amount of storage easily obtainable, by means of low dams, power can be developed much in excess of 130,000 h.p. The total drop is divided up into a series of precipitous falls, making the development of power by a series of plants exceptionally easy.

Description of Developments

The first abrupt falls are located about two miles from the center of the city of Great Falls, and are called Black Eagle Falls. By means of a low crib dam, built in 1890, on the crest of the falls the available head is increased to 45 feet, and 10,000 h.p. is developed. About 8000 h.p. is used by the Boston & Montana Smelter, located on the north side of the river, and the remainder is taken by the Great Falls Electric Properties' power station and the Royal Milling Company's flour mill on the south side. With the exception of that taken by the Great Falls Electric Properties' plant, none of this power is transmitted electrically, but is used directly at the falls and is transmitted by shaft or rope drive.

Three and one-half miles below Black Eagle Falls are located in close proximity to each other, Coulter's, Rainbow and Crooked Falls, having a combined natural fall of 80 ft. The largest of these is Rainbow, and from it the development at this point takes its name. The head made available by these falls is increased to 105 ft. by a rock filled crib dam 29 ft. high.

Below Rainbow Falls the river drops at a fairly uniform rate a distance of 110 ft. in four and a half miles and then plunges down vertically 77 feet, forming the Great Falls of the Missouri River. This is the greatest fall the Missouri encounters in its entire length, and will be the site of the next power development.

Fig. 5. Temporary Sluiceway During Construction of Dam

No excavation was required for the dam at Rainbow, as solid bed rock was already exposed across the entire site. The same solid rock foundation exists at the Big Falls as well as the intermediate falls between Rainbow and Big Falls, thus furnishing an unusually good foundation for both dams and power houses at the very lowest cost.

Flow of the River

The preceding figures of available power are based on a minimum flow of the river of 2300 cubic feet per second. Only a very few times during the last five years has the flow been less than the assumed minimum, and then for only a short time. With the amount of storage available these short low water periods can easily be bridged over so that the true working minimum with the plant in operation will probably be nearer 2500 cubic feet per second than 2300.

RAINBOW DEVELOPMENT

The development at Rainbow was started October, 1908, and completed July, 1910. It has a total capacity of 21,000 kw. in generators, and 36,000 h.p. in waterwheels, and operates at 105 foot head. The general scheme of development is typical of what may be called standard practice in the West for plants of medium head, and consists of a low diverting dam, a double pipe line feeding into a balancing reservoir near the plant, and individual penstocks supplying the turbines from this reservoir.

The dam is a rock filled crib structure 1146 feet long and 29 feet high, the upstream side of which slopes at such an angle that the stability of the dam is assured even under the greatest floods, the weight of the water acting to hold it down, so that the higher the flood the greater the stability. The down-stream side is also sloping and tapers off into a long apron so designed as to take care of any overflow which may occur without shock or commotion. (See Fig. 4.) The dam is founded on solid rock throughout its entire length.

Fig 6. Rainbow Falls Dam: Sluice Gates in Foreground

At the south end of the dam is a sluiceway having a discharge capacity of 8000 sec. ft. and controlled by hand-operated gates. (See Fig. 3.) Located at the north end is the intake to the pipes supplying the plant.

This consists of a concrete chamber or forebay into which the water is admitted by eight openings, 8 feet in diameter, controlled by hand-operated gates and provided with screens for the exclusion of trash. (See Fig. 3.)

The two main pipes are of riveted steel construction, 15 ft. 6 in. in diameter, and 2350 feet long. These are the second largest steel pipes in the country; a realizing sense of their size may be obtained by comparison with some familiar object; for example, they are large enough to readily allow a standard railway passenger coach to pass through from end to end. The amount of steel used in their construction was 2471 tons, or 62 car loads, and 436,000 rivets were employed, while the steel plates, if laid flat, would cover five acres of ground.

Both the inlet and outlet ends of the pipes are enlarged to form bell mouths, thus making the changes in the velocity of the water gradual and minimizing the loss of head. Stop log guides are provided at each end, so that either pipe can be shut down temporarily and emptied for inspection or painting while the other remains in operation and supplies water to the plant.

The balancing reservoir into which the main pipes discharge performs the important function of keeping the flow in the pipes steady while the quantity of water taken by the wheels varies with sudden changes in load. The 28,000 tons of water in the main pipes

Fig. 8. Interior of One of the 15 Ft. 6 In. Steel Pipes

cannot be suddenly started, nor when it is once in motion can it be suddenly stopped. The reservoir acts, then, as a buffer to make the variations in velocity demanded by the wheels apply gradually to the water in the main pipes. The reservoir at its lower end is provided with an overflow weir to take care of any unusually sudden rise in the water

Fig. 7. Steel Pipes, 15 Ft. 6 In. in Diameter

level. On its sides are twelve openings controlled by hand-operated gates and protected by screens which supply the 8 foot branch penstocks leading directly to the turbines. The reservoir as a whole is excavated in the hill side above the power house and has concrete walls resting on solid rock.

The power house is a three-story brick building with steel frame and concrete floors and roof. On the ground floor the generating units are located, and on the second floor overlooking them are the switchboard, low tension switches and step-up transformers. The third floor is devoted exclusively to high tension switching apparatus, busbars and lightning arresters.

There are six turbines having a normal capacity of 6000 h.p. each. These machines, which were built by S. Morgan Smith Co., are of the inward flow Francis type, with two runners on a horizontal shaft. Each runner is enclosed in a separate spiral casing fed by a separate pipe from the balancing reservoir and discharging into a common draft tube. The spiral casings are of cast iron and the runners of bronze. The gates are of the wicket type with bearings outside the wheel casing, thus insuring good lubrication. The wheels are controlled by Lombard Type N governors. A test of the wheels made under operating conditions showed an efficiency of 86 per cent at full load; an efficiency that has rarely, if ever, been exceeded by any

Fig. 9. Balancing Reservoir

On three occasions the turbines were opened up to full gate with no load on the generators—i.e. runaway conditions—and permitted to attain as high speed as they would, with no damage resulting to any part of the apparatus and no trembling or vibration indicating an unbalanced condition in either the turbine or generators.

The turbines were closed down very quickly so as to produce a water ram in the penstocks which showed a pressure on the gauges 100 per cent in excess of the regular operating pressure, and no damage was done or sign of distress developed in either the penstocks, wheel cases or foundations.

turbine. In the capacity test one of these turbine units carried a load of 5500 kw. on one of the 3500 kw. generators, showing ample capacity to drive the generators up to and above the maximum overload that would ever be put on them in regular service.

Each wheel is direct coupled to an alternating current generator built by the General Electric Company, and rated at 3500 kw., 6600 volts, three-phase, 60 cycles, 225 r.p.m. Mounted on an extension of each generator shaft is an exciter, each exciter having

Fig. 10. Rainbow Power House, Looking Up River

sufficient capacity to excite two generators. The exciters are so connected that any one may be used for auxiliary service about the station, such as lighting, charging the storage battery, operating the crane, etc.

The station is laid out with the idea of utilizing the output of two generators in the vicinity of Great Falls, a distance of about four miles. This power is transmitted at the generator voltage of 6600 and no step-up transformers are required. The output of the remaining four generators is stepped up to 102,000 volts and transmitted to Butte and Anaconda, a distance of 130 miles and 152 miles respectively. For this purpose there are installed four banks of single-phase transformers, rated at 3600 kw. per bank, and having a primary voltage 6600, and a secondary voltage 102,000. Five per cent taps on the high tension side and three per cent

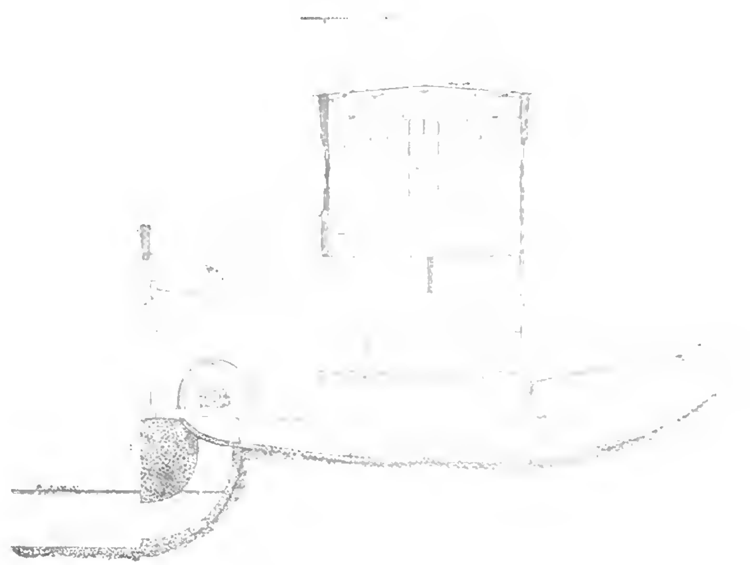


Fig. 11. Cross Section of Rainbow Station

Fig. 12. Generator Room in Rainbow Station, Showing Six 6000 H.P. Generating Units

taps on the low tension side are provided so that the actual voltage delivered can be adjusted and adapted to operating conditions as they may change from time to time. The transformers are connected in delta on both high and low tension sides. All transformers and switching apparatus were manufactured by the General Electric Company. The 6600 volt oil switches are Form H-3. The 100,000 volt switches are Forms K-10 and K-15; the former being used for the high tension side of the transformers and the latter for the outgoing lines. Electrolytic lightning arresters are used with horn gaps located on the roof of the station. The outgoing lines leave the building through oil filled porcelain bushings in the roof.

Transmission Lines

Power is transmitted to Butte, a distance of 130 miles, over two separate lines running parallel on the same right of way. (Shown in Fig. 13.) At the center of these lines is a switching station, equipped with oil switches and lightning arresters, by means of which a cross-over connection can be made and one-half of either line cut out while the remainder is in operation. Each line is further subdivided into 7 sections by means of outdoor dis-

Fig. 13 Transmission Line in Level Country

connecting switches. These switches are used for sectionalizing the line and locating trouble.

Feeding from the busbars in the Butte substation, a single line of the same construction as the Great Falls line is extended to Anaconda, a distance of 22 miles, making the maximum distance power as transmitted 152 miles, and the total length of single line 282 miles.

The transmission line embodies the most approved ideas in construction. The conductors are No. 0 B.&S. gauge, hard drawn copper strand. The insulators are of the suspension type, each insulator consisting of 6 units, 10 inches in diameter. The insulators will stand a wet test of over 300,000 volts, and were selected after long and careful tests by the company's engineers. The wires are carried on steel towers of the four-legged, single crossarm type, manufactured by Milliken Bros. The three conductors are suspended in a horizontal row from the crossarm, and there are no transpositions in either line. Above the power wires and symmetrically located are two galvanized steel strands, 3/8 in. in diameter, grounded at each tower, which serve as a protection against lightning.

The distance between towers in level country is 600 feet. In mountainous country, however, the spans are irregular in length and spans of 1500 or 2000 feet are common. The longest one in the line is that crossing the Missouri River and is equal to 3034 feet. The length of this span is such that a person standing at one end of it can see the wires go off and vanish into space while the tower at the further end is barely visible to the naked eye on a clear day. The towers at one end of this span are shown in Fig. 14. The line starts at an elevation of 3200 feet, rises to an elevation of 8200 feet as it crosses the Continental Divide, and again descends to 6100 feet, the elevation at Butte.

Midway between the two lines of towers a private telephone line is located. The telephone circuit is of No. 10 B.&S. gauge, hard drawn copper, supported on 25 foot

Fig. 14. Line Crossing Missouri River. One End of 3034 Ft. Span

cedar poles, spaced 175 feet. The line is transposed every fifth pole, and disconnecting switches are inserted every five miles for testing purposes.

(To be Continued)

THE REAL THEORY OF REAL ELECTRIC RATES*

By R. S. Hale

A certain politician once put forth some new theories, of which the critics said that much was new and much was good; only, unfortunately, everything that was good was not new and everything that was new was no good at all.

I shall forestall similar criticism tonight by saying at once that I shall not attempt to bring out anything that is really new. I am only going to speak of the real reasons for the real rate systems of today; and here I refer not to the skeleton systems that have been worked out by theorists, but to the flesh and bone systems that are in successful operation.

There are a great many of these successful rate systems, since every company that sells its product to the advantage of the community and at a profit to its investors uses a successful rate system, even if not a theoretically perfect one. If a practically successful rate system is theoretically wrong, then it is only so much the worse for the theory.

Let me take this opportunity to give my definition of the difference between theory and practice.

A theory is a statement of a case that should consider all the facts, but often does not. Hence the results of using such a theory may be bad. On the other hand good practice, if it is good practice, does take into consideration all the facts in deciding what to do, even if omitting some of them from its statement. Hence, good practice is better than bad theory; but a correct theory that takes into account all the facts is necessarily the best practice.

Now let us see what is really the rate question. Broadly speaking, it is the question of what price we shall charge for our product when it is sold under varying conditions, and I think we will agree that we are discussing a question of substance and not of form.

There is a difference between the question of the rates themselves and the question of the form in which they are expressed. For instance, we might have three drug stores in three adjoining towns, each with the same lamps and each using the same kilowatt hours per year. The first might be on a meter rate at 6 cents per kilowatt hour, paying $180.00 per year; the second on a Hopkinson, or readiness-to-serve rate, paying $60.00 per kilowatt plus 4 cents per kilowatt hour, making $180.00 per year; while the third might pay a fixed sum of $180.00 per year without a meter. It is clear that in all three cases the rates are really the same though the forms are very different.

If Chicago and Boston have readiness-to-serve rates, and New York merely wholesale discounts, then the forms may differ. But if we find that all the big department stores pay substantially the same rate, no matter in which city they may be, all the small drug stores pay another rate, but a rate which is substantially the same in the different cities, and so forth for all the other classes; then the rate systems are substantially the same in these different cities, even if the forms are not the same.

The next part of the question is what shall be the basis of rates, and in discussing rates the statement is usually made at the start that they depend on costs. This seems so obvious that it is often taken as the basis of all the subsequent discussions. I suppose it is necessarily true, when properly interpreted, but in the calculations made on this basis there often appears to be an error. The apparent calculated costs do not always determine the actual rate unless the calculations are carefully and judicially made. For instance: It costs more to build the second balcony of a theater than to build the orchestra seats, and yet there is no dispute that in spite of their greater cost it is proper to charge less for them.

If we want to fit the costs to the prices, we must look at it another way. We must first consider the orchestra seats alone. The cost of the performance and the fixed charges on the orchestra portion of the building total are, say $2000.00; therefore, $2.00 each for 1000 seats is correct. Then if we add 1000 balcony seats we also add say $500.00 to building expense, but nothing to the cost of performance; so that we may consider the cost of the balcony seats as only 50 cents each and make this the price.

We certainly could not average the cost of the performance equally among all the seats without making the cost and price of the balcony seats more than the cost and price of the orchestra seats. We must divide up the cost of the performance among the different seats in some apparently arbitrary way.

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* An address before the Eastern New York Section of the National Electric Light Association, February 7th, 1911.

Again, it costs a manufacturing plant a large sum to turn out the first article of some new design; nevertheless, the first article must be sold at much less than this cost. Subsequent items thereafter cost very little, but are sold at more than the apparent cost.

In this case, if we want to match cost with price we must do exactly the opposite of what we did with the theater. With the theater, we first considered the orchestra alone and then charged only the added expense against the added balcony seats. In the case of the sample article we must consider that the extra development expenses, or at least part of them, do not apply to the first sample but are part of the cost of the later productions.

We can even carry this one step further. If the new article were going to advertise our general business we could call all the development expense general advertising, so that we could sell all the items at a price based only on the cost of manufacture after the development expense had been paid, and could still say that the price depended on the cost. If, however, we divide the total cost by the number so as to get an average, we are apt to be wrong.

Take further the theatrical instance spoken of above. We could easily conceive of some special operatic performance, for which the balcony seats might become very much more desirable than the orchestra seats. In this case it would be proper to charge at least as much for the balcony seats as for the orchestra, and possibly more, and then we could fit the costs to the prices by ascribing a large part of the cost of such a performance as cost of the balcony seats.

Practical experience in nearly every line shows that if price depends on cost, then the question of how costs shall be divided among the different articles we produce—whether theater seats, manufactured articles, or kilowatt hours—is still a problem. We have seen from these examples that merely averaging does not solve the problem.

This fact, that the average results have no basis of fact back of them, is one that is seldom realized; averaging is merely taking a chance. It may be the best chance, but it is not a fact; it is a chance. The more we get rid of averaging the closer we come to the correct solution, but until we stop averaging altogether we are still taking chances and not using facts.

Take our own case: The average cost of electricity per kilowatt hour does not tell at all the cost of any particular kilowatt hour. This of course was understood even in the early days, and there have been many papers written on electric rates and costs, from the days of Hopkinson to the latest. Even before the days of electricity the gas men had discussions on gas prices, in which they analyzed their costs into fixed charges and running charges. Today there is a certain uniformity among many of the writers on electric rates. Most of them start out with the hypothesis that rates depend on costs. I have already stated, however, and shall bring out the point still further, that if rates depend on costs the question of how to apply this statement is still open and that merely averaging will not do.

Next, these writers analyze the costs into three classes.

First, general fixed charges, or cost of getting ready, or readiness to serve for the general supply. This, they say, is proportional to the demand or maximum amount of electricity used at any one time.

Second, customer fixed charges, or cost of getting ready, or readiness to serve the individual customer. This, they say, is proportional to the number of customers.

Third, running charges, or cost of producing the electricity. This, they say, is proportional to the kilowatt hours used.

Having analyzed the costs as just described and stated as a hypothesis that the prices should be proportional to cost, the next step of setting the price on the basis of a fixed charge per kilowatt, a customer charge, and a running charge, is an obvious one and it would seem as though the problem were completely and simply solved, but for the many practical difficulties that are encountered. No company has yet practically applied such a system, even to a majority of its customers. Prices may depend on costs but it is sure that proper prices are seldom proportional to average costs.

Of course the trouble with the foregoing proposition is that it is still the result of averaging, though among three classes instead of one, and not of taking the real costs. The basis of this solution is that costs can be divided into certain broad classes, such as demand costs, customer costs and running costs, and that the prices shall be correspondingly assigned. This is merely going two steps further than if we took only one item, as the number of seats in a theater or the number of kilowatt hours produced, and figured all our costs per seat or per kilowatt hour and made all our prices on the same basis. Instead of kilowatt hours, we might nearly as well take the number of customers, as the telephone companies used to do. If we take only one item, such as seats, kilowatt hours or customers, we do not get a practical system. If we go further and classify by three items, as fixed costs, customer costs and running costs, still we do not get a practical system, because there are many other items besides these three that affect cost; and these other items cannot be safely averaged up among factors of which they are independent.

To begin with, the fixed charges or investment depend on a good many other things in addition to kilowatts of demand. For instance, a demand in a district where wires must go underground would probably cost more to supply than a similar demand in an overhead district; and yet again it might be in such a densely settled district that it would cost even less. It is clear that the cost per kilowatt of demand is different in different cases and is not necessarily the same as the average obtained by dividing all the fixed charges by all the kilowatts of demand.

In the same way there is no figure of customer cost that is strictly proportional to the number of customers, since to make arrangements to serve fifty customers in an apartment house from one service, costs much less than to get ready to serve the same number of similar customers in separate houses. On the other hand, we cannot use services as our divisor instead of customers, since a large service costs more than a small one. The same thing is true of running expenses, since kilowatt hours at the end of a long feeder cost more than at the end of a short feeder, etc.

If we are going to take all the factors that affect costs, then, in addition to the three items of kilowatts of demand, number of customers and kilowatt hours, we must add at least the following items, which affect costs in each case.

First: Distance charges, or distance from the station.

Second: Street charges, i.e., whether overhead or underground, and if overhead whether in country districts where short, cheap poles can be used, or in residence districts where good-sized square poles are called for. If underground, whether street is of dirt or asphalt, etc.

Third: Quality charges, i.e., whether voltage is kept steady or allowed to vary and whether outages are kept negligible or allowed to become serious.

Fourth: Change charges, i.e., whether customers stay on the lines year after year, or on the other hand (as in a cheap apartment house) move every few months with resulting changes in records, meters, etc., all of which cost money.

Fifth: Distribution charges, i.e., whether the supply is in one large quantity at a single point or in many small quantities at separate points requiring much greater investment and operating expense for distribution.

These items and many others always affect costs and have been used in making rates. For instance, street charges are taken into account when prices for street lights are made higher because taken off the underground system.

Quality charges are taken into account when a company has a power circuit with fluctuating voltage and allows a customer to use light off that circuit at a less price than would be charged on the steady voltage lighting circuit.

Distribution charges are taken into account by wholesale discounts; and without continuing the instances it is obvious that there are a great many things that affect the costs and can be used to affect prices besides kilowatts of demand, kilowatt hours and number of customers. If costs are to determine rates, then the other factors of cost should have consideration as well as kilowatts of demand, kilowatt hours and customer charges.

Now, while the task would be tremendous, it would not be impossible to take all the costs of a company on the one hand and all the circumstances of supply on the other and work out a system of prices based on these costs. We should have on the one hand investment, coal oil, waste, lamps, etc., etc., and on the other hand, so many customers using each so many kilowatts of demand at such and such times of day; using so many kilowatt hours of direct current and so many kilowatt hours of alternating current; we would have so many services overhead, so many underground, so many miles of dirt street and so many miles of asphalt street, etc., etc.; and then we might work out a separate cost and a separate proper price for each separate customer. This might be possible, but it is obvious it would be complicated. It would be worse even than the postal guide or department store prices, or municipal water rates. When most rate experts find they cannot express all cost features as part of the rate, but must take only a few—like the kilowatt hours, kilowatts, kind of business, power and light, wholesale and retail, etc.—they say that the other cost items must be averaged among the items that are actually used in making the price, and the fallacy here is that we cannot safely average but must study each case by itself.

Costs determine prices to the extent that all our costs must, in some way, be divided among the prices; but it is never safe to average any more than it was safe for the old woman who offered to sell a cow and a hen at an average price of $15.00 each. She sold the cow. The average cost is sometimes the guide, but it is never a sure test of the real cost or proper price.

The rate expert who depends on averages first attempts to take all the costs and then divide them up so as to make prices. When he finds so many factors that the resulting system becomes top heavy he simplifies it by averaging; but this is correct only by accident. He finds, for instance, some item such as the cost of changing records every time a customer moves in and out of an apartment. He says that it is not expedient to make a special charge each time a customer moves in or out that will cover this item, but that this cost must be averaged among the rest of the business. It is true that it must be absorbed in some way by some part of the business if it cannot be charged directly to the customers who move; but merely because it amounts to a certain number of dollars and because we have so many kilowatt hours is no reason why each kilowatt hour should necessarily bear the same proportion of this particular item of cost. In this case, it might be very reasonable to say that residential customers alone should pay a little extra, while power and street lighting (being permanent business as compared with residential customers) should get a little better rate than residential, since the former costs less for changing records than the latter. This would be done by making a higher rate per unit to the class, by a higher monthly minimum, or in other ways.

The group of writers I have referred to say that certain items of cost, such as kilowatts, kilowatt hours, and customers should form the basis of charge and the other items of cost should be averaged.

As a matter of fact, there is no company that does not take additional items, such as wholesale and retail, power and light, etc., into account in making its rates, and I do not see any theoretical reason why the three items of kilowatt hours, kilowatts, and customers should be picked out and others neglected. For instance, distance from the station is probably the item that affects cost most. Why should not this be selected as the item to determine prices just as much as kilowatts of demand? Or if the underground investment is heavy, why not charge so much per foot of street, using one figure for dirt streets, another for asphalt, and another when the lines are overhead?

It is clear, I think, that the average cost theory heretofore put out has not, even when using three averages instead of one, been the real basis of the successful rate systems of today. If the rate theorists have not given us real flesh and bone rate systems, and if (as would appear from the above analysis) they will probably never work out practicable rate systems from cost alone, let us, if we can, find what has been the basis on which the present real systems have really been worked out.

What has really happened when a manager —the real man who made the rates—attacked the rate problem? It has not been to make rates proportional to costs, even after averaging out enough factors so as to make a simple system.

In practice, the real rate maker has done something quite different. He has not used any theory at all. The thing that he has done in making rates has been to select an existing system and take into consideration, all its costs, such as coal, oil, investments, labor, etc., and all its circumstances of supply, such as number of customers, kilowatts of demand, kilowatt hours, distances, etc. These, of course, are what any theoretical expert would consider, but in addition the responsible rate maker considers also the existing rates. It is important to remember that we can hardly imagine a set of cost data without an accompanying rate system on which these costs depend. Even a proposed company makes its estimates on the basis of selling at some rate or rates, and has these proposed rates, as well as its estimates of cost, before anything is done.

The manager then takes a complete existing system—rates as well as costs—and without making any theory starts to consider some proposed change. The question is, what will be the result of a particular change, and in figuring on this the practical man notes a thing which rate experts often forget; i.e., that costs depend on the rates just as much as they do on the price of coal or price of money. If we had always fully appreciated this fact we should have avoided some of the curious rates that have been suggested from time to time.

Note again this very important fact—costs depend on rates. This is true of all businesses. Suppose a lamp company makes and sells lamps for a year at 15 cents cost and at 15 or 16 cents price, and the next year decides to charge 20 cents. The sales will probably drop off; the overhead charges must be divided among fewer lamps; and the cost may become 16, 18 or even 20 or 30 cents, according to the number of lamps made.

In a like manner a reduction of price will probably, by increasing trade, diminish the overhead charges per lamp and thus decrease cost. Costs depend on rates, and every time we consider the question we must start by considering existing rates as well as costs.

Now, the practical man who makes real rate systems realizes this in fact if not in words, and when a change is proposed he starts out with his existing conditions and then estimates what will be the conditions after the change, inquiring what effect the changes of rates will have on the costs and whether these changes of cost will require any further readjustment in rates.

The following examples are made purposely rather elementary; in actual work far more complex conditions enter.

Supposing, for instance, we have nothing except a 15 cents per kilowatt hour rate and our company is paying running expenses and just making a fair profit on the investment. The theoretical rate expert might figure that the fixed charges were, say $60.00 per kilowatt of demand, and the running charges 1 cent per kilowatt hour, and that we could replace the 15 cent rate with a readiness-to-serve rate of $60.00 per kilowatt plus 1 cent per kilowatt hour and continue to get the same income. The rate expert might suggest a rate of $60.00 per kilowatt plus 2 cents per kilowatt hour as a means of increasing the profit.

If, however, the company established this rate and withdrew the old 15 cent rate, then some customers who were raised would go to gas while some present long-hour customers would save money, and, possibly but not necessarily, long-hour gas consumers might come on the system. The result might be more or less business and profit than with the old 15 cent rate.

On the other hand, if the 15 cent rate were kept as an option, no customers would be lost, but some income would be lost from existing long-hour consumers and, perhaps, some might be gained from former gas consumers.

No one could tell from the analysis of previous costs what would happen, since the change of rates would have its effect on business and on future costs. It is obvious, therefore, that we cannot tell surely from present costs whether a new rate is correct.

The practical and correct way of going at the rate problem is this: We have on the one hand the present rates which have produced certain definite classes of customers, each using so much electricity, or rather so much service and paying the appropriate rate. On the other hand, we have the present costs, composed of cost for investment, coal, meters, general expenses, etc., etc. We put all of these down as present conditions.

Next, we must put down the proposed rates and estimate what customers will be produced by these new rates and what they will pay us, and we must also set down what will be the cost for investment, coal, meters, general expenses, etc., under the new conditions.

Having set down all of these items, i.e., present rates and costs on the one hand and proposed rates and costs on the other, we compare the two and if the second gives better results than the first, we may try the change.

Sometimes this is very simple. For instance: Suppose we have a company doing all its business at a 15 cent per kilowatt hour rate in a residential district with 100 customers, each paying $25.00 per year and thus giving an income of $2500.00 a year, which, we will say, pays running expenses and just gives a fair profit.

Now consider a proposed rate, or rate system, to keep the 15 cent rate for all customers that pay less than say $3000.00 a year, and to give a rate of 3 cents to any customer who will pay over $3000.00 a year.

We estimate that the new customers produced by these new rates would be one factory paying $3000.00 a year; the old residential customers would remain just the same. The new costs would be the present costs plus the running expenses involved by the new business, the fixed charges involved on the new investment, and also any additional general expenses involved by taking on this particular additional customer.

We might estimate that by taking on this new customer all our expenses of every nature and description would be increased by only $2000.00 a year against an increase in income of $3000.00; it is at once obvious that it would pay us to try this change in rates.

A more common and also more difficult case would be to suppose that the change of rate suggested was merely to cut a 15 cent rate by 20 per cent, to 12 cents. In this case the new conditions would be that some of the customers would continue to use the same amount of electricity, paying 20 per cent less. Others of the old customers, however, would use more electricity and might pay as much or even more than they were formerly paying on the 15 cent rate; of course, using more electricity, which would increase the costs for coal and for investment, but only to a negligible amount for meters and billing. Some new customers would also be produced, which would increase the costs in every way.

We would estimate what would be the results after the change of rate had gone through and produced its effects and then we might easily decide that the conditions of the 12 cent rate would probably be better than those of the 15 cent and we might decide to try it.

Then we might consider a 10 cent rate, and this might turn out to be better even than one of 12 cents. Finally, of course, we would reach the point where the cut in rates would no longer produce enough new business to warrant the change.

The simplest and easiest case that arises is when we can classify business so that we can offer a new rate that will not cut any of the income from existing business. This is the case in the illustration used above of the residential district and the factory.

If an electric company were doing railroad business another method would be to announce a new rate applicable to railroads only, which would not affect any of the present income, and if the additional income obtained from the railway business more than paid for the additional costs, everything included, it would, of course, pay a profit.

This can be carried to an extreme, and if we were allowed to and could in practice make a special contract with each new customer, we could then produce the greatest and best results. In practice, however, to make a separate contract with each customer would lead to unfair discrimination, and the practical way in which the matter is handled is by classification.

The various classifications that are made are: First of all, by the normal and obvious basis of the number of kilowatt hours; second, by the kind of business, as power, lighting, street lighting, etc. In the railroad business, classification is made according to the value of the freight and the kind of freight. For instance, we might classify by the distance from the station; we do classify by wholesale and retail and in some cases by the quality of service. We classify by whether business is of long hours or short hours, and of course there are many other classifications that come up and are used. The practical man adjusts the prices in each classification so that the total results shall be the best.

Of course, we can have double and multiple classification, i.e., we can have a rate system with different rates for different kinds of business, and in the rate for each kind of business we have as part of the rate different wholesale discounts and different long hour discounts. Whatever system we have at any particular time is changed in practice only after first estimating the effect some change will have and then by trial and error attempting to get the best result.

Now in making rates, the chief problem is to determine what is going to be the effect on the costs, and the analysis of costs into demand, customer, and running costs will now be found very useful in making this estimate, provided we use it only as far as it is analysis and omit any question of averaging.

For instance, we propose a new rate; we then estimate that a certain number of existing customers will continue their use as before. The new rate then changes the income from these customers but does not change the cost. Some other existing customers we estimate will use more kilowatts of demand and more kilowatt hours. The analysis helps us to show what effect this will have on expenses, since each added kilowatt of demand may call for some new investment and each added kilowatt hour will call for more coal; but it is essential to remember that the new kilowatts and kilowatt hours will not necessarily cost the same as the present average.

The new rate will also, we estimate, bring in new customers, and in addition to more station investment, fixed charges, and coal and running charges, these new customers will require meters, etc., involving customer charges; but these again will not necessarily be the same as the present average customer costs.

The added expenses will seldom be as much as the present average. If, for instance, an analysis of costs shows an average fixed charge of $100.00 per kilowatt, it will usually be found that adding 1000 kilowatts more will not add over $50,000.00 a year to the fixed charges, or $50.00 per kilowatt. In the same way, if coal and other running costs average 2 cents per kilowatt hour we might probably add 1,000,000 kilowatt hours for an added cost of $10,000.00, or only 1 cent each.

Sometimes the reverse is the case and some particular addition may require a whole new engine, so that this particular addition costs more than the average. Of course in such cases the next addition costs practically nothing.

It is very easy to make errors as to what will be the increase in expenses when we add an item. For instance, the head of a department will often figure that if he adds one clerk to his pay-roll he merely increases his expenses by that amount. He forgets that when he adds a clerk the expenses for rent, light, heat, stationery, office boys, etc., etc., are all apt to increase before the clerk has begun to bring in any new income.

When we add a customer to an electric company we have, before we get through, additional expenses for meters, meter readers, billing, postage, complaint department, general expense, purchasing department, coal, labor, oil, waste, etc., etc., and even if an existing customer merely increases his current consumption, all of the above expenses may sometime or other be affected.

Errors can easily be made either way. For instance, the early proponents of the demand system put far too much emphasis on the kilowatts of demand. An analysis, of course, showed that the expenses of the company could be divided into fixed charges and running charges. They figured the fixed charges so as to come out at say $60.00 per kilowatt of demand and the running charges to come out at say 1 cent per kilowatt hour; and then these proponents, myself included, jumped at the conclusion that whenever a kilowatt of demand was added $60.00 was added to the expenses, and that whenever a kilowatt hour was added only 1 cent was added to the expenses.

As a matter of fact, each added kilowatt hour in most companies costs from a negligible amount (as in some water power companies), up to several cents. Each kilowatt of demand added costs from a negligible amount up to $25.00 or $30.00 and occasionally more. Each added customer costs from a few cents per month up to perhaps several dollars per month or more, independent of the costs of the electricity he uses.

There are also expenses that do not necessarily depend on the number of kilowatts, kilowatt hours or customers, but depend on other items, as, for instance, the distance from the station, or the quality of service supplied, etc., etc. These other expenses are not necessarily involved by the addition of kilowatts, kilowatt hours or customers, and yet their cost must, nevertheless, be charged to the business in some way.

We can charge more per kilowatt hour to everybody, or we can pick out certain classes, as for instance, light as distinguished from power, and charge more to that class only. A municipal plant might even say: "Well, these expenses for underground service shall be charged to the tax payers generally and not to the users of electricity."

While these expenses that are not proportional to kilowatts, kilowatt hours or customers, must be absorbed either by the whole business, or by some particular class or classes, we must always remember that while to average them either over the whole business or over particular classes may happen to be the best solution we can obtain, it is not except by accident a correct solution. Each case must be solved separately by comparison until we finally select the best of the lot, and even then we may later find a still better solution.

The foregoing discussion shows how successful experience has worked in making successful rate systems. Can we state any principles that will help us in experimenting? I think the following, though like most theories incomplete in at least some details, is at least useful.

1st. *Total price:* The total price of all the products of a company should equal the total of its costs. This is merely stating in new words that the company is entitled to a fair profit and no more.

2nd. *Minimum price:* The price to any individual, or rather to any class of customers, should never be less than the increment cost to the company of the class. Increment cost means, of course, added cost brought on by added business, or net saving in expenses if business of class is lost. Increment cost varies greatly from time to time. If we have idle investment the increment cost is apt to be small until the investment comes into use. Hence if we take on permanent business we must consider what effect this may have later, as well as the immediate effect.

A class of customers would here mean any division for which it is practical to have a separate price.

3rd. All the prices cannot be set at the lower limit because this would not give sufficient income to the company.

4th. *Maximum price*: Of course no price can ever permanently be more than what it would cost the customer to provide himself with the service in some other way, either by making the electricity for himself, or by using its equivalent.

5th. All prices cannot be set at the upper limit, because if not a monopoly, this would immediately invite competition; and if a monopoly, it would give too much income and would invite government regulation.

6th. *Actual prices between these limits:* Starting with any given set of rates we should always make changes as follows: We should add any proposed rates that apply only to customers not now using the service, provided they will give more income than the increment cost. Such new rates, since by hypothesis the customer cannot afford the present rates, will naturally always be lower than the present rates, and it naturally follows that the new rates should be no lower than necessary to obtain the business.

7th. We should cut any present rate to an existing class provided we feel sure that after we have cut the rate new business will develop which will bring in enough to pay its increment cost and also make up for the loss in income from the present customers.

8th. If any rate has developed a class of customers so that by losing the business we should save more in expenses than the loss of income (all things considered), then we should raise that rate or rather re-classify and raise the rate to the unprofitable class, but no more than enough to make that class profitable.

9th. Supposing we find that our existing business is giving us more than a reasonable profit. In such case we should, of course, reduce prices, unless we prefer to improve the service, which is the same thing in the long run as reducing prices, since it consists in giving more value for the same money.

If we decide to reduce prices it might occasionally be proper to reduce the price to all classes equally, as, for instance, by taking 1 cent per kilowatt hour off the price to each class; or we could reduce the prices in the same proportion, i.e., cut the price to each class by the same percentage.

It is obvious, however, that most often neither of these would be the best and that the most advantageous way would be to select those classes on whom the existing prices bore most heavily and cut the price to them. Such a procedure would naturally be the most apt to develop new business and thus allow the greatest possible reduction in price.

10th. On the other hand, we might have a case where it was necessary to raise prices: for instance, suppose the expenses should, for proper reasons, go up heavily. In such a case it is obvious that it would not be desirable to raise prices all along the line, but it would be better to pick out those classes on whom the existing prices bore least heavily and raise the price to them. This would have the effect of losing as little business as possible, and therefore in the long run result in the smallest possible raise.

Each case, however, would have to be analyzed by itself. Usually it happens that the increase in expenses applies chiefly to certain classes of business. So long as these classes remain profitable, that is, so long as these classes continue to bring in more income than would be saved if the business were lost, it would not be absolutely necessary to raise the price to these classes, especially if they were classes on whom the existing rates bore heavily.

If, however, the increase in expenses brought about a state of affairs so that these classes brought in less income than would be saved if the business were lost, then it is obvious that the price to these classes should at once be raised, at least to a point where they would bring in more than their increment cost.

In any case, since we cannot classify exactly, it would be probable that if an increased expense applied chiefly to the business of a particular class, then an increase in price to that class would discourage, or at least be apt to discourage some of the customers who were an absolute loss to the company, but who had to be included in the class.

The closer we can classify the better results will we get, but on account of the impossibility of complete classification we cannot always adjust rates at the best points.

11th. On the other hand, it is very easy to get too many classifications, and while a classification that pays is necessarily good, it is a good rule to simplify when in doubt. The following extreme example of classification that has been profitable to the public may perhaps be interesting:

A railroad was built to take ore from a mine to a smelter. The ore, so far as weight, ease of handling, etc., was all the same. The first established rate was $1.00 a ton, which was found to produce insufficient tonnage to make the railroad pay. This was because the lean ores could not afford to pay this rate.

The rate was therefore cut to 25 cents a ton, at which rate the tonnage was greatly increased, but still the income was not sufficient to pay the expenses. Finally, a rate of $1.00 a ton was established for the rich ore and 25 cents a ton for the lean ore, which did pay expenses and enable the road to run.

Of course this illustration is very familiar in the case of freight rate on anthracite coal from the mines to tide-water, where the rate is strictly proportional to the value of the coal rather than to the tonnage.

Another more amusing illustration was that of a bridge in Venezuela, where the tariff was first established at 5 cents, with the result that all the natives continued to use the ford and the bridge did not pay. Then the rate was made 1 cent and all the natives as well as the white people used the bridge, but still it did not pay. Finally, the rate was made 5 cents for everybody who wore shoes and 1 cent for everybody who went barefoot; everybody used the bridge, making it pay, and more bridges were built at other parts of the river to do business on the same basis.

Of course in both these cases we might fit the costs to prices by a little juggling with figures. In the case of the bridge, for instance, we could say that all the fixed costs of the bridge are to be paid by the white people who wear shoes, since the bridge is for their benefit; and the fixed costs, when divided among the number of people who wear shoes, makes 4 cents to which we add 1 cent for running expenses.

We say that none of the fixed charges is properly ascribable to the natives who do not wear shoes, because they do not want the bridge anyway and can use the ford just as well as the bridge; therefore we only charge them their cost, which is 1 cent for running costs.

Or we could use other figures: Say that we had decided that one-half of the cost should be charged up to the white people who wear shoes and one-half to the natives who do not wear them, figuring each as a class; then, when the cost to the class is divided among the number in each class, the result gives a rate of 5 cents to the few white people and 1 cent to the natives.

In similar ways we can juggle figures for other rates so as to make cost and prices match.

It is interesting to note in how many cases the average costs do actually fit the proper prices so that prices worked out on the average theory, especially when using several units, are usually pretty near right. This is natural, because the average is, by the theory of least squares, most probably correct; but it is important to remember that the average is not necessarily the correct figure and any worker on rates must always remember that the average is merely an artificial guide and not any real thing.

The foregoing has been a discussion of rate theories, but so far we have not said much about the rates themselves. What kind of real rates has the actual work in making real rate systems given us? In the first case it has given us a standard price per kilowatt hour. I do not know any company in the world that has not finally come to have some so-called maximum—a standard price per kilowatt hour varying from perhaps 5 cents in the lowest case I have heard of, up to 30 or 40 cents.

Next we find in nearly all cases that differentials have arisen from this standard price, based on the kind of business; power being usually charged for at a less rate than the lighting price, and also street lighting being charged at another rate. We then find that practical rate makers have produced wholesale discounts, the wholesale discounts resulting in prices lower than the standard price. Next we find that nearly all real rate systems contain long-hour discounts for certain classes of customers, such as drug stores, all-night restaurants, street lighting, power, etc. Again we find that certain special businesses, such as charging storage batteries, etc., have been given still lower rates than the other classes.

The above differentials that are found in practical rate systems are below the standard price and have been produced by the method outlined above of finding business affected by a new rate that would give additional income greater than the additional costs.

Practical rate makers have, however, in some cases produced differentials raising the rate above the standard price. One case is where a new customer comes on at a great distance from the existing lines, so that the expense of reaching him is so high that if he were taken on it would cost more to supply him than the income he would bring in. In such cases most practical rate systems provide that such a customer must guarantee a considerable amount of power use; and, of course, if he guarantees more than he will actually use, this is equivalent to a raise in price.

A second case where the practical rate makers raise the price, even above the standard price, is when a customer who has his own plant requires auxiliary or breakdown service. In such a case the practical rate makers require a guarantee proportonal to the kilowatts of demand, which, if the use is small, is equivalent to a raise in price.

The third case where the price is raised above the standard is in the case of customers who use so small an amount that the income does not pay for the metering, etc. These are taken care of by what is usually known as the dollar minimum.

These are the main differentials that have been produced by practical rate makers.

What are some of the items that have been suggested which have seldom been used by the practical men? In the first case I will speak of one, as to which there may be a considerable difference of opinion, and that is the so-called customer charge in the rates that provide for a customer charge, plus a charge per kilowatt of demand, plus a running charge per kilowatt hour. It seems to me that this customer charge has never been put in as necessary to get the business or to keep unprofitable business off the lines, but has only been put in as the result of theoretical considerations. Hence I do not consider it as a proper part of a rate.

Second, a number of theorists have called for maximum demand systems in every case and claimed that a very short hour customer was unprofitable at any ordinary rate per kilowatt hour. The practical rate makers have discarded this theory and are not only willing but desirous to take ordinary short hour customers at reasonable rates per kilowatt hour.

The reason of this, of course, is that a short hour customer, even if his demand is high, is so unlikely to use power at the time of the station peak that the probability of his adding to the real investment cost is small and therefore he can be given a very low rate in proportion to his number of kilowatts of demand. Further, the shorter the time of his power consumption, the less is his chance of interfering with the station peak.

Some maximum demand theorists call for a very low running charge per kilowatt hour to all customers—even as low as one cent. The practical rate makers, when they make long-hour discounts, have very seldom put their running charge to small customers below five cents, because this rate is sufficient to get the business of drug stores, etc., and it has not seemed right to the practical man to go lower in any rate (except the standard rate) than necessary to get the most business.

There might be theoretical arguments for making a price for companies that supply different kinds of current or different voltages, according to the kind of current. The practical men, however, have seldom put differentials of this kind into their systems. They have never put distance from the station into their rate systems, with the exception of the case spoken of above, of requiring a guarantee where a long run is needed for a new customer.

The practical men do not put the length of contract into the rate systems, with the exception of street lighting contracts. It was formerly the custom to make a very distinct differential for large customers, according to the length of contract, but the developments in the last few years have shown that this differential was not really on account of length of contract but was more the differential spoken of above, of making the customer, who involved a new investment on the part of the company, sign a guarantee. As these old contracts expire, they are being renewed at the old prices without requiring the customer to sign a new long term agreement.

How does this discussion help in some of the problems that are now confronting us? The most important is that of the Mazda lamps. Here the problem is, what shall we do when the Mazda lamp reduces the number of kilowatt hours and kilowatts that are required for a given service? When a customer puts in Mazda lamps we have a new set of conditions just like a new set of rates and the question is, what is the effect on cost and what changes should be made to take account of these changes in cost? Since all rates are solved by trial and error, each case will be different according to the rates with which we start.

In general, however, the customers who are now on a kilowatt hour rate will pay to the company less income, and the reduction in income will be greater than the reduction in expenses. The only way to get back to an even standing would be to raise the income in proportion to the number of kilowatt hours used. This can be done by raising the rate per kilowatt hour but it is doubtful whether any of us want to do this unless we have to.

Another way in which the income could be raised would be to add a customer charge to every bill. This, of course, would be the same as raising the total money paid in proportion to the kilowatt hours used, and it is a question whether we would wish to do this.

It is sometimes said that the companies which have a customer charge as part of their rate systems are fortunate in having some income that is unaffected by the Mazda lamp. This, however, is much smaller than is usually thought to be the case.

In Boston, for instance, we have an income of $5,000,000.00 a year, of which say $3,000,-000.00 is from light and $2,000,000.00 from power or other service which is not affected by the Mazda lamp. Out of our 40,000 customers perhaps 35,000 are light users. If all these 35,000 had been paying us a customer charge of $12.00 a year this would have given us an income of $420,000.00 a year unaffected by the Mazda lamp—14 per cent of the lighting income, or 8 per cent of the whole income.

If instead of getting a customer charge from all our customers we had an optional kilowatt hour rate on the one hand and a readiness-to-serve rate with a customer charge on the other hand, and had 10,000 customers on the readiness-to-serve rate; then the customer charge would have given us $120,000.00 a year, which would have been, roughly speaking, 4 per cent of our lighting income unaffected by the Mazda lamp, or $2\frac{1}{2}$ per cent of all income. As a matter of fact, it would have been a little less than this, since the Mazda lamp would have caused some customers to change from the readiness-to-serve rate to the kilowatt hour rate in order to get rid of the customer's charge.

This discussion therefore indicates that any such scheme of rates will not interfere with the results of the Mazda lamp, except by a very small percentage, and it looks as though no new rate system or old rate system would help us with the problem.

The dollar minimum is another most important question that is under discussion. In some cases it has been suggested that companies should be obliged to give up any minimum at all. Of course this will immediately produce a number of customers who will require meters and billing expenses and will produce less income than the mere expense of reading their meters and taking care of their accounts. This expense must be borne by other customers.

In general, therefore, it would appear as though we should have a minimum of some sort or else charge more to the man who uses a fair amount of electricity.

It is perfectly possible that there are customers who are mentally so constituted that they will pay the company $20.00 a year if there were no minimum in their contracts but who will not take any service at all if there is a minimum. If this class of customers should turn out by experiment to give sufficient income to pay for those customers who take the service and give no income, then of course a company could wisely give up any dollar minimum at all.

In regard to this, it is interesting to note that there should be a difference between companies that have apartment house business almost entirely and companies that have practically all separate house business.

In the case of apartment house business the service will almost surely be put in, so that a dollar minimum would not have any effect in reducing the number of services that brought in a very small income per service. In such cases giving up the dollar minimum entirely would have a less effect in increasing expenses, since the increase in expense would apply only to meter expenses, etc.

On the other hand, if the company were supplying separate houses entirely and gave up the dollar minimum, this would have a tendency to increase the number of services that paid a very small income per service and might mean a serious loss.

It follows, therefore, that companies which do almost entirely apartment house business would be more apt to give up the dollar minimum than companies who do separate house business, and this is exactly what has happened. Chicago and New York, for instance, are distinctly apartment house cities as compared with Brooklyn and Boston; Chicago and New York have given up the dollar minimum while Brooklyn and Boston have felt it necessary to keep it.

It should be noted, however, that the Mazda lamp may have an important effect on this question, since it would increase the number of small users, and they might become so large a portion of the business as to make a minimum imperative.

Another problem that confronts us is the suggestion that instead of using a meter to measure the kilowatt hours, we should use a limiting device to limit the kilowatts of demand, letting the customer use as many kilowatt hours as he desires, subject to this limitation.

Supposing we should adopt such a plan. We must use some definite figures, and I will take one that has often been suggested—that we should sell on such a basis as a cent a watt a month, or $120.00 per kilowatt a year, and compare it with a meter rate of 10 cents and an optional Hopkinson rate of $60.00 per kilowatt of demand per year plus 5 cents per kilowatt hour. We would see at once that we could not apply this to all the business without losing a considerable amount of income, because drug stores, all-night restaurants, and similar kinds of business now bring in considerably more than $120.00 per kilowatt a year.

We might, therefore, say that we would apply this only to residence lighting. Very few residences now pay $120.00 per kilowatt based on their individual demand, so that we could say that such a new rate would not reduce the income from existing customers unless they should change their use in order to get the new rate.

The question of what existing customers would do is of course problematical. A cent a watt, however, would mean that a customer who never used more than 300 watts, or six ordinary lamps, would have a bill of $3.00 a month, which is about the average of residential and apartment business. Three hundred watts would not allow the use of any flatirons or similar devices, although a very large proportion of existing apartment and residential customers do use them.

It is probable, therefore, that very few existing customers would take such a rate as this, since in order to have a flatiron, they would have to pay at least $6.00 a month, or $72.00 a year, which would be more than any of them pay except in the very best class of houses. These customers in turn would certainly want to use more than twelve 50 watt lamps, or twenty-four 25 watt lamps.

The question would then be what business would be produced by such a rate. We should get a certain number of new apartments and houses. In case of apartments, we would add to our expenses the cost of a limiting device, billing, etc., etc., which we will figure at 25 cents per month. The customer that took 100 watts would pay us $12.00 a year. He would, of course, use a great many more kilowatt hours in proportion to the kilowatts than the ordinary lighting customer. Supposing he used 2000 kilowatt hours a year for each kilowatt of demand, such a 100 watt customer would then use 200 kilowatt hours a year. Including fixed expenses, this would probably not add 4 cents a kilowatt hour, or $8.00 altogether to costs, to which should be added the cost of the limiting device, etc.; so that such customers would bring in $12.00 a year and would add to the expenses about $11.00.

If they were larger, i.e., if they were 200 watt customers paying $2.00 a month or $24.00 a year, the profit would be more than doubled.

On the other hand if such customers involved any large expenses for setting of poles, etc., it is very doubtful whether they would pay; but if they were almost all apartment house customers where the service expense per customer was small, or in houses that could be reached at very small service expense, it is probably that such business would be profitable.

It would be only by experiment that we could determine whether there would be sufficient customers of this class to warrant having a special rate for them, and also it would be only by experiment that we could check the assumption made above that very few existing customers would take such a rate in order to reduce their bills, or to use more kilowatt hours. I think it is very probable that such a rate, now that the Mazda lamp is available, would develop a class of business that would be profitable and that we are not now getting.

There is another question, however: With the Mazda lamp (which we have) and a very cheap (even if not extremely accurate) meter, which we ought soon to have, can we not get this class of business on our present rates? We can only tell by experience, and since it is hard to withdraw a rate when once offered, we have to experiment very slowly.

Let us now review the foregoing discussion.

We began with the present theories of rates and noted that some of the most elementary theories were the result of merely dividing the total costs by some single arbitrary unit, as for instance by the number of kilowatt hours produced in our own business, or by the number of telephones connected in the telephone business, figuring that the result of the division was the true cost, or proper price per unit.

We next noted that a number of investigators had made a very considerable advance on this theory by finding out that an average cost, or rate based on a single unit was wrong. Most of these investigators had suggested that for the electrical business three units should be used; viz., the kilowatt hours, the number of customers and the kilowatts of demand. They suggested that the costs and prices obtained from averaging on the basis of these three units were the true costs and proper prices.

We found, however, that rates based even on these three averages instead of one still did not give us rates that stood the test of experience as practical rates. Having found out this, and that even a much larger number of averages would probably still be impracticable, we inquired as to what had been the actual practice in making electric rates, and found that it had not been based on any theory of average cost, whether of single average or of averages based on three or more units.

We found that the real successful rate systems, as distinct from theoretical systems, had been based on experiment and judgment only and not on costs; except that the total of all prices usually depended on the total of all the costs.

We found that real rates had been developed in each case by taking existing rates and then experimenting with some suggested change, retaining the changes that did actually result in better conditions; and that, while the analyses and averages had proved very useful as suggestions, the averages had practically never been used as the final correct figure.

We then discussed some of the lines along which these experiments had gone in the past and would go in the future, coming usually to the conclusion that when rates bore so hard on any particular class of consumers as to diminish their use of current, such rates should be reduced so as to increase the business, but only to the point where the increase of business would give enough profit to more than make up for the loss of income.

In a similar way we found that when rates were such that the expense of supplying customers, or a particular class of customers, brought in less income than would be saved in expenses if that class of business were lost, such rates should be raised.

If we try to express this in a few words, we have to put it that while the total of all the rates should be proportional to the total costs, so as to just give a fair profit and no more, yet as between different classes the rates should be proportional to what the traffic will bear; or to put it in the way in which it is actually worked, that the rates should never be more than the traffic will bear, provided of course that they should never result in absolute loss.

This, as said above, relates merely to the ratio between the rates to different classes. The total of all rates should, of course, be based purely on cost, so as to give no more than a fair profit, and the total of the prices should have no relation to what the traffic will bear.

We next discussed in a general way what actual concrete forms the various experimenting had brought forth, and found that, in general, these consisted of a standard rate with two or three differentials that made the actual rate higher than the standard, such as the $1.00 minimum and the auxiliary service minimum.

We also briefly discussed one or two of the individual rate questions that are now being particularly considered.

Our final result shows that there is no easy theory of rates by which we can predict prices for any given set of conditions. Real prices are made by experimenting with existing prices until we finally get the best results, and while the rate expert can use the cost analysis and average cost and the various theories as given above as helpful guides, he must always be on the lookout that they do not lead him into error.

The test of any proposed rate is not whether it fits into any theory, but whether, when it is finally in use, it gives better results for the company and its customers than before.

As a matter of fact there is not, and probably never will be, any simple final concrete theory of rates, but the rate question is like other arts and sciences, and is still in process of development by means of intelligent experiment and consequent progress.

THE TESTING AND ADJUSTING OF A GENERAL ELECTRIC OSCILLOGRAPH

By Franklin L. Hyndman

Standardizing Laboratory, General Electric Company

Description

An oscillograph is an instrument that requires a thorough examination and an accurate adjustment of parts before it can be considered in proper condition to use. Before going into the details of adjusting and testing an oscillograph, a description of the instrument will be given for the benefit of those readers who are not familiar with its construction.

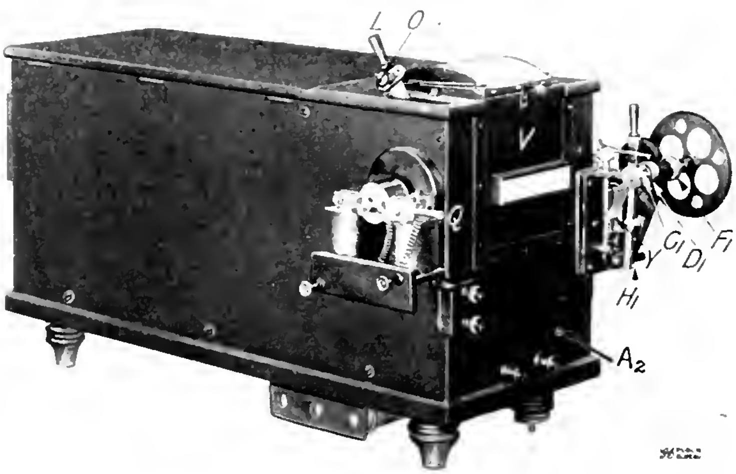

Fig. 1. The Complete Oscillograph

There are two patterns of oscillographs; namely, the three element electro-magnetic oscillograph, and the two element permanent magnet oscillograph. Only the electromagnetic instrument will be considered in this article, as the process of testing and adjusting is long and much of the work is duplicated in getting the permanent magnet instrument ready for use. The special features and advantages of both types were outlined in an article on the oscillograph by Mr. L. T. Robinson, published in the Review for November, 1910.

The complete outfit consists of, first, the oscillograph proper, in which is embodied the galvanometer and its three vibrators, the optical system (with the exception of the lens in the lamp), the shutter and its operating mechanism, the tracing attachment and the photographic attachment (see Figs. 1 and 2); second, the lamp and its rheostat; third, the synchronous motor with its rheostat for operating the tracing attachment; fourth, the film-driving motor with its special rheostat and the six cameras or roll holders; fifth, the rheostat for the galvanometer field circuit; and sixth, the various repair parts and accessories consisting of extra mirrors and suspension strips, films, mirror cement, damping liquid and complete instructions. There may also be supplied resistance boxes and shunts for taking current records.

Considering the parts in the order named, the oscillograph box is shown in Figs. 1, 2 and 3. In Fig. 3 the cover is removed to show the relative positions of the galvanometer at the left, the prisms "G," the shutter "SH," and the slits "O" at the right to control the width of the light.

The galvanometer (Fig. 5) is of the electromagnetic type made with three independent elements. The field of each element is concentrated at the point where the moving part of the vibrator is located. The pole pieces are concealed by the front of the cell box that holds the damping liquid. The vibrator (Fig. 4) consists of a single loop of flat silver wire strung tightly over a pulley and resting on two insulating bridges. The tension is maintained by the spring in the balance at the top. The vibrator has a short period and a low sensibility. The moving part is just the length of the strips between the bridges and hangs in the middle of the concentrated field. Adjustment of the position of the beam of light in the horizontal plane is controlled by the screw "W" (Fig. 5), and in the vertical plane by the screw "S."

The optical system consists of the short focus lens in the front of the lamp, the three prisms, the lenses in the front of the cells, the mirrors on the strips of the vibrators, and the cylindrical lenses in the front of the box. The light passes to each in the order named. (Figs. 3, 5 and 6.)

The shutter which controls the passage of the light into the box is operated by an electromagnet that has external contacts on the mechanism in the front of the box at the right; marked "D1" and "G1" respectively in Figs. 1 and 2.

The tracing attachment consists of the synchronous motor and the synchronous mirror which it rocks. The arrangement of the cam or eccentric and the mirror with its lens is shown in Fig. 6, where the support of the lenses and mirror has been removed from the box. The motor is of the iron cross type, with four poles in the rotor, and two field coils. (See Fig. 1.)

The photographic attachment, of which the optical system and shutter form the greater part, is contained in the box proper, but is supplemented by six film holders. (Fig. 7). The passage of the light into the box is controlled by the shutter and its operating mechanism, and the passage of the beam to the film by the shutter "U" at slot "R." The light comes to the slot "R" from the cylindrical lens shown in the lower part of Fig. 6, under the rod. The top of the drum is revolved away from the box in making an exposure, a small direct current motor being used to drive the drum. The speed is variable, and is controlled by a special rheostat.

The lamp is a small hand-feed affair with contact on the carbons and the feed combined. The feed consists of a pair of grooved wheels, one above and the other below the carbon. The adjustment of each carbon is separate from the other. Only a small amount of current is required to produce sufficient light for most work.

Series resistance boxes of a special type recently developed have been found convenient for use with the oscillograph. They have well-insulated frames supporting mica cards on which the resistance wire is wound. Various taps are brought out so that almost any resistance desired can be obtained.

In a general way, the relative positions of the main parts of the outfit as placed on a table for use, are as follows: The box is placed at the front right-hand corner of the table, so that the pulley is beyond the right edge. The lamp is placed at the left side of the box so that the light may pass straight through the lower of the two holes. The rheostats may be arranged on supports between the legs of the table convenient to their respective parts of the outfit. The resistance boxes and instruments are generally placed in the space at the left of the box and back of the lamp. The film-driving motor may be on the floor under the table or on the table back of the box. The switches should be on the top of the table in front of the box and lamp.

This arrangement, while convenient, is not inflexible and may be altered to suit the operator's ideas and the conditions of the test.

Adjusting and Testing

The elements of a proper test are somewhat as follows: the assembling of the parts

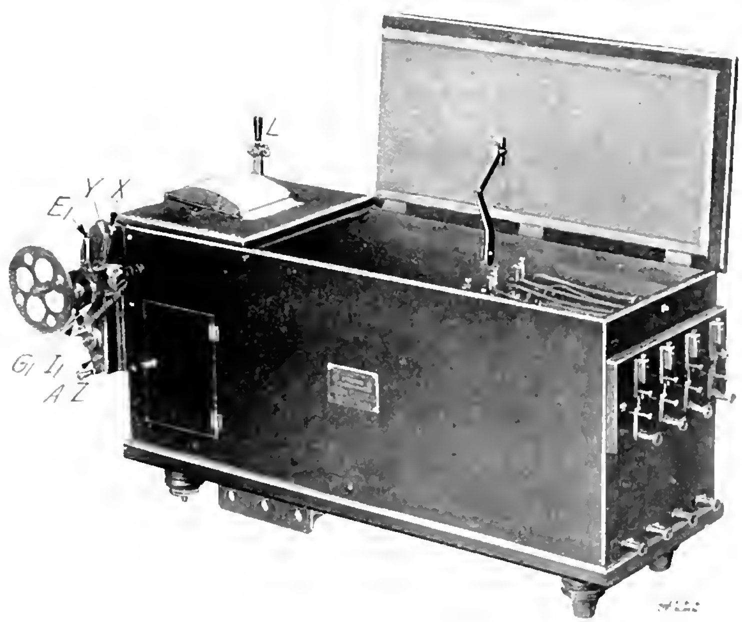

Fig. 2. Another View of the Oscillograph

and attachments and the correct adjustment of these parts in themselves and in their relation to others. The various parts will be considered in much the same order as that in which they are really adjusted. There are some parts which can be adjusted properly once for all without reference to the adjustment of other parts, while certain parts are quite dependent on their neighbors for position and adjustment.

One of the two cylindrical lenses in the front of the box is a two-inch focus photographic lens about five inches long, and the other a four-inch focus visual lens of the same length. The photographic lens is fixed

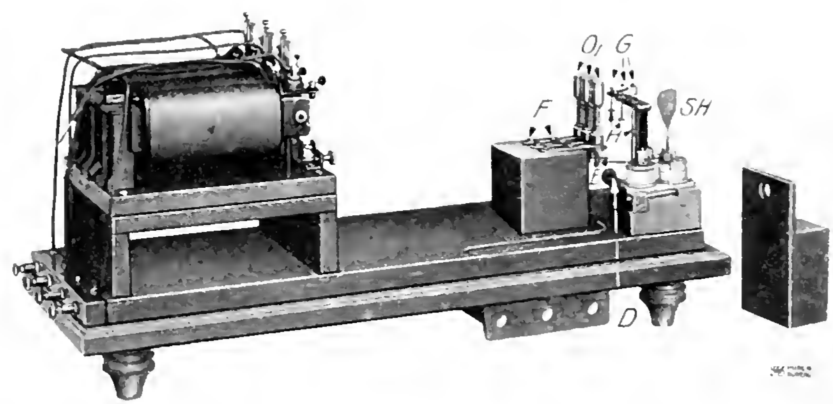

Fig. 3 Oscillograph Removed from Case, Showing Various Parts of Optical System and Galvanometer

in position and after being once focused is not moved again. The focusing is done on the ground glass, as this is in register with the film. The visual lens is definitely fixed before the synchronous mirror and requires no adjustment.

The Optical System

As stated before, the optical system consists of a fixed focus lens in the lamp, three totally reflecting prisms, three adjustable slits, three lenses in the front plates of the cells, two cylindrical lenses and a mirror in the top and front of the box, and a shutter which controls the entrance of the light to the box. Except for the shutter, the order is that in which the light strikes each and also the order of adjustment.

It would appear that almost any alignment of lamp, prisms and slits would do for ordinary operation, but such is not the case; very nice initial adjustment of the prisms with reference to the shutter and of the slots with reference to the prisms is required.

First, the lamp should project the beam, from the proper distance, through the opening in the shutter case and at right angles to the box or case; secondly, the prisms should be adjusted tentatively to throw beams on the cells and should be moved on their supports so that the shutter allows the light to strike all cells at the same moment. The slits are then moved so that the best part of the beam (the middle) passes unobstructed to the lenses in the cell fronts. They are then to be fastened securely, as they should need no further adjustment if the lamp and prisms are properly arranged in further work.

The Hand-Feed Lamp

The small hand-feed arc lamp used to furnish light for photographing and viewing requires no adjustment only an examination to make sure that the carbon holders make good contact and feed the carbons properly; also, that a movement of the lamp up or down within a short range can be secured.

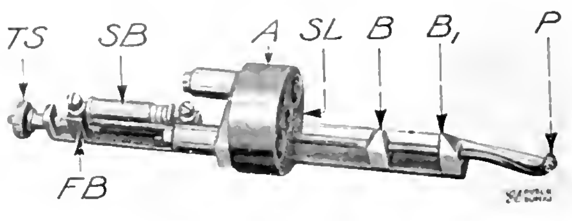

Fig. 4 Vibrator

The Galvanometer

Before assembling, the galvanometer is tested at 6000 volts alternating current between the windings and the cores; after assembling, the insulation between the cores and the cores and the windings must withstand 5000 volts alternating current for one minute. The only test made at the laboratory to try out insulation is one between cores and

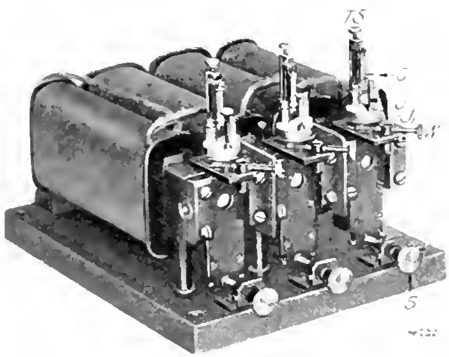

Fig. 5. Three Element Galvanometer

windings and between the cores at 500 volts direct current. To pass, the resistance must be at least thirty megohms.

The resistance of the field coils is measured and recorded. The coils are not measured separately, as any bad error in winding or connection would be evident as soon as the current was applied and the deflection of the vibrator observed.

The cells are tested by a standard gauge, pinning it down on the seat in the regular way and noting its position between the pole pieces. The cells are filled with oil to the proper height and any leak around the face plate is noted and stopped. The movements of the vertical and horizontal adjustments are tried and any irregularity is corrected.

The Vibrators

The three vibrators are examined to see whether the strips lie flat in the slots in the bridges and whether the mirror is straight and in its proper place. They are also tried in a standard gauge to see if the strips are in exactly the right plane in reference to the block which determines their position in the cells. Each vibrator is calibrated in one cell for equality of deflection each side of zero. One vibrator is used in each of the three cells successively and a set of five readings taken each side of zero, which is called "scale characteristic." This test shows whether the strips are located in the field properly, and whether the derivation from proportionality is negligible.

The Electric Shutter

This shutter consists of a pivoted armature located between two poles, moving a vane back and forth across the opening in its case. The armature is set by hand so that it is in that position at which the poles are exerting their maximum force when the shutter is open. In this position the vane or shutter is fixed to just clear the opening, and to strike a stop when the cover is in place. The spring which closes the shutter is next adjusted. It is also noted whether the shutter case is insulated from the two leads which enter at the bottom. The wiring of the shutter is examined for any faults, and the shutter finally adjusted for 600 r.p.m. of the film drum.

Shutter Operating Mechanism

Trials are then made with the worm contact to adjust the lever so that it drops into the thread about one revolution ahead of the contact wire. This is accomplished by turning the small screw near the bottom of the flat phosphor-bronze spring that is

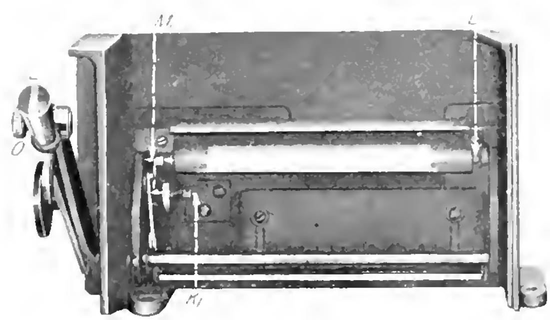

Fig. 6. Cylindrical Lenses, Cam and Cam Shaft

below the lever. This spring controls the "set" position of the lever and needs only this one adjustment.

The instantaneous or disc contact is next examined for the position of the spring contact with reference to the contact in the disc when "set." The adjustment should be such that when the releasing lever is pulled, contact is made just before the disk or wheel starts to turn; also in the "set" position the two contacts should be just far enough apart so that the wheel may be turned without closing the circuit. The contacts are held apart by an insulated post against which the lower spring rests until the lever is pulled.

Film Holders

The six film holders furnished with each oscillograph are tried with a lamp in a dark room to see if the shutter or joints leak any light. The shutter should turn easily and open and close completely. Each is tried in its place on the oscillograph box for fit and coincidence of slot with that of the end plate. The driving pin is put in place and joined to the driving lever, and is tried out to determine if the two shafts, that of the drum and that of the driving mechanism, are in line. The drum should turn easily so that there may be no unevenness of rotation.

Photographic Record

To record the adjustment of the electric shutter an oscillogram is taken at 600 r.p.m., using the "worm contact." This should show exposure for almost exactly one revolution, and only a small variation from exactness is allowed.

Tracing Attachment

The various parts, such as the synchronous motor cam and cam shaft, oscillating mirror, lens, levers and screen are mentioned in various places and their uses shown. The general scheme is a motor rocking a cam and mirror synchronously with the movement of the vibrator, this motion in turn causing the projected beam to outline any wave form on the screen. The parts are dependent on each other in some such fashion as this: first, the motor, running, rotates the cam; then, when the mirror is lowered into position, the lever on the mirror shaft rests on the cam, being held there firmly by a spring, and as the mirror is moved forward, the wave is outlined on the screen. The light is cut off by a revolving shutter for slightly less than half the time in order to allow the mirror to drop back and still not show any irregular curve produced by the return movement.

The cam and cam shaft should be inserted in the position in which they will be run, and the position of the lever on the mirror should be such that it rides evenly on the cam. When the control lever that moves the spring on the mirror lever is down, the pin should touch the cam during the whole revolution; but when it is up or back, the pin should just clear the point of the cam. This adjustment can be made by changing the position of the hub of the lever, which comes above the box.

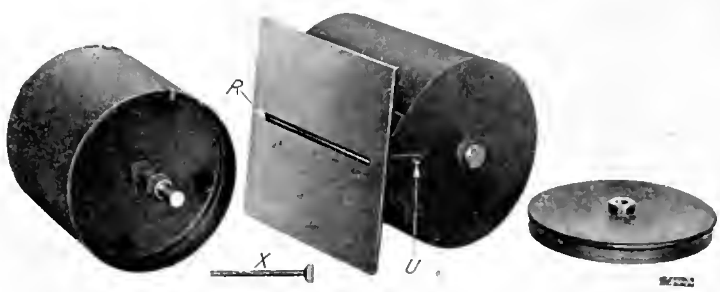

Fig. 7. Film Holder

There should be no end play in the mirror adjustment. After the mirror has been so adjusted on its pivots that the projected beam moves across the middle of the screen and all tracings made to show that the cam and other parts are properly set, the mirror is pinned to its pivot shaft to prevent any further movement.

The various parts are so adjusted that the wave lengths are about equal at any frequency; that the shutter or fan on the motor controls the light so that it is seen about the same length of time before and after the wave passes through zero; and that there is a steady and continuous wave shown on the screen. The lever may be raised from the cam so that there appears only a straight line on the screen parallel with the axis of the mirror; this is simply the reflection of the beam from the stationary mirror.

The tracing attachment is tested for proper currents to operate the motor and for the adjustment of the cam at three frequencies; viz., 25, 60 and 125 cycles. Tracings are made for record.

Cam and Cam Shaft

The cam or eccentric had to be set on the shaft (with a smaller nut than is finally used) so that the point comes in the same line with the pin of the coupling. The small movement of the cam necessary to change the lengths of the wave halves on the tracing table can be made by loosening the nut and revolving the cam in the proper direction. After the cam has been set in proper place and all the records taken, it is necessary to pin the cam to the hub to prevent any movement. The small nut is then replaced by the large one which covers the pin.

Synchronous Motor

The armature must rotate easily with little friction in the bearings. The fan or revolving shutter should run without striking the nuts or coils. Occasionally it is necessary to rebalance the armature; this is done with the fan attached.

The square circuit breaker must be adjusted to open the circuit at the proper time to make synchronizing easy, and the contact lever must also be set to move downward just far enough to open the contacts and allow the armature to turn when the bars are opposite the poles.

The motor should fit the box so that there is no trouble in meshing the coupling of the fan and the coupling of the cam shaft, and no unnecessary binding or friction when the armature turns.

Apparatus Specially Designed to Facilitate the Testing and Setting of Electric Shutter

To test and set the magnetic shutter, a mechanical device has been made which consists of a shaft with supports occupying the same place that the film drum does. In one end of the shaft is the regular driving pin and on the other a twelve tooth gear wheel. In place of the synchronous motor, there is a bracket holding a shaft fitted with a revolving fan (a semi-circle) and a twenty-four tooth gear wheel. The bracket has an opening which allows the light to pass to the prisms. The two gear wheels are in line and connected by a chain, so that the fan is revolved at the same speed as the synchronous motor armature, thus operating the cam and cam shaft.

The test is always made at 600 r.p.m. of the driving shaft, which in turn drives the fan and cam shaft at 300 r.p.m. The worm contact is used so that the time of opening and closing can be depended upon to occur at practically the same point every time. The scheme depends upon the movement of the synchronous mirror by the cam and the opening or closing of the electric shutter during that time.

The operation is as follows: The shaft is driven at 600 r.p.m. and the mirror is made to rock in the regular way by the cam, which runs at 300 r.p.m. If the electric shutter is held open continuously, the light will be seen moving across the screen half the time, but if the shutter is opened by the worm contact, it will be seen only during the time of contact. Now the time of contact may or may not be during the time when the light is seen on the screen, but one or the other, the opening or the closing, must be seen. The ends, or the points of opening or closing as shown by the beam on the screen, should come at the same point on the screen. Until they do so, it is necessary to change the tension in the spring.

The beams may be seen coming from the front of the tracing screen and stopping at a point, indicating the closing of the shutter; or from this point on the screen, or near it, to the back side of the screen, indicating the opening of the shutter. With this device, it is possible to calculate the time lag of the shutter as indicated by the position of the worm contact in reference to the driving lever. Trials of the setting are made till the tester is satisfied that the adjustment is correct The setting may take from five to twenty minutes, and to obtain the photographic record five more; whereas, before this device was put in use, the operation of finding the correct tension on the spring took from ten minutes to as many hours, depending on the number of photographs it was necessary to take.

If no trouble is encountered in testing an oscillograph, the time required for a complete test varies from two to three days. The time formerly required for this work has been materially shortened by changes in the instrument and by the use of certain devices which make the adjustment much easier and more certain.

FLUORESCENCE AND PHOSPHORESCENCE

By W. S. Andrews

Light is generally produced artificially by heating a solid or vaporized material to incandescence, the result being much heat and comparatively little light. Various organic and inorganic substances, however, possess the curious property of radiating visible light waves at normal atmospheric temperature, as in the case of phosphorescent insects, decaying wood and many natural and artificial mineral compounds.

The general phenomenon of *light independent of heat* has been termed "luminescence,"* and it has been subdivided under numerous headings, according to the nature of the excitation required, etc. Under the heading of "photo-luminescence" we find in certain substances the transient effect known as "fluorescence" and the persistent effect termed "phosphorescence." These two curious and wonderful phenomena of light are closely allied, but they differ from each other in one particular: for, whereas fluorescence can only be ordinarily observed in solids when influenced by the invisible ultra-violet weaves in the ether, phosphorescence is produced by a much wider range of vibrations, running from the infra-red, through the visible spectrum and extending far into the ultra-violet.

Fluorescence may be considered as an absorption of the invisible ultra-violet waves and their instant transformation and radiation in the form of longer waves that are visible to the eye in various colors of the spectrum, depending on the nature of the fluorescent material, which thus becomes a *frequency changer* of these vibrations in the ether. The term fluorescence is derived in a roundabout way from the Latin word "*fluo*" meaning "to flow." Many years ago it was found that a certain mineral was very efficient in the smelting of iron from its ore, causing the slag to *flow* freely and thus separate readily from the molten iron, and for this reason the mineral was named "fluorite" or "fluorspar." Long afterwards it was discovered that fluorspar also possessed the property of emitting light when excited by ultra-violet waves, and this property was therefore called "fluorescence." If small particles of chlorophane, which is a greenish variety of fluorspar, are thrown on a hot plate, they will flash up with a bright emerald-green or bluish light like little stars, remaining thus for a minute or two, after which their light will gradually fade away. The right name for this remarkable property is thermo-luminescence, as the small particles of fluorspar appear to absorb the long invisible heat waves from the hot plate and then transform and emit them as shorter waves of the visible spectrum. This is, however, only a possible explanation. We are as yet ignorant as to the secret and wonderful atomic mechanism by which this and other similar transformations in light waves are effected.

The phosphorescence of various animal and vegetable organisms is probably caused by chemical action, as it does not apparently depend on any outside source of excitation. Inorganic substances, however, which possess the quality of phosphorescence generally require external stimulation to develop it, and in these cases the energy of the ether waves appears to be absorbed and stored and then gradually radiated from the material, so that the latter continues to emit light after the exciting source is removed. The decay of luminescence is in some cases so slow that the substance continues to glow for hours. In other cases the decay is so rapid that phosphorescence can only be detected by special devices, while some fluorescent substances do not appear to possess any appreciable phosphorescent properties.

When a material is both fluorescent and phosphorescent, the same color or tint is usually seen in both conditions, but in some few instances the fluorescent and phosphorescent colors are different.

Many of the aniline dyes are beautifully fluorescent and one of them has been named "fluorecein" on account of the magnificent green color exhibited by its solution in water when excited by ultra-violet light. Rhodamin is another fluorescent aniline dye. It develops a beautiful red fluorescence, but only when in either liquid or solid solution. Thus, when dissolved in alcohol, it is highly fluorescent; but if the alcoholic solution is painted on a white card, after the alcohol has evaporated the dry rhodamin left on the card will show

* "Light—Visible and Invisible," S. P. Thompson (1911), p. 174.

no sign of this property. If, however, a piece of white cardboard be painted with a clear varnish colored with rhodamin, it will be red under the light of a mercury lamp, which is nearly devoid of red rays, and under which any non-fluorescent red color will appear black or slate color. The light of the mercury lamp is very rich in the violet and ultra-violet rays, but most of the latter are absorbed by the glass tube. Enough of them pass through, however, to cause the rhodamin to show its beautiful red fluorescence.

It is a rather curious fact that fluorescent and phosphorescent colors run mostly towards the center of the visible spectrum. Thus green is the predominating color, then blue and yellow occur in fewer instances, while red is more rare and violet is seldom observed. The luminescence of the glow-worm, the firefly, and various marine organisms, for example, is found to consist essentially of green and yellow light.

Several years ago, Mr. W. J. Hammer conceived the clever and ingenious idea of *coloring* inorganic phosphorescent substances with fluorescent aniline dyes, so as to produce changes in the original natural phosphorescent colors. A United States patent was granted to him in 1908 covering the details of this new art.

The well-known commercial preparation called Balmain's luminous paint is made by mixing phosphorescent calcium sulphide with a clear oil varnish. When any object is treated with this paint and exposed for a few minutes to sunlight, or any strong artificial illumination such as an arc light, mercury lamp, etc., it will continue to glow for a long time in the dark with a faint bluish color.

Mr. Hammer discovered that by the proper mixing in of different amounts of rhodamin, this natural bluish phosphorescence could be modified to assume many beautiful tints of violet and purple up to a shade of pink; but it is probably impossible to produce a pure red in this way on account of the original phosphorescent blue of the calcium sulphide, which cannot be entirely suppressed by the rhodamin. Most beautiful and artistic color effects, however, can be produced by these mixtures, which it would be difficult if not impossible to get in any other way.

This artificially colored phosphorescence has been adapted to the construction of a light-transforming reflector, by means of which a considerable amount of red light can be added to the illumination of the mercury lamp, thus making it more pleasing and natural. As before stated, the mercury vapor lamp emits a considerable amount of invisible ultra-violet light which, under ordinary circumstances, is naturally a waste product. This reflector absorbs these invisible waves and changes them into visible phosphorescent light, which by a secondary action is colored red by the fluorescence of the rhodamin; it therefore not only performs the useful purpose of transforming some of the visible rays to the red end of the spectrum, but also actually adds something to the efficiency of the light by turning what would otherwise be an invisible waste product into useful light.

Another strongly phosphorescent compound is known commercially as Sidot's Blende, and is a preparation of zinc sulphide. Like the calcium sulphide it can be mixed with clear transparent varnish and used like an oil paint without interfering with its luminous properties. This paint by ordinary light is white with a slight yellowish tint, but if exposed to a strong light and then viewed in the dark, it will be seen to glow with a beautiful green color. If a small quantity of rhodamin is added to this paint, its color by daylight will be changed to a pale pink, but it will then glow in the dark a light primrose yellow, and all the various tints from light yellow to dark orange can be obtained by varying the rhodamin contents. If a little calcium sulphide is added to some of the paint which phosphoresces a light yellow, a whitish phosphorescence may be produced; but owing to the fact that none of the phosphorescent colors are pure, it is hardly possible to get a clear white. By the proper manipulation of the calcium and zinc sulphides and the admixture of these with rhodamin and other fluorescent aniline dyes, an endless line of very beautiful phosphorescent tints can be produced, and we are much indebted to Mr. Hammer for his clever conception of thus giving artificial coloring to phosphorescent substances.

These color effects can be conveniently studied and exhibited by means of a simple form of phosphoroscope devised by the writer for this purpose, a short description of which may be of possible interest. Referring to Fig. 1: A is a thin disc of sheet metal or stiff cardboard, on the surface of which rings of the different colored phosphorescent preparations are painted. This disc is attached to the shaft of a small fan motor (the hidden parts of which are traced in dotted lines) by means of which it may be revolved at a speed of from 1000 to 1500 r.p.m. B is a light wooden box, closed on all sides excepting the one facing the disc and having a small mercury arc lamp C mounted inside and connected to the terminal posts seen on the left. This box is pivoted on a standard D, so that it can be rocked like a see-saw for the

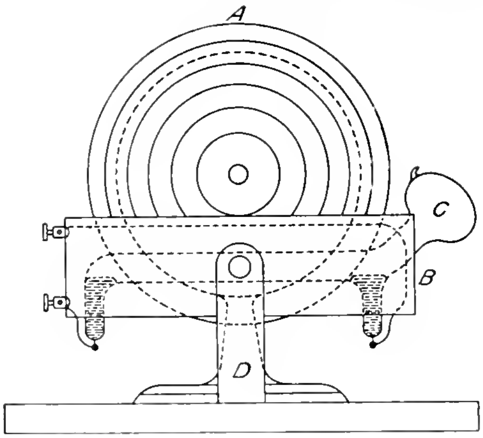

Fig. 1

purpose of starting the mercury lamp. The position of the motor must be adjusted so that the surface of the revolving disc just clears the box, in order to shut in as much light as possible. The mercury lamp being lighted, the motor can be started and the phosphorescent rings will shine up brilliantly in their respective colors, being under continuous excitation as they pass before the opening in the box containing the mercury lamp. The color effects may be varied by painting the phosphorescent materials in different designs on the discs, so that they may be blended by rotation. One of these designs is shown in Fig. 2. In this case the radial star is made with rhodamin paint and the ground is painted with plain calcium sulphide. On rotating the disc, the center appears red, blending through different shades to blue on the outside and producing a pleasing effect.

The sulphides of calcium and zinc have been referred to at some length because they are well-known commercial preparations, and also because their phosphorescent properties can be readily excited by almost any strong light. There are, however, a number of natural and artificial compounds which are responsive to only the shorter and invisible ultraviolet waves to which glass is partially or entirely opaque. For the excitation of these substances the high tension iron arc can be conveniently employed, as this produces an ultraviolet spectrum which extends about one octave beyond the visible violet.

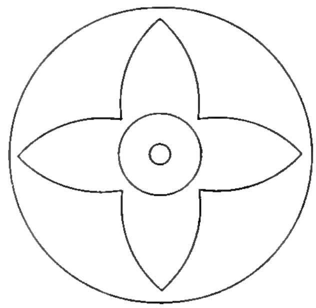

Fig 2

A selection of some of the most interesting of these compounds with their fluorescent and phosphorescent colors is given in the following list:

	Fluorescent Color	Phosphorescent Color
Platino barium cyanide	Bright green	None
Calcium tungstate	Light blue	Very faint
Willemite (natural) (zinc silicate)	Vivid yellowish green	Green
Willemite (artificial) (zinc silicate)	Pale green	Bright green
Strontium sulphide	Green	Green
Red calcite (calcium carb.)	Pink	Dark red
Barium sulphide (Waggoner's preparation)	Pink	Primrose yellow
Cadmium silicate (calcined)	Yellow	Yellow
Uranium fluoride	Bright green	Pale green
Salicylic acid and its salts	Blue	None

All of these compounds respond vividly to the excitation of the iron arc, but are influenced very little by the mercury lamp; for, as before stated, the glass tube of the latter absorbs the high frequency ultraviolet waves that are required to bring out their fluorescent colors. For the same reason these compounds cannot be mixed with varnish and applied as oil paints like the sulphides of calcium and zinc, the varnish being opaque to the required exciting waves. In preparing them for examination, however, they can be reduced to a powder and sifted over a surface previously painted with thin gum water or some other adhesive. In this way discs may be prepared for rotation in the phosphoroscope referred to above, an iron arc being substituted for the mercury lamp.

Designs of flowers, leaves, etc., may also be prepared with these compounds, which, under ordinary light, will appear only in shades of gray or white; but as soon as the invisible ultra-violet rays fall on them they will immediately show their characteristic fluorescent colors.

The iron arc naturally emits a considerable amount of visible light in addition to the invisible ultra-violet waves, and it may be suggested that it is this visible light which produces the fluorescent colors. To show that this is not the case, however, a piece of thin window glass or a piece of clear mica only two or three thousandths of an inch thick may be interposed between the iron arc and the prepared card. Although the glass or mica is incompetent to interfere with the passage of visible light from the iron arc, as may be seen by the illumination of the material, yet its rays will now produce no sign of the former colors. On removing the glass or mica, the colors immediately appear, although the visible illumination is practically no stronger. It can thus be conclusively shown that the fluorescent colors are created by the invisible ultra-violet waves to which the glass and mica are opaque.

There are, however, certain substances which are alike transparent to these visible and invisible waves. Thus if a plate of clear quartz or selenite is used for a shield between the iron arc and the fluorescent material, the color of the latter is not destroyed as it is with a shield of glass or mica.

The beautiful effects that are produced by fluorescence and phosphorescence should not be passed by as merely pleasing to the eye and interesting to the scientific mind, for they contain a message of profound meaning which may be interpreted in the future for the general welfare of mankind. Unfortunately, we do not know at present how to produce this *cold light* of sufficient brilliancy for practical purposes, but we all realize the wasteful inefficiency of our present artificial illuminants, and it is not unreasonable to hope that some day we may gain such insight into the workings of nature as will enable us to duplicate to some useful extent the light producing mechanism with which she has endowed the firefly and the glow-worm, or at least discover some other photogenic process which will be more economical than our existing methods.

AGRICULTURAL ENGINEERING AND THE DEMAND FOR AGRICULTURAL ENGINEERS.*

By Samuel Fortier

Chief of Irrigation Investigations, U. S. Department of Agriculture.

Half a century ago engineering attracted little attention. Then only a small number of men followed this vocation and there were few institutions which gave instruction in this subject. It was not until after the people of the North were pitted against those of the South in a war to the death that men began to recognize the value of technical training and to question the wisdom of compelling all college students to spend so large a part of their time in a study of dead languages and a dead past.

The widespread demand for an education differing from that given by the classical colleges culminated in the passage by Congress of the Land-Grant Act of July 2, 1862. This act gave to the several states and territories public lands for the benefit of instruction in the arts and sciences relating to agriculture and the mechanic arts. In 1909, sixty-seven of these land-grant colleges had been established.

The importance of these institutions may be gathered from a few statistics taken from the annual report of the Office of Experiment Stations for 1909. From this it appears that the permanent funds and equipment of these colleges amount to $112,000,000, and the revenue from all sources, state and federal, to over $18,000,000 a year. In regard to the courses of study and the number of students in each, one finds a larger percentage of students in the preparatory, special, and short courses than in the four-year courses. In 1909 there were enrolled in the four-year courses, 27,579 students, of whom 21,930 are grouped as follows:

Engineering	17,892
Agriculture	1,999
Household economy	1,443
Forestry	223
Veterinary science	215
Horticulture	158
Total	21,930

According to the report of the Commissioner of Education for 1909, the total number of engineering students in all the universities,

*Paper read before the American Society of Agricultural Engineers.

colleges, and technical schools of the United States was 31,748, of which number 17,892 were found in the land-grant colleges and 13,856 in the state institutions other than land-grant and private technical schools.

The foregoing statistics disclose two facts that are not generally known. These are, first, that the land-grant institutions are engineering rather than agricultural colleges; and second, that they are training more than 56 per cent of all the engineering students of the nation.

So great is the preponderance of engineering students and engineering courses in these public institutions that it would seem proper to review briefly the character of the instruction given and the courses offered in these subjects. I shall do so on the ground that it is a matter which deeply concerns both the individual states and territories and the nation as a whole. The nation donated 10,500,000 acres of its public lands for the benefit of "instruction in the arts and sciences related to agriculture and the mechanic arts," and last year both state and federal aid, exclusive of tuition fees, amounted to nearly $17,000,000. I shall not attempt to discuss the right of the land-grant colleges to instruct by means of state and federal aid nearly 18,000 students in engineering and only 5,000 in agriculture. This is not germane to my theme. I merely wish to call attention to the fact that the kind of instruction given and the courses offered in engineering do not seem to me to be in full accord with the act under which they were organized and the purpose for which they are maintained. One has but to scan the list of courses offered to find that nearly all are classified under civil, mechanical, electrical and mining engineering, thus placing these colleges in the competition with a large number of state universities and private technical schools. Nor is this all. In their eagerness to train civil engineers for railroad corporations, mechanical engineers for manufacturers, and hydro-electric engineers for water-power companies, they are neglecting to train men for the engineering work of the farm. Only one out of the sixty-seven institutions—the Iowa State College of Agriculture and Mechanic Arts—offers a degree in agricultural engineering and few devote much time or attention to this phase of engineering.

Now, in the brief time alloted to me I shall endeavor to outline the scope of agricultural engineering and to indicate the need and the demand for training along this line. As I view it, the general courses may be subdivided into six branches, three of which relate to the farm and three to agricultural communities. This tentative subdivision is as follows:

1. Farm machinery and farm motors.
2. Farm structures, including rural architecture.
3. Rural water supplies and sanitation.
4. Public roads.
5. Drainage.
6. Irrigation.

These six major studies would, of course, be supplemented by instruction in English, mathematics, drawing, agricultural chemistry, physics, soils, surveying and elementary engineering.

One or more of the subdivisions of this course as outlined is now taught in most of the land-grant colleges, but with a few exceptions they are mere side issues to what is considered the more important work of training men to become professional engineers. The institutions of this class located in the West give instruction in irrigation as part of the civil engineering course. Those of the Mississippi Valley have more or less complete courses on farm machinery and farm motors, while the subject of roads and pavements is included in a large number of civil engineering courses; but, as we shall see later, this instruction is chiefly adapted to the needs of the municipal engineer. Rural water supplies, farm sanitation, and farm structures are for the most part overlooked. What is urgently needed, in my opinion, is an engineering course in each of the agricultural colleges which will combine the courses of farm machinery and farm motors as now given in the University of Nebraska and the Iowa Agricultural College; irrigation as now given in the University of California and the Agricultural College of Colorado; rural architecture and cement work as given in the University of Wisconsin; and highway engineering as taught at the University of Kentucky. That there is an urgent need for better and more general training for the engineering work of the farm is evidenced by the following facts, which relate to the main branches of such a course as I have outlined.

Farm Machinery and Farm Motors

According to the report of the Secretary of Agriculture, the crops of corn, cotton, wheat and oats for the past season aggregate a value of over $3,400,000,000. All four are annual crops, requiring the preparation of the soil and the subsequent operations of seeding, cultivating, harvesting and marketing. When one tries to estimate the large number of implements, machines and motors required for a task of this magnitude, some realization is had of what is annually expended by American farmers in the purchase and maintenance of this necessary equipment. The census of 1900 estimated the value of farm implements and machinery at over $761,000,000, and the annual expenditure for new implements and new machinery at over $100,000,000. This was ten years ago and since then not only the number of implements and machines, but more particularly the number of motors, has been greatly increased. The simple, inexpensive implements used by our fathers have been, for the most part, replaced by more complicated and more expensive machines. Out of the hand flail of the fifties has been evolved the steam thresher of today. The modern harvester does the work of a large number of men, women and children equipped only with the sickle; and motors, trolley cars, and railroads have relegated the saddle bags to the museum. These great changes during the lifetime of men still living, and more particularly the substitution during the past decade of motors for horses and mules, have created a widespread demand for young men possessing a knowledge of motors and machines and the principles which underlie their construction and use. Studies of this character are now as essential to the ambitious farmer boy as anatomy is to the embryo doctor. The simple arts of mending a flail, whetting a scythe, or harnessing a team have grown into a complicated business, demanding not only experience and skill but special training as well.

Farm Structures

Some colleges now give instruction in rural architecture, others in farm architecture, and still others in cement and concrete. I have attempted to combine these under one head and to make the subject broad enough to include such types as the design and construction of concrete drinking troughs, silos, barns and country residences. A number of the land-grant colleges give a course in architecture, but like many others it is designed to draw men away from the farm. Undergraduates who are taught to design and supervise the erection of the palatial homes of the rich, find the city or its suburbs the most convenient place to practice their profession. Nearly fifty years ago the nation provided for instruction of a kind suitable for the boys and girls on the farm; but the millions of poorly-designed farm houses which still mar the landscape are mute evidences that the instruction given did not include rural architecture. The improvement in farm buildings so urgently needed does not call for money so much as a knowledge of how to do things. Out of the same materials and with very little extra labor may be built a pleasant, convenient, healthy, and durable country residence, or the reverse. The main difference is one of plan and execution.

Rural Water Supplies and Sanitation

The contrast between rural and urban residences is still more strongly emphasized in relation to the water supplies and sanitation of each. Skilled engineers are employed to provide an ample supply of water for cities and equally skilled biologists determine its purity, while but little attention is given to farm water supplies and sanitation. Most of the laborious work which falls to the lot of farmers' wives and daughters is due to the lack of proper facilities for providing a plentiful supply of fresh water and for removing the waste. Day after day and year after year the old oaken bucket is pulled up out of the open well by means of a wet, dirty rope, and later on the same water may have to be carried by tired hands from the kitchen to pollute the dooryard.

Farmers procure water for their needs from the same sources which supply water to the residences of cities. These are springs, wells, cisterns, reservoirs, lakes and rivers; but the training and experience necessary to utilize such sources for the benefit of the one class differ in many essentials from those of the other. The civil engineer may succeed in building a distributing reservoir for a city and yet fail in his effort to build a cistern for a farmer. His computations for a high water tower may be correct and those for a windmill wholly wrong in principle. It is true, both belong to hydraulic engineering, but so long as engineers are trained to solve the problems of the city and to neglect those of the country, we need not expect a high class of engineering on the farm.

Farm sanitation is of even greater importance, for on it depends in no small degree the health of the farmer and his family, and to a less extent that of the dweller in cities. The milk can washed in polluted water from the farm well may carry disease to thousands.

The farm water supplies of Minnesota have recently been investigated by Messrs.

Kellerman and Whittaker of the Department of Agriculture, in co-operation with the Minnesota State Board of Health, and after making a careful examination of seventy-nine typical farm water supplies of that State, they concluded their report as follows:

1. Both farm and city are suffering from the careless management of rural sanitation.

2. Exhaustive data upon seventy-nine carefully selected and typical rural water supplies show that twenty were good and that fifty-nine were polluted; the chief cause of the polluted wells being due to careless or ignorant management.

3. During this investigation twenty-three of the farms examined showed a record of typhoid fever.

4. The protection of farm supplies by common-sense methods obvious to anyone who will try to discover the dangers incident to his own water supply, would render safe the majority of farm supplies which are now polluted.

Public Roads

In 1904 the office of public roads of the United States Department of Agriculture collected and compiled from every county in the Union data pertaining to the mileage, revenues, and cost of country roads; this information was condensed in Bulletin No. 32 of that office, from which the following facts are taken:

The total road mileage of the United States is classified as follows:

	MILES
Improved roads	153,664
Unimproved roads	1,997,906
Total	2,151,570

The improved roads are further classified as:

	MILES
Roads surfaced with gravel	108,233
Roads surfaced with stone	38,622
Roads surfaced with special material	6,810

In the same year the total expenditures for public roads and bridges was nearly $80,000,000. This was furnished by counties, townships and districts, and included poll taxes, labor, bond issues and state funds.

The most striking feature of these statistics is the enormous extent, comprising nearly 2,000,000 miles, of unimproved roads in the United States. The same authority estimates the cost of macadam roads at $4500 per mile; of gravel roads at $1500 per mile; and of other surfacing materials at $1000 per mile. It is thus obvious that an expenditure of something like $3,000,000,000 will be required to convert the common earth roads of this country into even good gravel roads. That this change is desirable few will gainsay; that it is necessary under modern conditions and the relations now existing between producer and consumer, is also quite generally admitted.

The rapid increase in urban population has greatly multiplied the demand for the perishable products of the dairy, truck farm and orchard, and the value of such products depends to a large extent on their speedy transportation from the country to the city. For this and other reasons the auto truck and similar product-carrying motors are taking the place of the horse and cart and the farm wagon. Public sentiment in favor of better roads is rapidly spreading to each farm and hamlet. As a result of this awakening, our 2,000,000 miles of earth roads cannot much longer remain in their present condition. American farmers cannot afford to pay on an average of 23 cents to haul a ton a mile when 10 cents would suffice if the highways were improved.

In casting about for ways and means to bring about a change, one of the vexing problems which now confronts the states which have decided in favor of better roads, is the honest and efficient expenditure of road funds. The citizens of California recently voted to bond the state for $18,000,000 for the construction and maintenance of state highways. The majority of those who opposed this measure did so on the ground that no definite plan had been worked out to show where the highways were to be built and what method of construction should be followed. Furthermore, that there was no provision in the act for the maintenance of these roadways when built.

I am of the opinion that California would receive much more benefit from the expenditure of this special fund and that of the $2,000,000 which the State annually expends for highways if her agricultural college had seen fit to establish years ago a good course in highway engineering. The state engineer and other state and county officials would not now have their best efforts impaired by the lack of men competent to plan and locate, construct and maintain the public roads of the State. It is true, the University of California for a number of years has given instruction in highway engineering as part of the civil engineering course, but the main purpose of such instruction is evidently designed for the benefit of the municipal engineer in the construction of city streets and pavements, since the time given to the subject is wholly inadequate for a comprehensive study of both city streets and country roads.

The Drainage of Farm Lands

In 1903 a committee on rural engineering, of which the writer was a member, was appointed by the Association of American Agricultural Colleges and Experiment Stations to prepare and submit a report on this subject. From this I quote the following:

"The marsh and overflowed lands along our seacoast and the bottom lands bordering many of our rivers, are at present unsightly, unproductive, and in some instances a menace to the health of surrounding districts. They need only to be diked and drained to be the most valuable lands in the country. The carrying out of these improvements will add immensely to the agricultural values of the country, and the work is certain to be undertaken in the near future. It involves, however, a larger knowledge of agricultural engineering than can now be obtained in our land-grant colleges. In fact, the profession of agricultural engineer, so prominent in Europe, is almost unknown in this country. Very little has been done in this country to develop a satisfactory drainage practice. The principles of drainage are understood by but few, and instruction in our colleges is meager and far from being up-to-date."

Since the above was written and in response to a resolution of the United States Senate of December 9, 1907, more definite information has been collected on this subject by Mr. C. C. Elliott, Chief of Drainage Investigations, as of the Office of Experimental Stations. Mr. Elliott classified the unreclaimed swamp, overflowed, and wet farming lands of the United States and estimate their extent as follows:

	ACRES
Permanent swamp lands .	52,665,020
Wet grass lands .	6,826,019
Periodically overflowed lands	14,747,805
Periodically swampy lands	4,766,179
Occupied farm lands needing drainage .	150,000,000
Total	229,005,023

In showing the effect on public health of draining swamp lands, the pamphlet recites many instances where the number of deaths from malaria has been grea: y reduced as a result of such drainage. The benefits of agriculture from the same cause are placed so high in the millions as to be well nigh incomprehensible. Perhaps the most surprising thing about this inquiry is that each state in the Union is in need of drainage. The figures giving the total extent, exclusive of occupied farm lands, varies all the way from 8000 acres in Little Rhody to nearly 20,000,000 acres in Florida.

Irrigation

Of even greater importance is the subject of irrigation. Two-fifths of the United States is arid and the remaining three-fifths, although humid, is subject to periodical droughts during which crop failures can be averted only by artificial watering. In the past ten years nearly 16,000,000 people have been added to our population. The public lands suitable for cultivation in their natural state have been taken up and the farms for the future millions must be wrested from the desert by irrigation or from the swamps by drainage. About 13,000,000 acres of desert land have been reclaimed. The water which is applied to this area each crop-giving season would cover the whole of New England to a depth of 15 inches. The handling of this enormous volume, its distribution over widely-scattered areas, and the preparation of the surface of fields so that water may be spread evenly over them, call for an amount of experience and skill not equaled in any other branch of agriculture. Western farmers deserve great credit for the lands they have relcaimed, but their task is not completed. So great is the waste of water at present that 50 to 100 per cent more land might be reclaimed if the waste waters were saved and utilized. It is, however, doubtful if the farmers will accomplish this reform by their unaided efforts. They have gone about as far as they can without the assistance and supervision of the trained specialist. All over the irrigated West from every district and from nearly every farm, and also from the drought-stricken states of the East and Middle East, comes the call for help: How shall I line my ditch to prevent loss from seepage; how much water is needed for this and that crop; when should it be applied; how shall I prepare my fields so that the ditch water will moisten the soil uniformly; and what is the most suitable device for measuring water. In other instances men want information on the construction of reservoirs and tanks, the installation of pumps, the erection of windmills, and the drainage of seeped lands. These calls for help come with every mail to both the

Department of Agriculture and the agricultural colleges and experiment stations. Our branch is doing what it can in this direction, but the appropriation is much too small to cover even a small part of the entire field. As for the agricultural colleges and experiment stations, only a few of our far western institutions maintain strong departments in irrigation. The large majority is engaged in other lines of investigations.

I offer in conclusion the following brief summary:

1. The great middle class of this nation—those who toil in fields and shops—intended to provide a practical and scientific education suited to the needs of their sons and daughters by the establishment of the land-grant colleges.

2. At present over sixty-four per cent of the collegiate students in these colleges are being trained for the engineering profession.

3. The kind of training which these engineering students obtain tends to draw them away from the farm and shop to the city where they become the able lieutenants of corporations and municipalities.

4. For a quarter of a century or more, the land-grant colleges have been catering to the demand for engineers on the part of corporations and municipalities and have expended little effort or money in training specialists for the engineering work of agricultural communities.

5. Unless the curricula of the engineering course of these institutions are modified there is certain to be overcrowding in the older branches of the engineering profession.

6. Meanwhile progress in agriculture and the improvement of rural districts are being immeasurably retarded through the lack of competent agricultural engineers.

COMPENSATORS*

PART III

BY W. W. LEWIS

Compensators for Boosting Voltage of Power Stations

(a) Single-phase. Occasionally a slight boost in line voltage may be desired, say from 2200 to 2400 volts. In cases of emergency a standard 10 to 1 ratio Type "H" transformer may be used. Fig. 24 shows the manner of connection. Since the secondary of the standard transformer is not insulated for 2200 volt service, when used as a compensator in this way, the transformer must be insulated

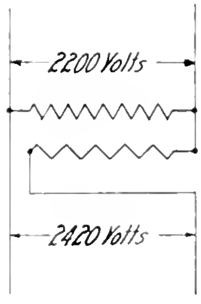

Fig. 24

from the ground by mounting in a dry place on a wooden platform, or by some similar method. For a larger boost in voltage, a special compensator must be provided. Fig. 25 shows such a compensator rated 25 cycles, 280 kw., 11000 9900 volts primary, 2300 volts secondary, designed for 375 kw. output at 9900 10175 10450 10725 11000 volts with 2300 volts impressed. The maximum conditions are as follows:

Section	Current	Volts	Watts
ab	128.8	2300	230,000
bc	37.9	8700	330,000
			560,000

$$\frac{560,000}{2} = 80 \text{ kw.}$$

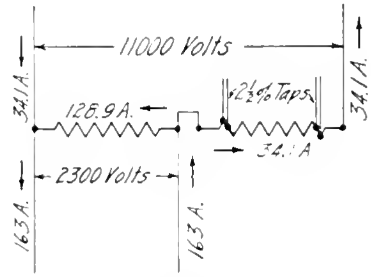

Fig. 25

(b) Two-phase to three-phase.

Case 1: three-phase voltage greater than two-phase. (Fig. 26-a.)

Case 2: two-phase voltage greater than three-phase. (Fig. 26-b.)

Case 3: two-phase and three-phase voltages equal. (Fig. 26-c.)

An inspection of Figs. 26 and 27 will show

*Parts I and II of this article were published in the December, 1910, and February, 1911, issues of the REVIEW, respectively.

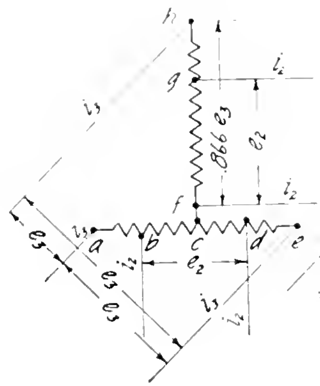

Fig. 26-a

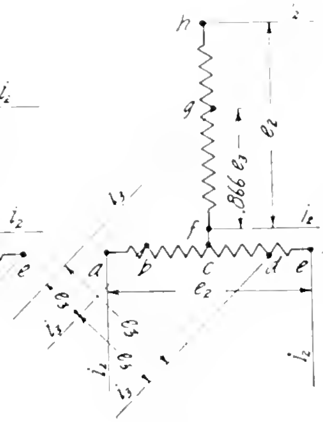

Fig. 26-b

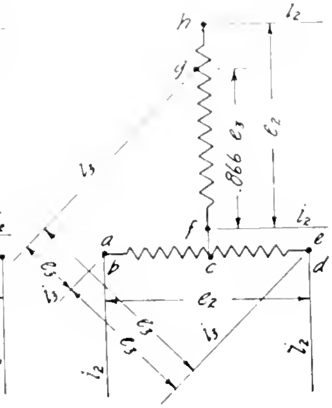

Fig. 26-c

the following current and voltage relations:

In section hg:

Case 1: current i_3; voltage $(0.866e_3 - e_2)$.

Cases 2 and 3: current i_2; voltage $(e_2 - 0.866e_3)$.

In section gf:

The three-phase current i_3 is in direct opposition to the two-phase current i_2. The resultant current in the section will therefore be the algebraic sum of the three-phase and two-phase currents.

Case 1: current $(i_2 - i_3)$; voltage e_2.

Cases 2 and 3: current $(i_3 - i_2)$; voltage $0.866e_3$.

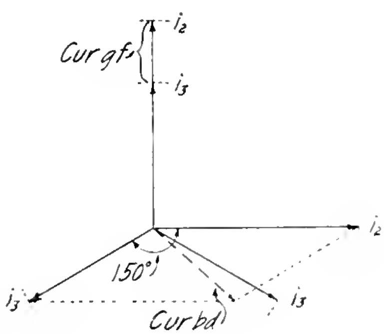

Fig. 27

Sections ab and de. Case 3: *a* and *b* and *d* and *e* coincide, but for the sake of uniformity the current may be considered as i_2.

Case 1: current i_3; voltage $(e_3 - e_2)$.

Case 2: current i_2; voltage $(e_2 - e_3)$.

Case 3: current i_2; voltage $(e_2 - e_3) = 0$.

In section bd:

The current in this section is the resultant of the two-phase and three-phase currents, which are 150 degrees apart. (Fig. 27.) In all three cases this resultant is

$$i_r = \sqrt{(i_3 \sin 30°)^2 + (i_2 - i_3 \cos 30°)^2}$$

$$= \sqrt{(\tfrac{1}{2} i_3)^2 + (i_2 - 0.866\, i_3)^2}$$

Case 1: voltage e_2.

Case 2: voltage e_3.

Case 3: voltage $e_2 = e_3$.

Then for the general case we may write:

1. The current in section *hg* is i_3 if $0.866e_3$ is greater than e_2; otherwise i_2.

2. The current in section *gf* is the algebraic sum of i_3 and i_2 equals $(i_3 - i_2)$.

3. The current in sections *ab* and *de* is i_3 if e_3 is greater than e_2; otherwise i_2.

4. The current in *bd* in all cases equals

$$\sqrt{(\tfrac{1}{2} i_3)^2 + (i_2 - 0.866\, i_3)^2}$$

Likewise we may write for the voltages:

1. The voltage across section *hg* is the difference between e_2 and $0.866e_3$, or $(e_2 - 0.866e_3)$.

2. The voltage across section *gf* is e_2, if $0.886e_3$ is greater than e_2; otherwise $0.866e_3$.

3. The voltage across section $(ab+de)$ is the difference between e_2 and e_3, or $(e_2 - e_3)$.

Then the rating of the teaser will be one-half the following quantities:

Case 1: $i_3(0.866e_3 - e_2) + e_2(i_2 - i_3)$.

Cases 2 and 3:

$i_2(e_2 - 0.866e_3) + 0.866e_3(i_3 - i_2)$.

The compensator rating of the main will be one-half the following quantities:

Case 1:

$$i_3(e_3 - e_2) + e_2\sqrt{(\tfrac{1}{2} i_3)^2 + (i_2 - 0.866\, i_3)^2}$$

Cases 2 and 3:

$$i_2(e_2 - e_3) + e_3\sqrt{(\tfrac{1}{2} i_3)^2 + (i_2 - 0.866\, i_3)^2}$$

Example:

To transform 600 kw. at 50 cycles from 6600 volts two-phase to 6600 volts three-phase, case 3 will apply. Referring to Fig. 26-c:

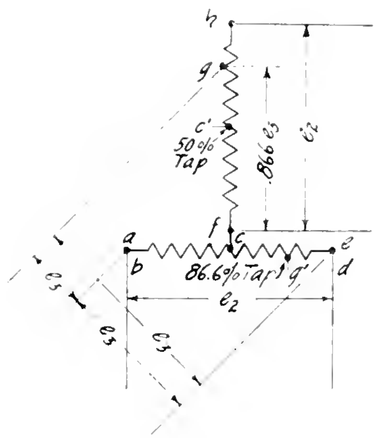

Fig. 28

$e_2 = 6600$
$i_2 = 45.5$
$e_3 = 6600$
$i_3 = 52.5$

Teaser:

Current in $hg = i_2 = 45.5$

Voltage across $hg = (e_2 - 0.866\ e_3) = 880$

Current in $gf = (i_3 - i_2) = 7$

Voltage across $gf = 0.866\ e_3 = 5720$

Rating of teaser

$$= \frac{45.5 \times 880 + 7 \times 5720}{2} = \frac{80080}{2} = 40 \text{ kw.}$$

Main:

Current in bd

$$= \sqrt{(\tfrac{1}{2}\ i_3)^2 + (i_2 - 0.866\ i_3)^2} = 26.25$$

Voltage across $bd = e_3 = 6600$

Rating of main

$$= \frac{6600 \times 26.25}{2} = \frac{173250}{2} = 87 \text{ kw.}$$

For this purpose, therefore, compensators could be furnished as follows: teaser (1) H, 50 cycle, 40 kw., 6600 volt (three-phase) to 6600 volt (two-phase); and main (1) H, 50 cycle, 87 kw., 6600 volt (three-phase) to 6600 volt (two-phase).

The usual practice is, however, to furnish two interchangeable units of identical size and design, which practice requires larger units but is more satisfactory in case of future repairs or replacements. A spare unit may be provided to be used in case of breakdown of either main or teaser. In this case an 86.6 per cent tap is provided in the main at g' (Fig. 28), and a 50 per cent tap in the teaser at c'. Then the capacity is calculated as follows:

Maximum current in hg or $g'd$ when used as teaser equals 45.5.

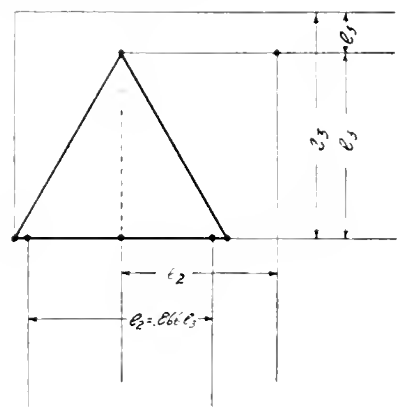

Fig. 29

Maximum current in fg or ag' when used as main equals 26.25.

Capacity equals

$$\frac{45.5 \times 880 + 26.25 \times 57.20}{2} = \frac{190190}{2} = 95 \text{ kw.}$$

for which installation (2) H, 50 cycle, 95 kw., 6600 volt (three-phase) to 6600 volt (two-phase) interchangeable units would be furnished.

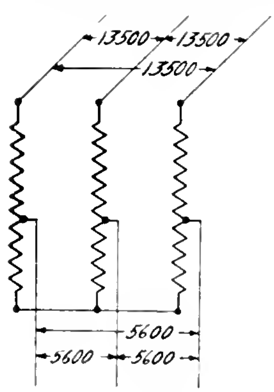

Fig. 30a

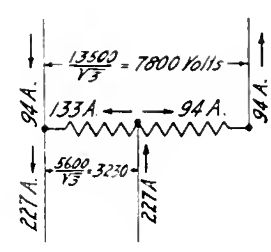

Fig. 30b

For the particular case of $e_2 = 0.866\ e_3$, three- to two-phase transformation may be accomplished by the use of three compensators, connected as shown in Fig. 29, but this has no advantages over the "T" connection and is seldom used.

(c) Three-phase to three-phase.

Example: The transformation of 2200 kw., 50 cycles, from 5600 volts three-phase to 13500 volts three-phase. (Fig. 30.)

$\frac{2200}{3} = 733$ kw. output per phase

$94 \times 4570 = 430{,}000$
$133 \times 3230 = 430{,}000$
$860{,}000$

$\frac{860{,}000}{2} = 430$ kw.

$430 \times 3 = 1290$ kw., rating of compensator.

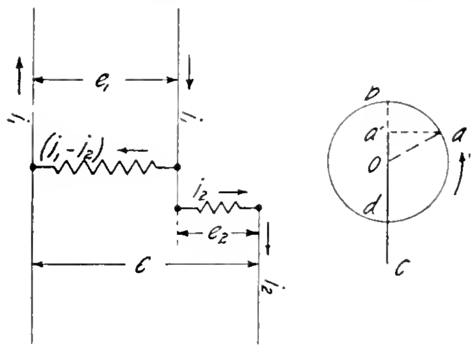

Fig. 31-a

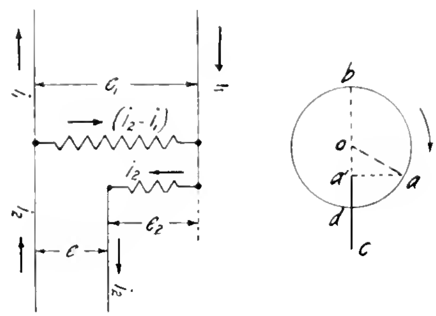

Fig. 31-b

Regulators

We have heretofore considered compensators whose primary and secondary voltages were fixed, or which could be changed only by means of taps. We will now take up induction regulators, which may be regarded as compensators, with the primary or movable coil across the line and the secondary or stationary coil in series with the load. The delivered voltage e may be varied from e_1+e_2, at maximum boosting position of the rotor, to e_1-e_2 at maximum bucking position. The movement of the rotor produces an effect equivalent to shortening or lengthening the secondary coil bc from a positive maximum to a negative maximum. (Fig. 31.) The rating of the regulator is the product of the maximum boost or buck and the delivered line amperes, that is, $e_2\ i_2$. Thus an IRS-2-22-60-2200-220-100 signifies a 2 pole, 22 kw., 60 cycle, single-phase induction regulator with an output of 100 amperes, and capable of maintaining a constant delivered voltage of 2200, with a maximum variation in the generator voltage of 220.

In the three-phase regulator (Fig. 32) the secondary voltages ad, bf and cg may be considered to revolve around the centers d, f and g. The phase voltage at any time is then the resultant of the primary and secondary voltages, and the delivered voltage is this resultant times $\sqrt{3}$. Thus the maximum phase voltage is Oa, the minimum Oa''. Then the delivered voltage e' equals $\sqrt{3} \times Oa'$. The rating of the compensator is figured as before: thus an IRT-4-19-60-2200-220-50 refers to a 4 pole, 19 kw., 60 cycle, three-phase induction regulator, capable of delivering 50 amperes at a constant voltage of 2200, with a maximum variation of 220 volts in the generator voltage. The rating equals $220 \times 50 \times \sqrt{3} = 19$ kw. The windings, of course, are designed to carry the maximum current that will flow at any position of boost or buck.

The principle of operation of two-phase and six-phase regulators is similar to the above.

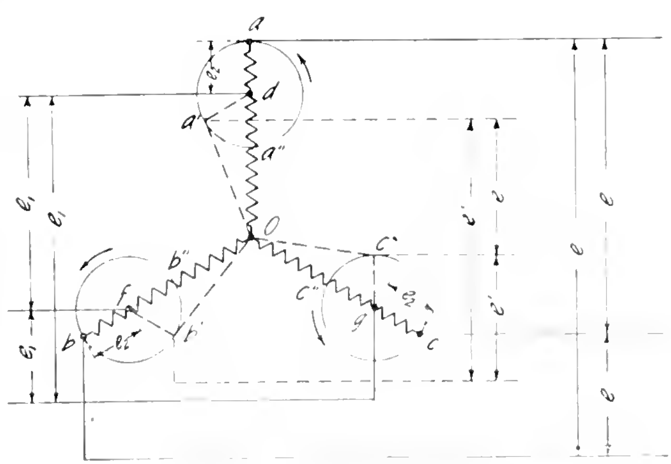

Fig. 32

THE ARLINGTON MILLS

The Arlington Mills of Lawrence, Mass., constitute one of the most important groups of textile mill buildings in the United States. Their equipment comprises 120,000 worsted spindles, 62,000 cotton spindles, and 2400 looms; the raw material handled annually amounting to 40,000,000 pounds of wool and 6,000,000 pounds of cotton. The finished products consist largely of worsted and cotton yarns.

The electrical equipment of these mills is particularly interesting, owing to the fact that both the group and individual systems of drive are exemplified. Some of the recent buildings were originally designed for electrical drive, but the larger part of the buildings now equipped electrically were changed over from mechanical drive.

The extent to which the electric drive has been adopted is indicated by the fact that there are installed at present about 1100 motors, aggregating more than 12,000 horse power. Practically all of these motors are applied directly to the operation of textile machinery, and for this service the polyphase induction motor has been adopted as a standard throughout. There are also some direct current motors which are used for the operation of yard locomotives and coal handling machinery. Nearly all of the motors installed in this plant are of General Electric manufacture.

The mill buildings are arranged as shown on the chart. (Fig. 1.) Current is supplied to the various groups at 600 volts, three-phase, 40 cycles by means of one 5000 kw. and one 2000 kw. Curtis steam turbine generator set. In addition to these generators there are two engine-driven units, one of 600 kw. and one of 350 kw. capacity, which are ordinarily held in reserve, but can be operated in parallel with the steam turbine sets. All the mill buildings will eventually be supplied from the turbine generator station, but there are at present two small isolated plants, one consisting of two 150 kw. belt-driven generators, which supply current for the motors in the cotton twisting room, and the other consisting of one 200 kw. generator, also belt-driven, which supplies current for the arc lamps lighting the yards.

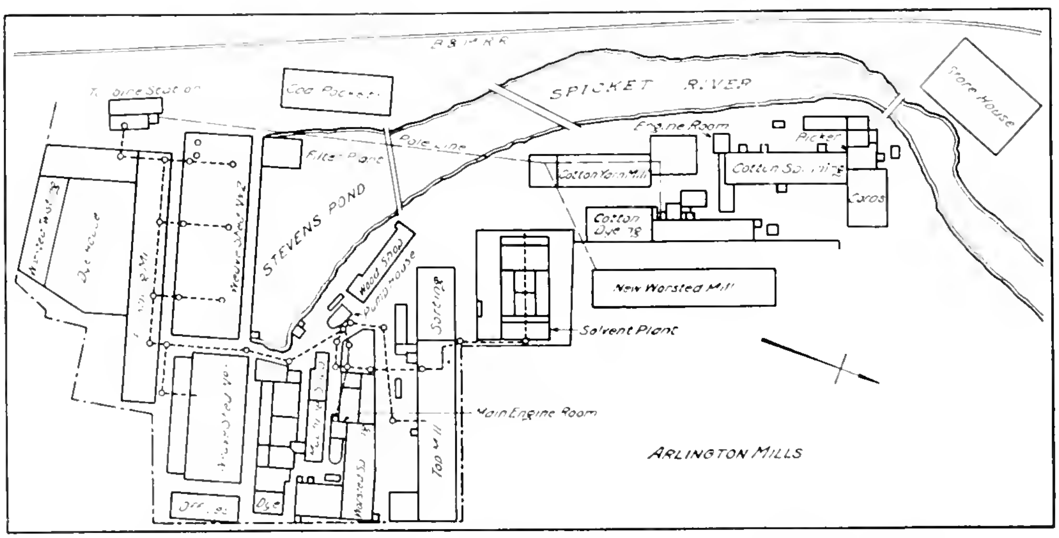

Fig. 1. Ground Plan of Mills. Dotted Lines Between Buildings Represent Underground Conduit System

Current for the motors is distributed from the turbine station by means of underground conduit carrying three three-phase circuits, which enter the various buildings through the basement. There is also an auxiliary pole line carrying two circuits as shown on the chart, which will eventually be replaced by underground conduit. This installation indicates the efficiency and economy of electric, as compared with the mechanical transmission of power for the operation of machinery located in widely separated buildings. Prior to the adoption of electric drive, the various buildings were provided with engines to which steam was supplied by separate groups of boilers. The power was applied through lines of shafting and belting which, due to the length of the buildings consumed a large percentage of the initial power in friction and belt losses. While a few of these engines are still in use, all of the buildings will eventually be supplied with electric current from the main turbo-generator station, with a practically negligible loss in transmission. With this system in operation a very considerable saving will be effected, due to the concentration of the generating equipment which will result in a reduction of the maintenance charges and avoid the expense of labor and supervision involved in the operation of separate boiler equipments.

Fig. 3. Drawing and Roving Frames

In the manufacture of worsted at the Arlington Mills, the wool is received in bales which are broken and the contents sorted by hand, after which the material is carried by a conveyor to an adjacent building where it is freed from natural oil by the solvent process. The qualities of reliability, simplicity and safety, which are inherent in the polyphase induction motor, are of particular value in the electrical equipment of this solvent plant, owing to the necessity for operating the motors in the same building with large quantities of naphtha. This liquid is circulated in a closed system by means of a non-explosive gas mixture which is stored under pressure by motor-driven compressors. Six motors are used to drive the necessary machinery, including gas and air compressors, blowers, exhausters, and centrifugal and vacuum pumps. The motors range in capacity from 30 h.p. to 300 h.p. and drive by means of chain belts as shown in Fig. 2. Due to the absence of all moving contacts on the squirrel cage polyphase induction motor, these machines can be safely operated in close proximity to the naphtha circulation system, but as an additional precaution the machinery and motors are separated from

Fig. 2. Motors Driving Compressors and Pumps in Solvent Plant by Chain Belts

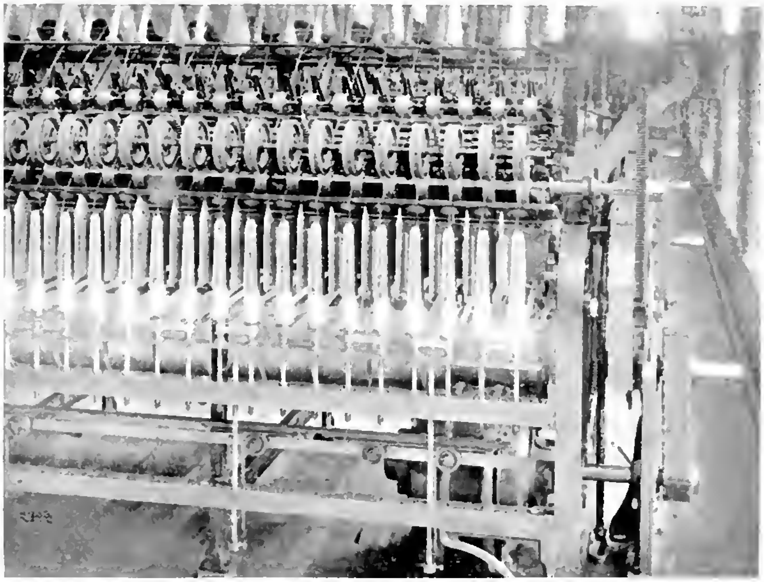

Fig. 4. 7½ H.P. Induction Motor Arranged for Individual Drive of Spinning Frames (Gear Cover Left Off)

the digesters, tanks, etc., by a brick wall.* After leaving the solvent plant the wool is thoroughly washed and dried and is then ready for carding and combing.

The carding and combing machinery is still mechanically-driven through long lines of shafting from the main engine room which is located in an adjacent building. On some sections of the shafting it has been necessary to install motors to relieve the load on the engine, and arrangements have already been made to entirely replace mechanical drive with motor drive.

After being taken from the combs the worsted, which is now in the form of "tops," is carried to the spinning frames. A considerable portion of the product is sold in the form of "tops," and this is wound loosely into balls by means of balling machines, which are operated from motor-driven shafting, as shown in Fig. 3. This illustration also indicates the arrangement of the motors for a number of the spinning frames, which in this mill are driven in groups by induction motors mounted on the ceiling and either belt connected or direct connected to overhead countershafts; the compensators and controller panels being mounted on the supporting posts of the building as shown in Fig. 3.

While this method of motor drive has proven satisfactory in service, a higher efficiency has been obtained in more recent installations by providing each frame with a separate motor mounted under the frame itself and driving the drum through a short chain belt, as shown in Fig. 4. This system of motor application does away entirely with overhead shafting and belting and the power losses thereby entailed, while the amount of current consumed in the operation of the various

Fig. 5. View in Worsted Spinning Room, Showing Individually-Driven Frames

*All of the starting compensators for the six motors are located on a platform elevated above the floor and under the control of one man.

frames is directly proportional to the work done; this feature being of particular value when portions of the mill are shut down. As compared with group drive, the use of individual motors for driving spinning frames through short chain belts in this way eliminates the variation in speed inherent in the latter method, due to the slippage of belts and the fluctuation in the load caused by the starting and stopping of individual frames. These advantages are combined with a cleanliness and a general improvement in the appearance of the plant (see Fig. 5) not otherwise obtainable.

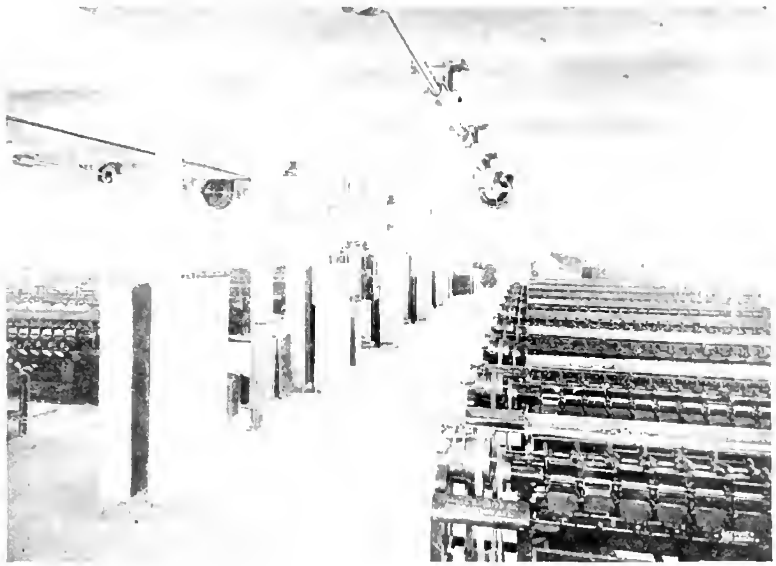

Fig. 6. Cone Winders in the New Yarn Mill

The method adopted for driving the cone winders is shown in Fig. 6, and consists of several group drives, each comprising a 25 h.p., 600 r.p.m. induction motor mounted on the ceiling and direct connected to countershafting. The motor is located at the center of this shaft, each half of which is provided with five pulleys, each pulley driving a single cone winder through belting.

Fig. 7. Jack Spoolers Driven by $1\frac{1}{2}$ H.P. Motor

The relative location of shafting and cone winders is shown in Fig. 6, which illustrates an unfinished installation in the foreground, and also a group of cone winders in operation; this latter group being shown in the left-hand of the illustration.

The method adopted for driving jack spoolers is indicated by Fig. 7, which shows one of several $1\frac{1}{2}$ h.p. induction motors mounted on the ceiling and belt connected to a countershaft which drives sixteen jack spoolers through belting. In this case a belt tightener head was necessary in order to place both shafting and motor within one bay and thus save cutting through a cement beam. On account of the extremely small amount of power required for the operation of these machines, it is not advisable to adopt individual drive for this class of service.

The worsted twisting machines are driven in small groups through countershafting. There are nine 25 h.p. motors installed on the ceiling, each driving four frames, while a 50 h.p. motor, connected to two countershafts, drives eight frames. These

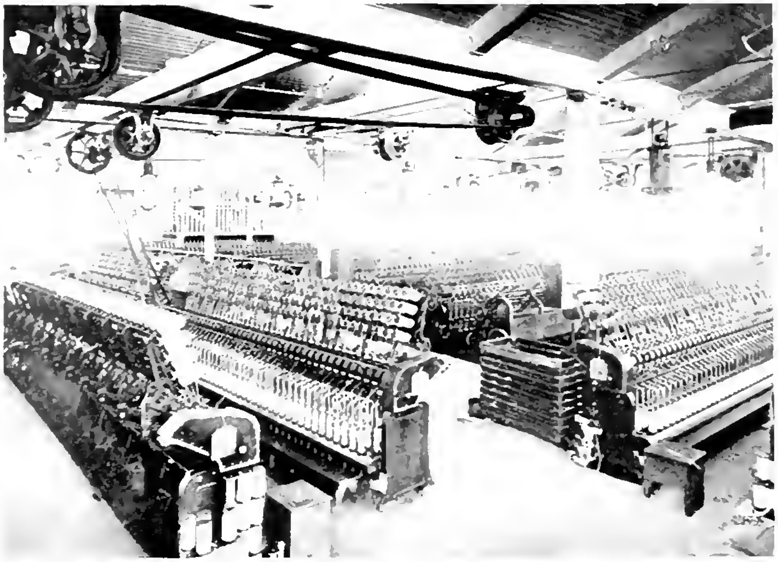

Fig 8 Roving and Twisting Frames

system were successively adopted.

The carding and combing machinery of the cotton spinning mill is driven through lines of shafting by means of a steam engine located at one end of the building, the main shaft and countershafts and belts being located in the basement.

As the loss involved in the operation of this mass of shafts and belts is fully appreciated, this entire section will eventually be provided with motor drive. At the present time two 150 h.p. induction motors are belt connected to the main shaft and by means of friction clutches can take up the load when the engine is shut down. This arrangement was made necessary, owing to the fact that this section of the mill works twenty-four hours a day. In order to avoid starting the motors under load they are thrown into service before the engine is shut down and while the shafting is still in motion.

The twisting room of the cotton mill is provided with one 40 h.p. and six 60 h.p.

twisting machines are located in one of the older buildings and at present serve to take overflow work from the new worsted mill, in which the general arrangement of the twisting machines is similar to that indicated above.

The worsted yarn is now ready for the weaving operations, although a considerable portion of it is sold in the form of yarn.

In the manufacture of cotton yarn electric drive is extensively used. The picker room is at present driven by a 100 h.p. induction motor located in the basement, but the 18 machines which constitute the equipment of this room are being provided with individual motor drive by means of $5\frac{1}{2}$ h.p. and 7 h.p. motors, mounted directly on the frame work of the machines and driving through short belts. The equipment of this picker room is an illustration of successive developments in power application, as the machinery was originally driven by steam engine, and thereafter the group system of motor drive and the individual

Fig 9 Cotton Twisting Room

induction motors, which drive the machinery in groups as shown in Fig. 9; the general arrangement being similar to that adopted for the operation of the yarn twisters.

The cotton yarn is sold in various forms, depending upon the particular manufacturing process for which it is intended.

The cone winders for cotton yarn are driven in groups by means of 30 h.p. induction motors, as shown in Fig. 10. On account of the rather unsteady nature of the load, these machines are well suited to group drive. A comparison of the illustrations (Figs. 6 and 10) will indicate the reduction in the amount of belting effected by the direct connection of the motor to the driving shaft. The number of countershafts is also reduced and the various machines in each group are belted direct to the overhead shaft, which is located at right angles to the machine shafts, driving them through quarter-turn belts.

Fig. 10. Cone Winders in the Cotton Department

Fig. 11 View in the Dye House

The 2400 looms which constitute the weaving equipment of the mills are motor-driven throughout, both group and individual drive being employed. The later installations are all individual drive, and changes are now being made in the equipment which will materially reduce the number of group-driven looms.

Fig. 11 shows the method of drive adopted for the dye house, the motors being mounted on the roof beams and connected to the various dyeing machines through belts. In the center of the illustration four centrifugal extractors are shown belt connected to overhead driving shafts. A second group of these extractors is equipped with individual drive, each extractor being direct-driven by a vertical shaft motor.

The water supply for all the mill buildings is furnished by a filtering plant in which three centrifugal pumps are installed, one being driven by a 65 h.p. motor, and the other two by 35 h.p. motors. The motors are direct connected to the pump shafts.

In order that the steam required in the dye house operations be supplied with the greatest economy, the generating station is located near the dye house, and by a special arrangement the steam is taken from the second stage of the turbines at a pressure of about 5 lbs.; the turbines in this case acting as pressure reducers in addition to their normal functions as prime movers.

The mill yards are served by an individual railway operating three locomotives, which are provided with standard General Electric direct current 550 volt railway motors. Current for these locomotives is supplied by means of a 200 kw. rotary converter installed in the main power house. In addition to this rotary converter there are two direct current generators, one of 150 kw. and the other of 75 kw. capacity, which are belt connected to steam engines and normally held in reserve. They are used for the operation of yard locomotives during periods when the main power station is shut down. The importance of this industrial railway is indicated by the fact that it handles annually approximately 23,000 tons of raw materials used in manufacturing and 100,000 tons of coal.

The auxiliary machinery of the coal handling equipment comprises conveyors and coal crushers operated by means of direct current motors which take their power from the feeder wires of the industrial railway system; all the direct current motors operating at 550 volts.

The yards and buildings throughout are electrically lighted, the buildings being equipped with both arc and incandescent lamps, while the yards are lighted by 250 enclosed arc lamps. The buildings are provided with 1100 series direct current arcs, current for which is supplied by means of two Brush and sixteen Wood engine driven arc generators. The enclosed arc lamps operate at 110 volts alternating current, 40 cycles, and are supplied from the power circuits through step-down transformers. Tungsten incandescent lamps are used extensively for auxiliary lighting, the equipment containing a number of the 250-watt size.

Birdseye View of Arlington Mills

ESSAYS ON SYNCHRONOUS MACHINERY

PART III

BY V. KARAPETOFF

VOLTAGE REGULATION OF ALTERNATOR

Voltage regulation is defined in this country as per cent rise in voltage when the rated load is thrown off, the field current and the speed being kept constant (*Standardization Rules* of the Amer. Inst. Elec. Engrs., Articles 192 and 207). Let it be required to predetermine the voltage regulation of a given machine at a certain load. Referring to Fig. 2, the terminal voltage e, the current i and the external phase-angle ϕ are given. It is required to calculate voltage E_1; knowing the latter the necessary field excitation M can be found from the no-load saturation curve of the machine. In order to calculate E_1 it is necessary to determine the value of the total induced e.m.f. E and the angles α and β.

The voltage E and the angle α can be determined from the figure $OABD$. Projecting this figure upon the direction OA and upon that perpendicular to OA we have

$$\left.\begin{aligned} E\cos\alpha &= e+ir\cos\phi+ix\sin\phi = a \\ E\sin\alpha &= ix\cos\phi-ir\sin\phi = b. \end{aligned}\right\} \quad (10)$$

Here a and b are introduced for the sake of abbreviation to denote the right-hand side of the equations; a and b are known quantities because e, i, r, x, and ϕ are supposed to be given. Squaring both equations and adding them together we get

$$E = \sqrt{a^2+b^2} \quad (11)$$

or, according to the binomial expansion, very nearly, $E = a + \frac{1}{2}b^2/a$ (11a)

Dividing the second equation (10) by the first gives

$$\tan\alpha = \frac{b}{a} \quad (12)$$

Angle β can be determined from the triangle ODF; i.e., we have

$$\sin\beta = \frac{E_2}{E} \quad (13)$$

where E_2 is determined by equation (7), (REVIEW, February, 1911, page 58).

The internal energy component c_1 of the current which enters into equation (7) can be determined from the triangle OHK; namely, $c_1 = i\cos(\phi'+\beta)$ (14)

where $\phi' = \phi+\alpha$. Substituting the value of c_1 from (14) into (7), and denoting the known part by E_2' we have

$$E_2 = E_2'\cos(\phi'+\beta) \quad (15)$$

where

$$E_2' = k_2 k\, k_s n T i x \quad (16)$$

Substituting the value of E_2 from equation (15) into equation (13) and solving for β we obtain

$$\tan\beta = \frac{\cos\phi'}{(E/E_2')+\sin\phi'} \quad (17)$$

Knowing angle β we find

$$E_1 = E\cos\beta \quad (18)$$

and

$$c_2 = i\sin(\phi'+\beta) \quad (19)$$

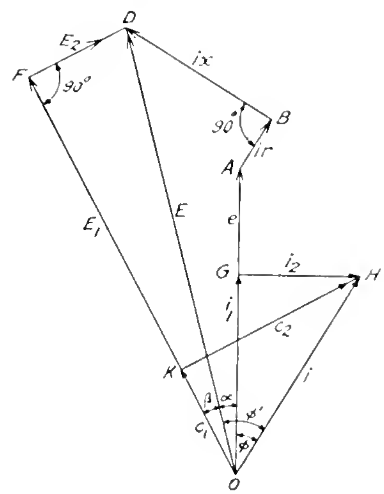

Fig. 2. Vector Diagram of Voltages in an Alternator

After this, the demagnetizing ampere-turns M_1 are calculated according to formula (5), and the net field ampere-turns M_t corresponding to E_1 are found from the no-load saturation curve, which is supposed to be given. The required field excitation under load is $M = M_t + M_1$.

Numerical Illustration. It is required to calculate per cent voltage regulation of a 12 pole, 150 kv-a., 2300 volt, 60 cycle, three-phase, Y-connected alternator at a power-factor of 80 per cent lagging. *

Errata: February REVIEW, page 57, first column.
Equation (1) should read: $M_1 = k_1\, n\, T\, c_2$.
Equation (2) should read: $= 0.573$ (*sin* $^1{}_{2\pi}$ *etc.*)
Paragraph beginning, "Formula (1) presupposes, etc.," should read "Formula ²) presupposes, etc."

* The manufacturer's notation of this machine is ATB 12 150-600-2300-P; the data are taken from *G. E. Technical Report* No. 7152.

The resistance of the armature winding is 0.45 ohm per phase (hot) and the rated current of the machine is 37.6 amp. Since the machine is Y-connected, the effective ohmic drop, referred to the line voltage, is $ir = 37.6 \times 0.45 \times \sqrt{3} \times 1.5 = 44$ volts. The factor 1.5 is introduced in order to take into account the effect of eddy currents and the skin effect (see REVIEW, March, 1911, page 115). The reactive drop is estimated to be about 10 per cent of the rated voltage, so that $ix = 230$ volts. A power-factor of 80 per cent corresponds to the angle $\phi = 37°$; $sin\ \phi = 0.60$. According to equations (10) we have

$$a = 2300 + 44 \times 0.8 + 230 \times 0.6 = 2473 \text{ volts};$$

$$b = 230 \times 0.8 - 44 \times 0.6 = 158 \text{ volts}.$$

From equations (11a) and (12), $E = 2478$ volts; $tan\ \alpha = 0.064$; $\alpha = 3°, 40'$. Consequently, $\phi' = \phi + \alpha = 40°, 40'$.

In order to evaluate E_2', it is necessary to know the value of v. From the straight part of the no-load saturation curve of the machine, it is found that 2000 ampere-turns are required for 1230 volts; hence $v = 1230/2000 = 0.615$ volt per ampere-turn. From equation (16) we find

$$E_2' = 0.30 \times 0.966 \times 1 \times 3 \times 18 \times 37.6 \times 0.615 = 362 \text{ volt}.$$

Here 0.966 is the value of k_b for two slots per pole per phase in a three-phase machine; $k_c = 1$, because the machine has a 100 per cent pitch winding; 18 is the number of armature turns per pole per phase. From equation (17) we find

$$tan\ \beta = 0.7585\ [6.84 + 0.6517] = 0.101.$$

Therefore, $\beta = 5°\ 15'$; $E_1 = E cos \beta = 2465$ volts; $\phi' + \beta = 46°\ 25'$; and $c_2 = 27.25$ amperes. From formula (5) the demagnetizing ampere-turns per pole $M_1 = 1065$.

The voltage $E_1 = 2465$ volts requires M_n to be about 5000 ampere-turns on the no-load saturation curve of the machine. Consequently, the excitation required at the load under consideration is $M = M_n + M_1 = 5000 + 1065 = 6065$ ampere-turns. When the load is thrown off, the voltage of the machine rises to that value which corresponds to 6065 ampere-turns on the no-load saturation curve. Referring to the curve we find this to be 2690 volts. The regulation of the machine at 80 per cent power-factor is

$$\frac{2690 - 2300}{2300} = 17 \text{ per cent}.$$

Per cent voltage regulation at values of power-factor near unity varies considerably with small variations of the power-factor.* In the machine used above as an illustration the calculated regulation is 5.9 per cent at unity power-factor, and the regulation is 7.6 per cent at a power-factor of 99.6 per cent, corresponding to a small phase displacement $\phi = 5°$. The regulation determined from the actual load test was 7.4 per cent. While the load used for the test is supposed to be non-inductive, it is possible that some inductance is unavoidably present; for instance, in the leads, in the metal resistances, in the iron plates of water tanks, etc. Therefore, the observed regulation actually refers to a power-factor of between 99.6 and 100 per cent, and may be considerably lower than the regulation on a strictly non-inductive load. This fact must be kept in mind when fulfilling guarantees, because the maker of the machine is put to a disadvantage by the presence of small inductance in the load.

For this reason, it is more correct to calculate per cent regulation at unity power-factor according to the above given method, than to determine it from an actual test under ordinary commercial conditions. The calculated value is particularly accurate if a reliable short-circuit curve and a good reactance curve are available.

At values of power-factor, say below 90 per cent, the regulation is not much affected by one or two per cent difference in the value of the power-factor. Therefore, sufficiently accurate test results are easily obtainable if the customer objects to the calculated value of regulation. Some years ago Mr. B. A. Behrend called attention to the fact that at values of power-factor below 20 per cent the value of voltage regulation is practically constant. See V. Karapetoff, *Experimental Electrical Engineering*, Vol. I (second edition) p. 352, Fig. 253, and p. 355, Fig. 256.

* For a confirmation of this statement see very accurate curves of voltage regulation in Vol. 34 of the *Journal* of the British Institution of Electrical Engineers, p. 479. It will be seen there that the curve of voltage regulation at 100 per cent power-factor differs considerably from that at 99.5 per cent. On the contrary, at comparatively low values of power-factor several per cent difference in its value affects per cent regulation but very little.

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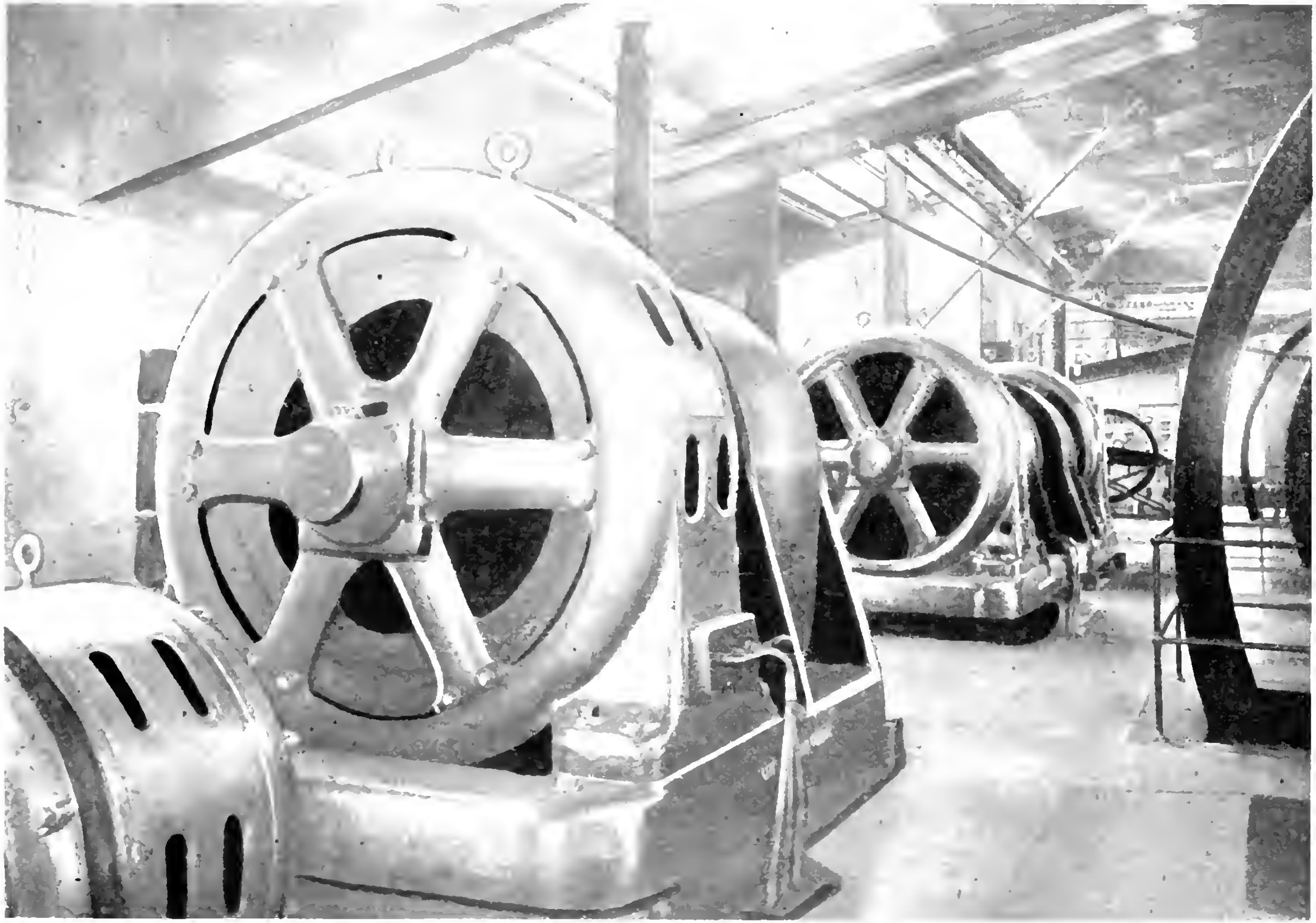


300 H.P. Induction Motors for Driving Air Compressors for the Operation of Mine Hoists

(See page 207)

GENERAL ELECTRIC REVIEW

TYPICAL SYNCHRONOUS CONDENSER INSTALLATIONS

The employment of synchronous condensers for the improvement of power-factor has been discussed several times in these pages. On the first occasion Dr. E. J. Berg treated the subject mathematically under the title "Potential Control of Alternating Current Systems by Synchronous Motors with Tirrill Regulators." In the March, 1909, issue Mr. A. L. Jones outlined their action in a practical and non-mathematical article, entitled "Rotary Condensers in Steel Mills." Their effect was also described by Mr. John Liston in the February, 1910, issue of the REVIEW. In the present number the same author, after briefly rehearsing the functions of these machines, tells of the results that have been obtained in a number of different instances.

Thus in the Illinois Steel Company, of South Chicago, Illinois, the power-factor was raised from 0.74 to 0.917, the kilowatt capacity being increased from 5800 to 6400. Similarly, the Chalmers Motor Company and the Cadillac Motor Car Company, both customers of the Edison Illuminating Company, of Detroit, have experienced most satisfactory results.

Among other instances cited are the installations: Witherbee-Sherman Company, of Mineville, N. Y., where the resulting increase in generator and line capacity enabled them to materially augment their motor equipment; the Saxony Worsted Mills, Bemis, Mass., where the power-factor was raised from 0.64 to 0.85, and the Northern California Power Company, Kenneth, California; the improvement in power-factor here being from 0.79 to 0.96.

Other cases are also described in which the power-factor has been materially improved, increasing the capacity of the systems and conducing to better voltage regulation. In some of these instances the synchronous motors are employed to perform a moderate amount of mechanical work, in others they simply float on the line.

Taken in conjunction with the previous articles on this subject, these descriptions form interesting examples of those applications of the synchronous motor that have formerly been discussed theoretically.

COMMERCIAL APPLICATION OF THE TURBINE TURBO-COMPRESSOR

The first turbine-driven air compressor installed in this country for blowing a blast furnace has been erected at Oxford Furnace, N. J. In this issue Mr. Richard H. Rice contributes an interesting article describing this unique plant and explaining certain special features which it possesses. First among these is the fact that the apparatus is designed to keep the rate of discharge constant at any predetermined value, irrespective of the varying conditions within the furnace. The means for obtaining this result are entirely new, and the regulation itself constitutes an advance in blast furnace practice that can hardly fail to result in better operation.

While in the present installation the apparatus employs high pressure steam, the author points out that low pressure turbines can be used with equal facility for driving compressors. Thus where reciprocating blowing engines are used, low pressure turbines may be installed to operate from the exhaust steam, thus realizing the well known large economies and increased capacity that result from their employment in this manner.

OPEN SLOT VERSUS OVERHUNG SLOT INDUCTION MOTOR

The choice between open and overhung slot design depends upon several factors, which become of greater or less importance according to the capacity of the machine involved. For instance, the electrical characteristics of motors approximately 25 h.p. and above, are not widely different when either open or overhung slot design is used. The mechanical requirements of the windings, however, are such that the use of completely insulated and formed coils becomes of great advantage as the sizes increase, principally due to the larger and consequently less flexible conductors used, the presence of increased electrical stresses, requiring a higher degree of insulation between turns and layers, and finally, the introduction of greater mechanical strains, both during assembly of windings and after the motor is put into commercial operation.

However, as motor capacities decrease, the above requirements become of relatively less importance, and, furthermore, a much wider difference exists, favoring the electrical characteristics of partially closed slot design.

Induction motor stators can be designed:

(1) With windings assembled in open, or "straight" slots, in which case the coils are usually completely insulated and formed into the shape that they must take after assembly into the field frame; or,

(2) The windings may be threaded into partially closed or "overhung" slots, in which case the coils are insulated both during and after assembly in the slots.

In very small motors (approximately $7\frac{1}{2}$ h.p. or less), efficiency and power-factor constants suffer materially when open slots instead of partially overhung slots are used, so much so that it may become necessary to reduce the horse power rating or, what is the same thing, increase the size of frame for a given output. At the same time, the labor cost is increased materially on account of the difficulty in making small completely taped and formed coils, composed of a large number of fine gauge conductors.

Consulting and operating engineers unfortunately spend most of their time and attention on the larger apparatus and, when making up specifications for units of small capacities, naturally are inclined to demand the desirable features obtainable only in the larger motors; this without taking into consideration the difficulties involved in applying such features. In very small sizes there is little difference in the cost or time involved in the repair of an open slot stator and one which is provided with the so-called random-wound coils assembled in partially overhung slots. To guard against breakdowns, the carrying in stock of a complete motor of small size is comparatively inexpensive, and is always preferable to stocking individual coils.

Where motors of widely varying capacities are called for, it is highly desirable that the specifications covering the mechanical and electrical features should bear a distinct reference to the capacity of the motors involved. Furthermore, the same specifications should not be used to indiscriminately cover a 1 h.p. and a 50 h.p. motor.

Totally enclosed motors of the closed slot design can be supplied where the apparatus is to be subjected to extremely severe operative conditions; for example, in installations where dirt, oil, or grease, carbon dust, sawdust, etc., may be present in excessive quantities. These totally enclosed units can be supplied at lower cost than corresponding capacities of open slot taped coil motors, and will develop higher efficiency and power-factor characteristics.

To sum up: In small sizes and for installations under conditions which make the use of formed, completely taped, and insulated coils highly desirable, motors should be furnished totally enclosed with the usual standard overhung slot windings—owing to the lower first cost, higher electrical characteristics, and comparatively small amount of money involved in carrying complete spare motors for breakdown service. The above rulings apply to motors of standard speeds. Special ratings may alter these conclusions.

J. B. Wiard

COMMERCIAL APPLICATION OF THE TURBINE TURBO-COMPRESSOR*

By Richard H. Rice, West Lynn, Mass.

The General Electric Company recently put in operation at the Oxford Furnace, N. J., plant of the Empire Iron & Steel Company, a turbine-driven air compressor (Fig. 1) for blowing the blast furnace, which is the first installation of this type of apparatus to be made in this country.

2. The unit consists of a six-stage compressor operating at a normal speed of 1650 r.p.m. and driven by a direct-connected four-stage Curtis steam turbine. The design is such that this normal speed produces a blast pressure of 15 lb. per sq. in. The unit, however, is designed to regulate the volume of air delivered per minute so as to keep the rate of discharge constant at any value, determined by the furnace superintendent, within its capacity. The manner in which this is accomplished will be fully described in the sequel, but it may be said here that the regulation is effected by means of speed variation; so that the machine is a constant volume, variable speed piece of apparatus, and not one of constant speed as in other classes of blowing units.

3. The compressor has six stages arranged in series, so that the air enters at the end nearest the steam-turbine driver and passes successively from stage to stage until it reaches the other end of the compressor casing, where it enters the discharge pipe. The impeller wheels are so designed that there is no unbalanced end thrust, and therefore the ordinary means used in the Curtis turbine for locating the rotating elements and preserving proper clearances are sufficient for the entire apparatus.

4. The air is cooled in each stage during compression, and also when passing between stages, by suitable water chambers in the

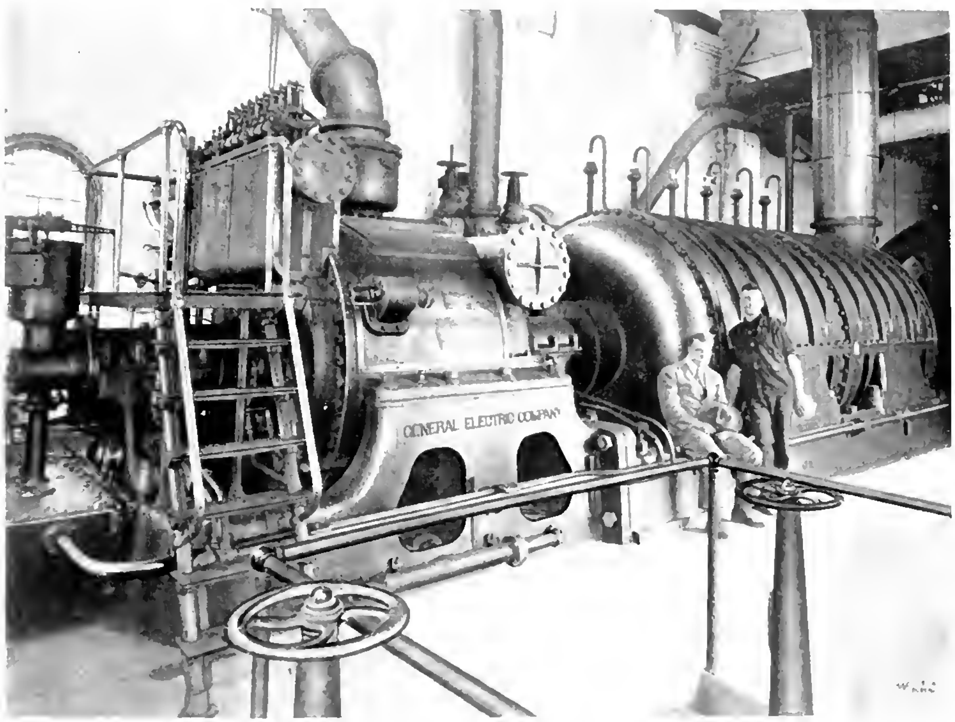


Fig. 1. Air Compressor Direct-Connected to Curtis Steam Turbine, 1500 R P M. Empire Iron & Steel Co., Oxford Furnace, N. J.

*Paper presented before the American Society of Mechanical Engineers.

diaphragms, this cooling being sufficient to maintain the compression approximately along the adiabatic line.

5 No valves or rubbing surfaces are used in the compressor construction and, as in the turbine, the rotating elements revolve freely with ample clearance so that no wear or deterioration can take place; therefore, the efficiency of compression must remain constant.

6 Fortunately, both turbine and compressor attain their best efficiency under similar conditions as regards rotating speed, making the combination a logical and efficient one. Under conditions usually met with in blast furnace operation involving pressures of blast of 10 to 20 lb. per sq. in., the efficiency remains sensibly the same. A curve of efficiency at varying volumes is shown in Fig. 3 and above this has been drawn a curve of speeds and pressures which, taken in connection with the first named curve, shows the variations of efficiency with pressure at rated volume.

7 This latter curve shows graphically the variation of pressure with change of speed, which follows the law of squares; that is, doubling the speed gives four times the pressure, etc., from which it will be seen that only moderate changes in speed are necessary to give considerable changes in pressure. It is these changes in speed, increasing or decreasing the blast pressure, that are utilized to maintain a constant rate of flow of air into the furnace, against the varying resistances set up in the tuyeres and furnace by varying furnace conditions; as, for instance, clogging of tuyeres and changes in the size

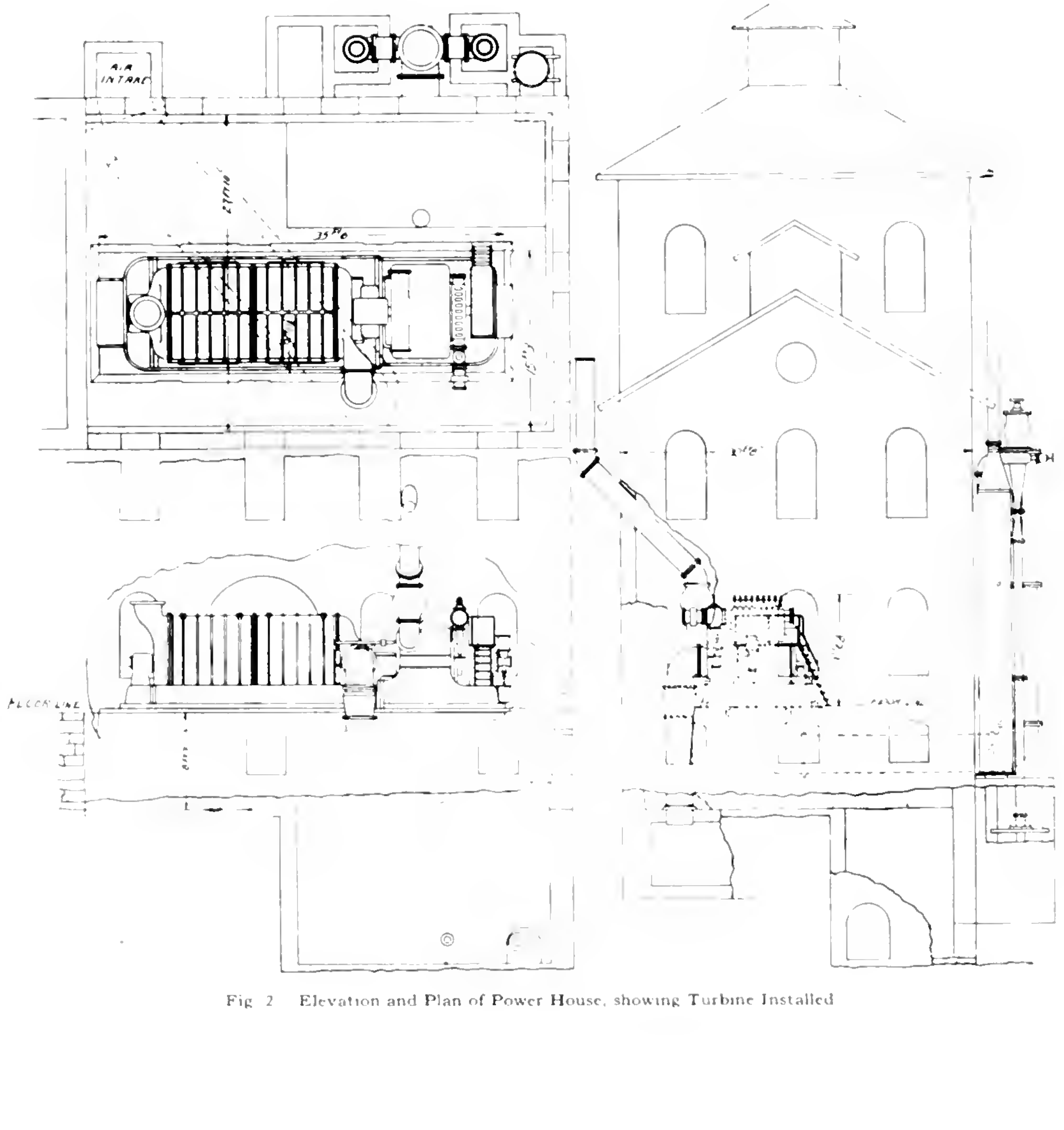


Fig. 2 Elevation and Plan of Power House, showing Turbine Installed

and composition of the charge, temperatures, etc.

8 The means by which these changes of speed are produced in the manner necessary to keep up a constant rate of influx of air per minute is shown in Fig. 4. This diagram shows a steel disc *d* sustained on the inflowing air current within a conical enlargement of the inlet pipe. By means of the sliding weight *a*, the resistance of this float and displacement by the air current is adjusted in accordance with a scale on the scale beam *b*, which is graduated accurately in cubic feet per minute to read volumes of free or atmospheric air. By setting this weight at the graduation corresponding to the rate of discharge of air desired, the disc is caused to assume a position in the conical enlargement *c*, which results in supplying steam to the turbine in quantity sufficient to establish the proper speed of the compressor and pressure of blast to cause the required flow of air through the furnace. In case the rate of air flow tends to decrease, the disc *d* sinks to a lower point in the enlargement *c*, since the supporting air current decreases its sustaining power. More steam is therefore admitted to the turbine and the speed is increased, resulting in increase of pressure, and this increased pressure re-establishes the desired flow of air. In case too much air tends to flow into the furnace, the reverse of all these effects takes place. In practice, the operation of this device is most regular and satisfactory.

9 This method of governing, by the indications of a properly calibrated scale beam, gives an entirely new instrument, which, in the hands of a skilled furnace manager, will undoubtedly enable improved results in furnace operation to be obtained, since an accurate knowledge of the amount of air supply is always at hand by this means.

10 Such knowledge cannot be obtained from reciprocating blowing engines, because

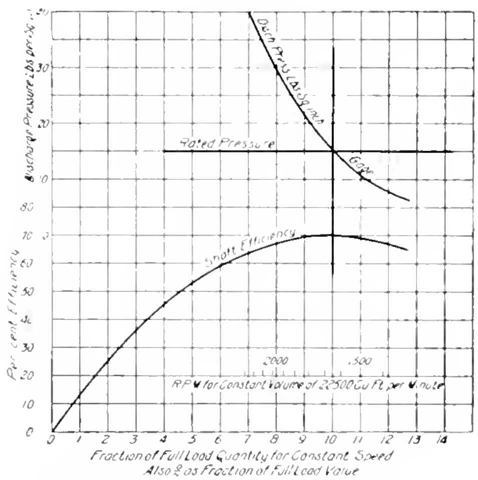


Fig. 3. Efficiency and Pressure Curve with Constant-Volume Governor. Compressor with Six Stages

the expansion of air in clearance spaces causes an error increasing in amount as discharge pressure increases, because leakage increases with increase of discharge pressure, and because the slip is a variable and uncertain amount. On the contrary, the air governor is unvarying in its action and will not change its indications with time, since wear and leakage are absent.

11 It has been stated before that this is a variable speed machine. In normal blast furnace operation pressure may vary from 10 to 20 lb. per sq. in. These pressures require

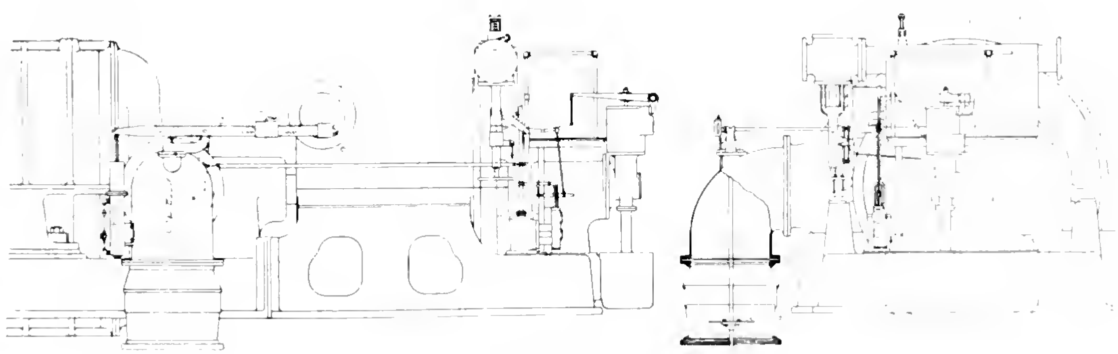


Fig. 4. View Showing Constant-Volume Governor

speeds in the particular apparatus under description of about 1500 r.p.m. for 10 lb. pressure to 1800 r.p.m. for 20 lb., as appears on the curve, Fig. 3. The blast furnace operator therefore instructs the engineer operating the compressor not to maintain a

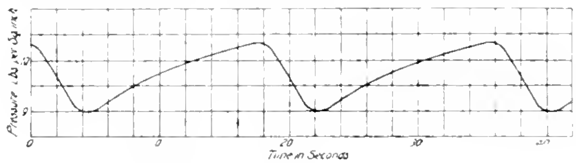


Fig. 5. Pressure Curve During Pulsations

certain number of revolutions, as is customary with reciprocating engines, but to set the scale beam weight for the required volume in cubic feet per minute.

12 The graduation and calibration of the scale beam in cubic feet per minute is determined during the shop test of the apparatus before shipment by accurate tests with standard orifices and pitot tubes, and these graduations are accurate within about two per cent.

13 A simple oil dashpot *D*, Fig. 4, attached to the scale beam, prevents any racing or undue fluctuations of speed.

14 In operating the blowing unit, it is only necessary to manipulate the hand throttle valve in the main steam pipe when it is desired to bring the compressor to rest. At all other times control is effected through the scale beam, with wide-open throttle. At times of checking the furnace or casting, the weight *a*, Fig. 4, is moved to the extreme end of the scale beam at the position indicating the minimum volume for which the scale beam is graduated, and still further decrease of speed and pressure is produced by adding an auxiliary weight at this end of the beam or by depressing it by hand. On removal of the auxiliary weight and replacement of the sliding weight *a* at the running volume graduation, the compressor speeds up until the volume required is obtained. This manipulation is in practice of the simplest character.

15 The air governor acts upon the pilot valve of the hydraulic valve gear commonly used on the larger sizes of the Curtis turbine, through a system of floating levers, in such wise that when the turbo-compressor nears the maximum speed for which it is designed, in this case 1950 r.p.m., a centrifugal governor of the usual type comes into action and keeps the speed at this maximum as long as the resistance to air flow in furnace or tuyeres remains so high that the volume of air, for which the air governor is set, cannot be forced through at the maximum pressure to which this speed corresponds, in this case 25 lb. per sq. in. During this period the air governor is out of control of speed, but it comes into action immediately when the furnace resistance decreases.

16 In case of breakage or sticking of the governor mechanism which permits the speed to exceed 1950 r.p.m., an emergency governor mechanism, entirely independent of the mechanism previously described, comes into play and closes the main throttle valve, bringing the compressor to rest.

17 In all high-speed apparatus the certainty of the oil supply is an important feature and it is particularly so in this service. In this unit there are three shaft bearings requiring automatic lubrication, and this is furnished by a valveless gear pump, worm-driven from the main shaft, which circulates oil under 15 to 25 lb. pressure. The same pump also supplies this necessary oil to the hydraulic cylinder which actuates the valve gear. The oil is returned from bearings and cylinder to a tank where it is settled and strained before re-use. In order to guard against any stoppage of oil circulation, an alarm is provided which causes a steam

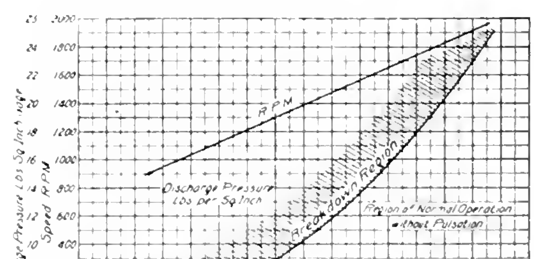


Fig. 6. Curve of Breakdown Points from Factory Tests. Pressure and Revs. per Min. Plotted Against Cu. Ft. per Min.

whistle to blow in case the oil pressure falls to 5 lb. per sq. in.

18 The oil is cooled in the bearings at the point where the heat is generated, by means of water-cooled coils embedded in the bearing linings.

19 The apparatus described uses, of course, high-pressure steam. Obviously the compressor is adapted equally well to the use of low-pressure turbines for drivers, and so driven affords a ready means of increasing the efficiency of existing plants containing reciprocating blowing engines, by the usual method of exhausting from the reciprocating steam cylinders into the low-pressure turbine. The governing by volume of air discharged is equally applicable here, and all the advantages of this system can therefore be realized.

20 Increased efficiency of the plant to the extent of 20 per cent. to 50 per cent. may be thus realized with a very moderate addition to the cost.

21 The installation at the Empire Iron & Steel Company, which the photographs accompanying this article represent, was put in operation on the furnace on March 8, 1910, and has been in continuous operation ever since. At the time this apparatus was put in service, it was not expected that the volume of air required by the furnace would be at such a low figure as turned out to be the case, the machine having been designed for a normal volume of 22,500 cu. ft. per min. Upon putting the machine on the furnace, it was found the volume required was only about 15,000 cu. ft. per min. and the pressure corresponding to this volume

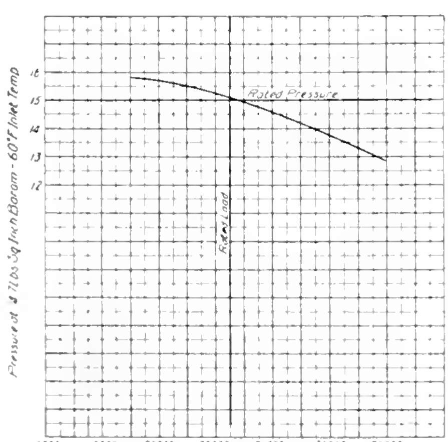


Fig. 7. Factory Test, showing Pressure Plotted Against Quantity of Air, 1650 R.P.M.

under furnace conditions ranged from 10 lb. to 12 lb. Under these conditions, it was found that pulsations were met with in the pressure line, this pressure fluctuating about 2 lb., and in order to overcome this pulsation it was found necessary to throttle the inlet opening. Fig. 5 shows the character and magnitude of these pulsations. Since this time, a convenient butterfly-valve throttling mechanism has been designed and applied, which is found to eliminate these pulsations without appreciable loss of efficiency.

22 The pulsations in pressure above noted are an inherent characteristic of all centrifugal blowing apparatus of similar construction, and they occur when the apparatus is operated at loads and pressures widely differing from those for which the apparatus is designed; that is, from normal full volume and pressure. At any given volume they occur at a certain critical pressure and at all higher pressures, but do not occur at lower pressures than the critical. As volume is increased, critical pressure increases also. The critical pressure is slightly affected by the density and the humidity of the air.

23 Fig. 6 gives the characteristic critical pressure-volume curve of this compressor.

24 The rate and extent of the pulsations are affected by the capacity of the discharge piping, stoves, etc., into which the air flows. The larger the capacity the longer the period or wave length and the greater the wave magnitude, and vice-versa. The diagram in Fig. 5 shows the pressure waves from the machine installed at Oxford Furnace. When tested in the shop with very short piping of small capacity, the wave length was only a second or so, and of very small height.

25 The pulsations occur only at such loads that the characteristic pressure curve of the apparatus is rising with increase of volume or remains horizontal, and the effect of the throttling is to superpose a drooping pressure curve, falling with increasing volume, which alters the shape of the resultant pressure curve and makes it droop also. As the throttling required to remove entirely such pulsations is only a few inches of water, it has no appreciable effect on the efficiency of the compression.

26 Fig. 7 is the curve of pressure and volumes for this compressor at *constant speed*.

27 At the time this was written the blast pressure at Oxford Furnace varied from 10 lb. to 11 lb. during the day, with volume constant at 16,000 cu. ft. per min. The speed varied from 1500 to 1600 r.p.m. The average steam pressure was 135 lb.

28 The figures in Table 1 are taken from a typical station log, showing the variation

of pressure and volume during the 24-hr. period of operation.

TABLE 1. ENGINE ROOM REPORT MARCH 17, 1910

Empire Iron & Steel Co., Oxford Furnace, N. J.

Time	Volume cu. ft.	Blast Pressure Lb.	r.p.m.	Steam Pressure Lb.	Vacuum In.
a.m.					
1	15750	13	1540	140	24
2	15750	12.5	1490	135	25
3	15750	13.5	1580	135	25
4	15750	12	1510	140	24
5	15750	13.5	1530	155	24
6	15750	13	1550	150	25
7	15750	12.5	1550	150	25
8	15750	12	1490	120	h.p.
9	15750	11.5	1500	130	h.p.
10	15750	13.5	1580	160	26
11	15750	12.5	1520	155	26
12	15750	12.5	1500	150	26
p.m.					
1	15750	13	1530	140	26
2	15750	12	1490	150	26
3	15750	13	1560	130	26
4	15750	13	1560	150	26
5	15750	11	1445	145	26
6	15750	11.5	1450	130	26
7	15750	11	1490	135	26
8	15750	13	1510	140	26
9	15750	12.25	1500	155	25.5
10	15750	11	1383	140	25
11	15750	11.5	1410	150	25.5
12	15750	11.5	1440	145	25

Made 208 tons of iron in 24 hours.

29 The apparatus used for blowing the furnace before putting this machine into operation consisted of two vertical reciprocating blowing engines built by the I. P. Morris Company, each of the following dimensions: Steam cylinder diameter, 54 in.; blowing cylinder diameter, 72 in.; stroke, 72 in. The blowing cylinder displacement was 339 cu. ft. per revolution and the maximum speed rating, 30 r.p.m. giving 20,300 cu. ft. per min. total displacement. The actual maximum speed was 23 r.p.m. each, giving 15,000 cu. ft. per min. total displacement. The average blast pressure was 8 lb.

30 Judging from the revolutions of this engine, it was thought that the volume used was about 14,500 cu. ft. On putting the centrifugal compressor into action, an immediate increase in the amount of iron melted by the furnace was experienced. The output went up from an average of 139 tons per 24 hr. in February 1910, to 176 tons in April 1910, and the iron was found to be of a more uniform character, and the operation of the furnace was improved. A gradual increase in the amount of air has since taken place and the corresponding increase in pressure required to force the air through the furnace has been necessary as was to be expected. This increase of air has resulted in an increase in the production of the furnace from 176 tons on starting to the present average of about 190 tons. The machine is now operating with 16,000 cu. ft. of air and the production of ore is 185 tons per 24 hr. average. It is proposed to continue this increase to 200 tons per 24 hr., the limit of the charging apparatus.

31 The dimensions of the furnace are as follows: Diameter at bosh 17 ft. 6 in.; at hearth 11 ft.; at top throat 12 ft.; height from hearth to dumping ring 80 ft.

32 The condensing apparatus is of the barometric type, and the injection water is supplied by a turbo-driven centrifugal pump, placed in the sub-basement; and at the outset, when the machine was first put in operation, difficulty was encountered with the condensing water supply, which made it necessary to operate the machine for a considerable period of time non-condensing. Owing to the unfamiliarity of the fire-room force with the new boilers which had been installed it was even necessary to operate with steam pressures as low as 60 lb. per sq. in. gage for various periods, under which conditions the compressor set operated with entire satisfaction.

33 Owing to the fact that the condensing apparatus is of the barometric type, the further fact that the machine is operating far below its designed capacity and the difficulties involved in making an accurate boiler test to determine the amount of feed water under present conditions, no tests have been made to determine the actual efficiency of the machine. It is, however, furnishing considerably more air than the old machines, as is evidenced by the greatly increased product of the furnace, and is at the same time operating with fewer boilers. Also these boilers are more easily worked than when operated with the engine.

34 There is great difficulty in making comparisons of the performance of this type of blowing unit with reciprocating types, either steam or gas driven, owing to the absence of actual test figures, since none have been published which permit of accurate and satisfactory comparison. With the results which have been obtained from all sources as

to the actual performance of such machines and from actual experience with this machine and its sister machine installed at the Northern Iron Company, in line with tests which have been made in the factory, it seems that the following conclusions are correct in reference to this apparatus as compared with reciprocating engines for blowing blast furnaces:

a That the output of the furnace is increased on account of the greater steadiness of operation and more uniform conditions obtaining in the furnace.

b That the quality of the product is improved.

c That the steam consumption is equal to, or less than, that of the best compound engines blowing similar furnaces.

d That the engine room space occupied is only a fraction of that needed by reciprocating engines, either steam or gas.

e Considering all factors, including consumption of fuel; cost of operation, including oil and supplies, attendance, etc.; cost of buildings and foundations, interest on the investment; and cost of maintenance of plant; that the centrifugal compressor is a blowing apparatus which can be operated for a lower net cost than any other means of blowing furnaces.

WATER POWER DEVELOPMENT OF THE GREAT FALLS POWER COMPANY, MONTANA

Part II

By M. Hebgen, General Manager

Butte Substation

The 100,000 volt substation at Butte is located near the center of the district in which the power is distributed. The substation building is 150 feet by 50 feet in plan and 50 feet high. (See Fig. 15.) It is a brick walled, steel framed structure with concrete floors and roof.

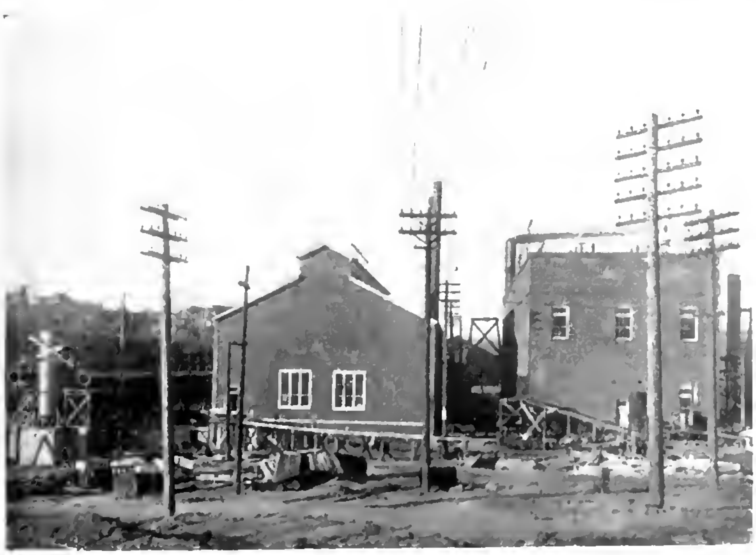


Fig. 15. Butte Substation on Righ 3600 H P Hoist Compressor Plant on Left

There are installed at present four banks of single-phase transformers, rated at 3600 kw. per bank and connected in delta on both high and low tension sides. They step the voltage down from 102,000 to 2500, at which voltage it is distributed to customers. The transformers are installed in fireproof compartments, entirely shut off from the rest of the building by brick walls and opening only out of doors. The transformers are mounted on wheels and can readily be run out onto a flat car which stands on a track running parallel with the building in front of the row of transformer compartments. This arrangement furnishes a convenient method of handling the transformers, both at the time of installation and afterward, in case it is necessary to make repairs.

On the gallery above the transformer compartments are located the electrolytic lightning arresters. On the gallery opposite are the 100,000 volt line switches.

Fig. 16 Interior of Butte Substation, showing Special Busbar Construction

The switchboard is in two sections, one section operating all line and transformer switches, which are remote controlled; the other section taking care of the 2500 volt feeders, which are controlled by hand operated automatic switches.

All electrical apparatus in the substation was supplied by the General Electric Company.

The load supplied in Butte is confined entirely to the mines, the power being used chiefly for the operation of motor driven air compressors and electrically driven pumps. The load is very nearly uniform for twenty-four hours each day throughout the year. The load factor is, in fact, close to 90 per cent.

Possibly the most unique feature of the electrical layout is the 100,000 volt bus construction. For flexibility in switching, duplicate busses are provided. The busses themselves are made of $1\frac{1}{2}$ in. iron pipe suspended by standard line insulators from the roof trusses of the building. The three conductors of each three-phase bus are suspended one above another, each being supported by the next one above. (Fig. 16.) The connections to the lines are also of iron pipe, making the bus structure as a whole quite rigid and well adapted to the use of suspension insulators.

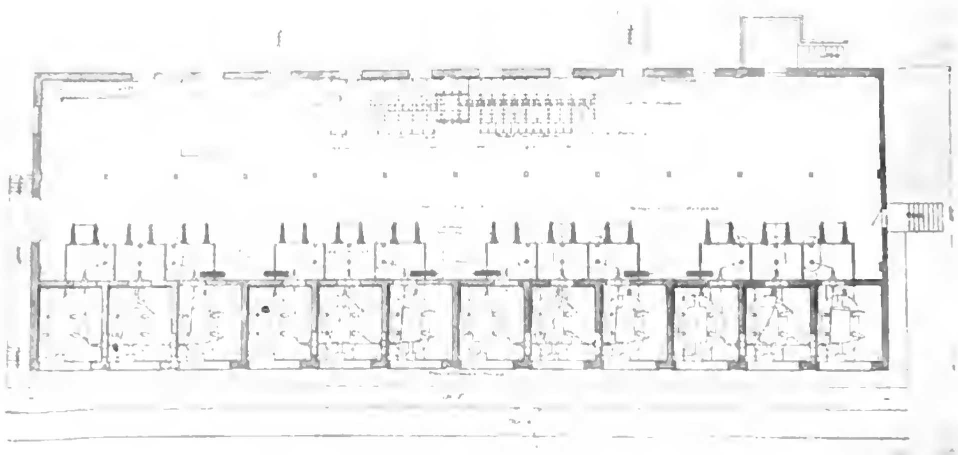


Fig. 17. Plan of First Floor of Butte Substation

Compressed Air Hoisting

Up to the present time practically all the hoisting in Butte has been done by steam.

Twenty-five of the larger steam operated hoists in Butte are driven by engines with an aggregate capacity of 40,000 h.p. The service required of these hoists is so intermittent and the percentage of time during which they operate at full load is so small that the average power required to operate all the hoists does not exceed 1600 h.p. On account of the intermittent load, steam oper-

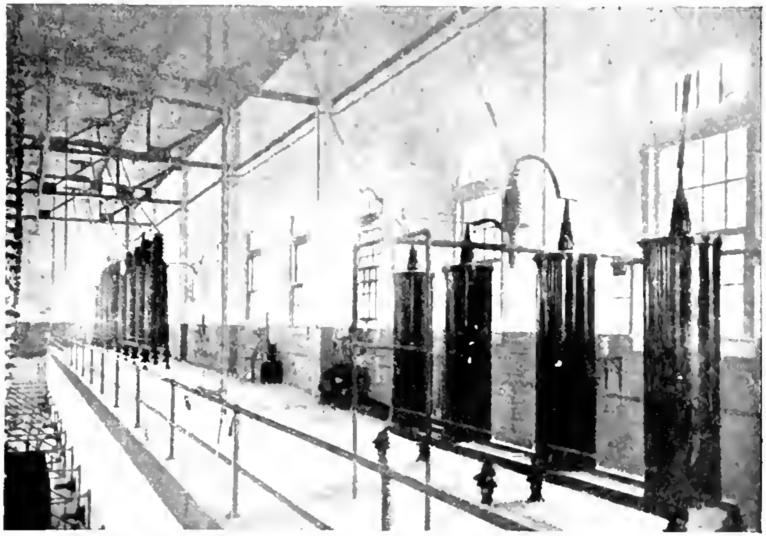


Fig. 18. Butte Substation, showing Electrolytic Lightning Arresters

ation is very uneconomical, and it has long been desired to substitute electric power for the steam, if this could be conveniently done.

Fig. 19. Interior, Butte Subst ion, showing 100,000 Volt Line Switches

This led to the adoption of a compressed air system for hoisting, the compressed air being supplied by one large central plant with synchronous motor driven compressors. This plant is located on top of a steep hill adjacent to the Great Falls Power Co.'s substation. By providing a large storage of air, a system has been worked out which will have sufficient capacity to equalize the variation in load of the entire system. On top of the hill is a steel water tank holding 60,000 cu. ft.; 208 ft. down the hill are air receivers having an equal capacity. The water tank is connected to the receivers, so that as air is drawn from the receivers water under pressure will take its place and maintain the full pressure of 90 lbs. until the receivers are empty.

With these receivers connected to the hoisting system, not only will the load be equalized but there will be sufficient reserve power to operate the hoists for several trips from the storage alone if in any emergency the compressor plant is temporarily shut down.

With this system of hoisting the original hoists will in all cases be used, some comparatively inexpensive changes only being necessary to adapt them to the use of air instead of steam.

Installed in the compressor plant there are at present three 1200 h.p. direct connected synchronous motor driven compressors. The motors are specified to operate at full load and 80 per cent. power factor, so that they have considerable reserve capacity for regulating the power factor of the load in Butte, thus keeping the voltage of the system constant. This is of no small advantage to the Power Company.

Fig. 20. Boston & Montana Smelter at Great Falls, showing 500 ft. stack—the highest stack in the world

Anaconda Substation

The power delivered to Anaconda is used entirely for the operation of the Washoe Smelter, the largest smelter in the world. The substation building belongs to the Washoe Copper Company and is a fireproof brick structure. There are at present installed three 1200 kw. transformers, with one additional transformer as a spare. In the near future this number will be increased to six, making two complete banks, with a total capacity of 7200 kw., or 9650 h.p. The transformers are in every respect duplicates of those installed in Butte. They are controlled by a General Electric K-15, 100,000 volt oil switch and protected by an electrolytic lightning arrester.

The load, like that at Butte, has a very high load factor and consists almost entirely of induction motors in large sizes.

Operation

The load carried by the Great Falls Power Company is practically constant 24 hours a day and 365 days in the year. There are no lighting peaks and there is no appreciable difference between the summer and winter loads. The leading current taken by the long high voltage line just about neutralizes the lagging current taken by the load, so that the power factor at Rainbow plant is very near unity. This combination of high power factor and high load factor makes an unusually favorable operating condition, which is probably not excelled by any system in the country.

In addition to this, a working agreement exists between the Great Falls Power Company and the Butte Electric & Power Company, which allows an exchange of power between the systems of the two companies. This arrangement is of immense advantage to both systems. The Butte Electric & Power Company has power plants on the Big Hole, Madison, Jefferson and Yellowstone rivers, with a total capacity of 25,000 h.p. It also has immense storage reservoirs which allow, for short periods of time, the development of power much in excess of the low water capacities of the plants. This excess power is at all times available for the use of the Great Falls Power Company if in any emergency it should be needed.

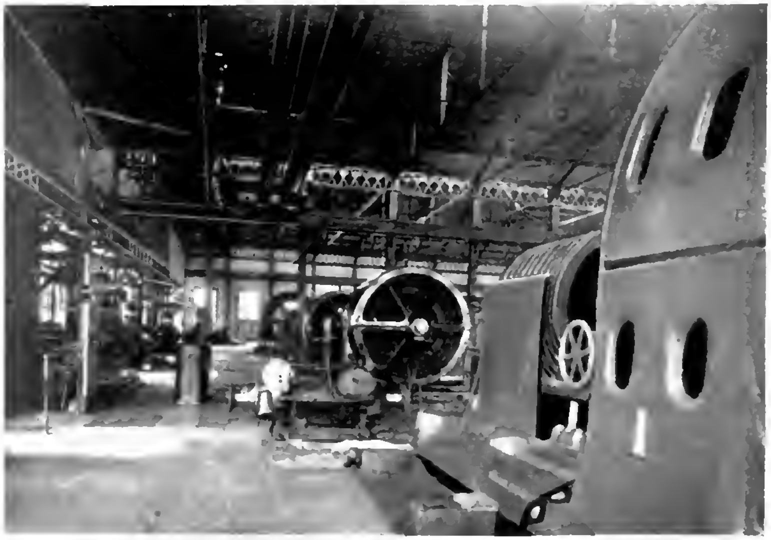


Fig. 21. Leonard Compressor Plant, showing 2300 H.P. in Motors

A further advantage is that the various plants of the two systems are widely separated and are on rivers whose water sheds are subject to different climatic conditions. Thus periods of excessive high water and excessive low water occur at different times at the different plants. If, for a few days, the flow of the Madison River or Big Hole River is less than normal and the capacity of the plants on these rivers is reduced, the deficiency will be made up from the Rainbow plant. Later, when the excessive low water is felt at the Rainbow plant, the Madison and Big Hole plants will have regained their normal output and be ready to make up any deficiency that may occur at Rainbow.

Power Market

With a power system located in the center of a district that is growing at the rate that Montana is growing, it would be difficult to estimate the amount of power that could eventually be sold; however, this much is known: Before Rainbow plant was completed, contracts had been entered into with one of the largest copper mining companies in the world, to continue during the life of the mines. Under these contracts all requirements for electric power are to be supplied by the Great Falls Power Company. To fulfill the immediate demands of these contracts nearly the entire output of the plant is required.

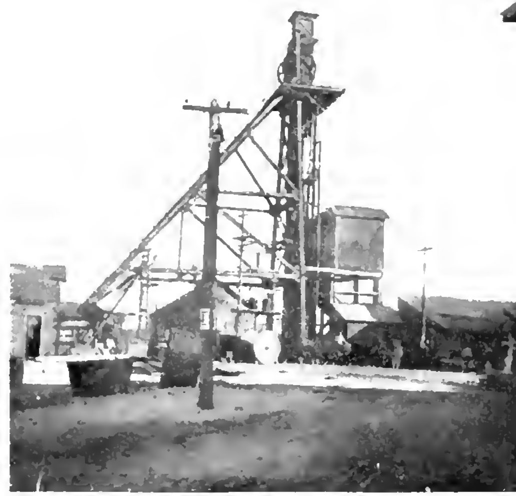


Fig. 23. Mountain View Hoist, operated by Compressed Air

Prospective Power

It is only a question of time when the railroads traversing the mountainous parts of Montana will be electrified, and two companies are already investigating the subject. Manufacturing industries requiring

Fig. 22. Leonard Compressor Plant, showing 2300 H.P. in Compressors

large amounts of cheap power will also increase in number, and tend to center around the large power developments. As the country grows, the demand for power for lighting, urban and interurban railways, irrigating, milling, etc., will increase.

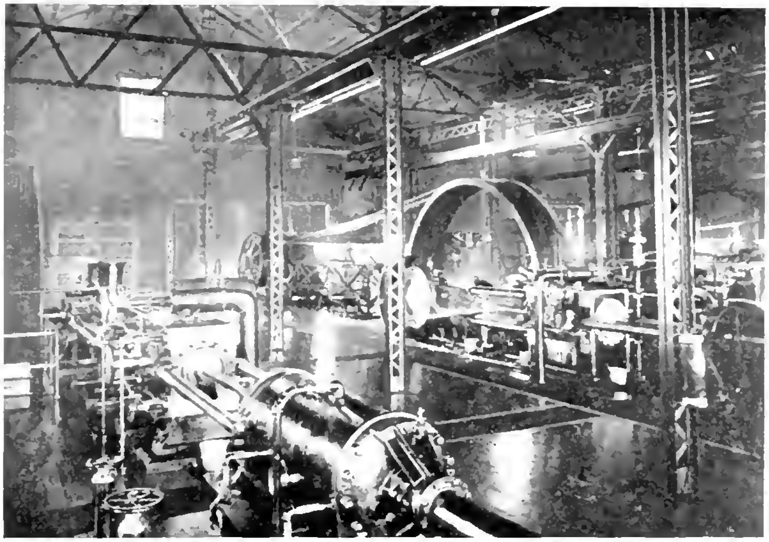


Fig. 24 Bell and Diamond Compressor Room, showing Four 600 H.P. Motors in Operation

Great Falls is in the midst of a large agricultural region. The Power Company's lines touch upon or parallel four transcontinental railroads and one local road. The company is in a position to furnish not only cheap electric power at Great Falls, but also factory sites along the banks of the river for several miles. With unlimited amounts of power and water, and good railroad facilities, this location seems ideal.

No definite figures can be given which will show the exact rate of increase in the demand for power, but with the Big Falls of the Missouri still to develop, possessing a capacity of 75,000 h.p. for peak loads, it is probable that whatever the demand may be it can be supplied for a great number of years to come.

True Conservation

Much has been said of late years on the subject of conservation, many of the arguments being to the effect that water power development should be restricted so that the people may not lose the power which nature has given them. It would appear more to the point to argue that water power development should be *encouraged* so that the people may not lose the power which nature has given them.

A few figures will show the saving that the power already developed at Great Falls will effect.

Coal in Butte and vicinity costs from $4.50 to $7.50 per ton, $5.00 being a fair average figure. 17.5 tons of this coal per year are required under ordinary conditions to produce one horse-power. To produce the 46,000 h.p. that is at present developed at Black Eagle and Rainbow Falls would require 805,000 tons of coal per year. At $5.00 per ton this would cost $4,025,000. With further developments at Great Falls this amount can be doubled.

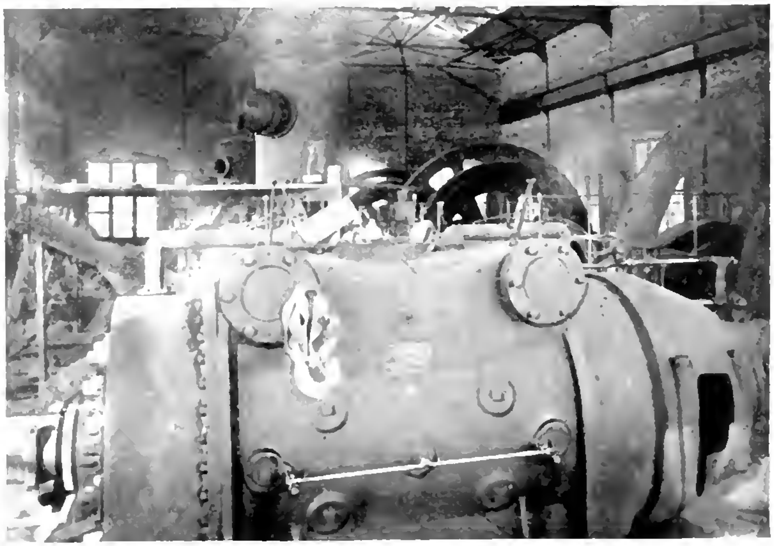


Fig. 25. Interior of Hoist Compressor Plant During Construction

Now to re-state the question; does the saving of four million dollars worth of coal each year conserve the resources of the country or not? We think it does.

The total cost of generating steam power in Butte is $100.00 per horse-power year. Electric power can be bought for half this amount, and less than half in large quantities.

Conclusion

It is believed that the power development herein described is in every way qualified for the greatest success.

The immense natural falls of the river did away with the necessity of an expensive dam, and made the development exceptionally cheap. The existence of a market to take the full output of the development at the very start assures an immediate revenue and obviates the long wait suffered by most plants in gradually accumulating a load.

The working agreement with the Butte Electric & Power Company, as has been explained, is of great advantage in every way.

Last but not least, the permanent construction of the power and substation insures long life and high efficiency, and it is believed that from a standpoint of mechanical strength, high insulation and electrical efficiency, the transmission lines are not excelled by any in the country.

A description of this power development would be incomplete without mention of those chiefly responsible for it.

To Mr. John D. Ryan, President of the Company, belongs the credit of originating the enterprise and standing back of it with steadfast support until its completion.

Mr. Henry A. Herrick, Resident Engineer, representing Chas. T. Main of Boston, was in direct charge of the work at Rainbow, and largely to his experience and good judgment is due the excellence of the hydraulic design of the plant.

Fig. 26. Never Sweat Compressor Room, showing 900 H.P. Motor Driving Air Compressors

Mr. Frank Scotten, Superintendent, carried on the construction of the plant at Rainbow with characteristic energy and completed the entire development in 21 months—a remarkable record for an undertaking the size of this.

Mr. H. H. Cochrane, Electrical Engineer, prepared the designs for substations and transmission lines, and helped solve many problems which arose as the work progressed.

ESSAYS ON SYNCHRONOUS MACHINERY

Part IV

By V. Karapetoff

PHASE CHARACTERISTICS OF SYNCHRONOUS MOTOR AT NO LOAD

The purpose of this article is to show how to predetermine the relation between the field current and the armature current of a synchronous motor at no load*. The lower curve in Fig. 3 which shows this relation is called the no-load phase characteristic of the synchronous motor. The upper curve is the full-load phase characteristic and represents a similar relation at a constant input of 530 kilowatts. This curve is the subject of the next article of the series.

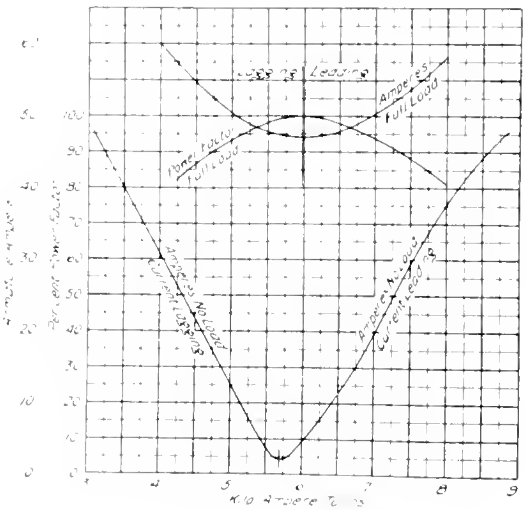


Fig. 3. Phase Characteristics of Synchronous Motor for No Load and Full Load

Phase characteristics (on account of their shape also called V-curves) give information about the performance of the synchronous motor, and in this respect take the place of the voltage characteristics of an alternator. They permit one to determine, in particular:

(1) Fluctuations of the armature current and of the power factor with a varying load, the field current being kept constant.

(2) Range of variation of the field current necessary in order to maintain a prescribed value of the reactive power input, when the motor is used for improving the power factor of the system.

(3) Maximum reactive kilovolt-amperes obtainable with the highest permissible field current; or the field ampere-turns necessary to produce a specified amount of reactive kilovolt-amperes in addition to the required mechanical load.

Assume first that the motor is running at no load with its field considerably over-excited, so that the motor draws a large leading current from the line. The energy component of the armature current is small, being just sufficient to overcome the iron loss, friction, and the copper loss in the armature. The leading reactive component demagnetizes the field and reduces the induced e.m.f. to a value consistent with the line voltage. Neglecting the small energy component (that is to say, assuming the machine to run without losses) the current and the voltage relations are those shown in Fig. 4. The same notation is used as in Fig. 2 (February 1911 Review, p. 56); in fact, Fig. 4 is a particular case of Fig. 2.

The current i_2 is purely reactive and leads the line voltage $OA' = -e$ by 90 degrees; $OD = E$ is the induced counter-e.m.f. of the motor. Subtracting from it the reactive drop ix and the resistance drop ir the voltage $OA = e$ is obtained, which is equal and opposite to the line voltage OA'. It must be clearly understood that there are two equal and opposite voltages at the terminals of the motor; these voltages balance each other. One voltage, OA', is that impressed by the line; the other, OA, is generated by the motor itself acting as a source of electromotive force. The energy component of the current being comparatively small, the cross magnetizing action of the armature current is negligible. Therefore $E_2 = O$, and $E_1 = E$.

The problem is to find the field ampere-turns for a given value of i_2. It will be seen from Fig. 3 that E is practically equal to $e + i_2x$, because i_2r is small and is perpendicular to the vector e. Consequently E can be calculated and the corresponding *net* excitation M can be found from the no-load saturation curve. This excitation is less than the actual field ampere-turns M by the amount M_1 of the direct armature reaction. The latter is determined by eq. (5) in which

* For a general theory of operation of the synchronous motor see a series of articles by Professor Comfort A. Adams in the *Harvard Engineering Journal*, January and April 1908 and January 1909. Professor Adams' articles "are intended primarily for those who wish to get a thorough understanding of the physical phenomena involved in synchronous motor operation as well as a working theory of the same."

approximately $c_2 = i_2$. The required field ampere-turns $M = M_o + M_1$. This value of M is used in Fig. 3 as the abscissa corresponding to the assumed value of i_2 as ordinate. Strictly speaking, the total armature current, $i = \sqrt{i_1^2 + i_2^2}$, ought to be used as the ordinate; but i_1 being small, i is approximately equal to i_2.

For small values of field ampere-turns the armature current is lagging; the electrical relations are shown in Fig. 5. The current i_2 lags 90 degrees behind the line voltage, and the induced voltage $E = e - i_2x$ is smaller than the line voltage. Therefore, the armature reaction M_1 strengthens the field, and $M = M_o - M_1$.

The lower curve in Fig. 3 is constructed by assuming various values of i_2, both leading and lagging, and calculating the corresponding values of M as explained above. Neglecting the loss component i_1 of the armature current, the lowest point of the curve should touch the axis of abscissæ. This point corresponds to the field excitation at which the induced voltage of the machine is equal to the line voltage. In other words, the abscissa of this point is found directly from the no-load saturation curve of the machine for the ordinate equal to voltage e. In reality there is a small current through the armature at this excitation when the machine is running as a motor. This current, i_1, practically consists of the energy component only, and can be calculated, knowing the iron loss, friction and windage losses. The lower part of the curve is therefore corrected by raising the lowest point to a distance i_1 from the axis of abscissæ.

It is sometimes required to plot a curve of power factor as a function of the field current. Such a curve is shown in Fig. 3 for the full-load conditions; the corresponding curve of power factor at no load having a similar shape. It reaches its maximum of 100 per cent at the field excitation of 5700 ampere-turns, and drops rapidly almost to zero in both directions, because the armature current is practically reactive. This curve is omitted in order not to obscure the figure.

Numerical Illustration. The curves shown in Fig. 3 refer to an 18 pole, 530 kv-a., 400 r.p.m., 6600 volt, three-phase Y-connected synchronous motor.(*) The points on the no-load phase characteristic have been calculated as explained above; the computations can be conveniently arranged as shown in the table on page 216. The energy component of the no-load current is found from test to be about 2 amp. The effective resistance r of the armature, reduced to the line voltage,

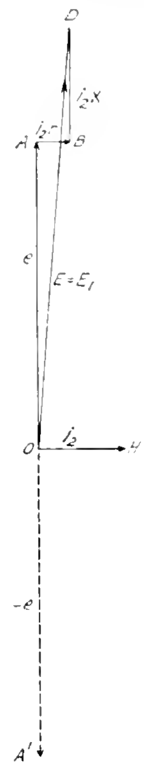


Fig. 4

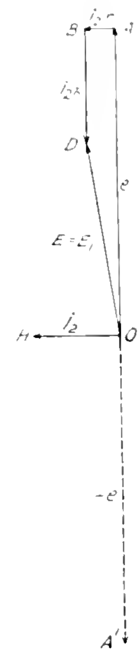


Fig 5

is 1.35 ohms. The armature reactance x is estimated to be about 14 ohms, according to the rules given in the second article of the series. The machine has 16 turns per pole per phase distributed in 2 slots per pole per phase; the winding pitch is 100 per cent. According to formula (5)

$$M_1 = 0.75 \times 0.966 \times 3 \times 16c_2 = 34.8i_2.$$

The calculations are performed in the following order: First, various values of the reactive component i_2 of the armature current are assumed, both leading and lagging (column 1). For these values of current the reactance drop i_2x is calculated and is entered in the second column. Adding this drop to the line voltage of 6600, the values of the induced e.m.f. E are obtained (third column). The fourth column contains the net ampere-turns M taken from the no-load saturation curve of the machine for the corresponding values of E. In the fifth column are given the values of the armature reaction which

* The manufacturer's notation of the machine is ATB-18-530-400-6600 V-C. The data are taken from G.E. Technical Report No. 7225.

NO-LOAD PHASE CHARACTERISTIC

Reactive Component i_2 Amp.	Reactive drop i_2x Volt	Induced Voltage $E = e + i_2x$ Volt	Excitation M_0 Corresponding to E Amp.-turns	Direct Armature Reaction M_1 Amp.-turns	Calculated field Excitation $M = M_0 + M_1$ Amp.-turns	Field Excitation from test Amp.-turns
45 leading	630	7230	7000	1565	8565	8690
35 "	490	7090	6600	1217	7817	8050
25 "	350	6950	6400	870	7270	7340
0	0	6600	5700	0	5700	5700
25 lagging	−350	6250	5200	−870	4330	4350
35 "	−490	6110	5000	−1217	3783	3910
45 "	−630	5970	4800	−1565	3235	3400

were calculated according to the formula $M_1 = 34.8\, i_2$. The sixth column gives the required field ampere-turns, $M = M_0 + M_1$. The lower curve in Fig. 3 is plotted, using the values in the sixth column as abscissæ against the values in the first column as ordinates. The lowest point on the curve is raised from zero to 2 amperes on account of the energy component of the armature current.

The values of the field current obtained from an actual test on the machine are given in the last column of the table. It will be seen that they agree quite closely with the calculated values given in the preceding column. This shows that the method gives reliable results provided that the value of the armature reactance has been correctly determined.

DIELECTRIC HYSTERESIS*

By Eugene D. Eby

The question of energy loss in a dielectric subjected to rapid reversals of electrostatic strain is one which has received much attention. On the other hand, little definite information is available concerning the exact nature of dielectric losses and their dependence upon the material and condition of the dielectric. Numerous investigators have each contributed some useful facts relating to this interesting subject, but the results of these investigations are so widely varied in character, both from difference in the materials tested and from methods of test employed, that any extensive tabulation for useful reference is practically impossible.

The term "dielectric hysteresis" has also been the cause of some contention, some writers holding that a part of the losses in a dielectric are of a truly hysteretic nature, some denying it, and others claiming that hysteresis occurs only in solid materials, with no evidence of it in fluids. It is not within the compass of this paper to state even personal views in this disagreement, which remains alone to those who by careful investigation and experimentation have a just right to express such opinions. I shall confine myself, therefore, to facts of test, to laws announced by some of the best authorities, and to concrete examples from our own test records. No claim is laid to originality in the material given later, for which credit is due to various experimenters in this subject. I shall treat it, furthermore, as "dielectric losses," arising from conduction and radiation as well as pure hysteresis. In such losses we have cause to be concerned as voltages for transmission and testing purposes increase, since these losses have a direct bearing on insulation strength or ultimate breakdown, and comprise as well the greater part of the no-load losses in certain high-tension systems, thereby materially affecting the efficiency of transmission.

General Equation of Dielectric Loss

The law of variation of loss due to variation of voltage was first announced by Dr. Steinmetz in 1892, at which time he stated that the "energy loss in a dielectric subjected to an alternating electrostatic strain is directly proportional to the square of the intensity of the electrostatic strain." Other men have placed the exponent between the limits of 1.5 and 3. Dr. Bruno Monasch, in a series of carefully conducted experiments (London *Electrician*, 1907, Vol. 59, page 417) has proven, however, that the square law is correct, and that apparent variations from it are due to variations in some of the other quantities affecting the dielectric loss. He

* Paper read before the Class in High Tension Phenomena, Pittsfield Section A.I.E.E., Pittsfield, Mass., Feb. 11, 1910.

says: "In all the dielectrics tested (various kinds of glass, ebonite, dielectric of the Grisson condenser plates, impregnated paper, rubber, impregnated jute, etc.) the square law is obeyed with perfect accuracy as soon as the voltage alone is varied."

Digressions from the square law result from variations in other influencing quantities, such as the temperature, and point discharges or radiation losses. The losses in glass and ebonite increase appreciably, even with a small rise in temperature. Tests on cables have shown that the loss was not materially affected by temperature except at voltages much higher than the working pressure. The effect of temperature will be considered somewhat more fully later. The energy loss due to point discharges increases much more rapidly than the square of the voltage, and at increased high potentials gets so far in excess of the dielectric loss, that the latter is inappreciable by comparison.

The energy loss in the dielectric is proportional to the capacity, and may be considered as proportional to the frequency through the range of frequencies used for technical purposes.

From these statements, based upon the best investigations that have yet been made, the general equation of the dielectric loss may be written.

$$A \text{ (loss)} = 2 \tan \theta .\ n.\ c.\ E^2$$

Where n = frequency of the applied e.m.f.
C = capacity of the system tested.
E = applied e.m.f
θ = complement of phase angle between the electromotive force and current.

For a given dielectric the phase difference θ may therefore be considered as a constant; $2 \tan \theta$ is the loss taking place during a cycle in a condenser of capacity 1 at the voltage 1.

The above formula is approximately correct for constant low temperatures.

A few laws deduced from and applying to conditions met in practice, will be of interest.

Variation of Temperature Due to Variation of Stress

(a) With moderate stress the temperature rises rapidly at first, then more slowly, finally becoming constant. The actual rise for a given voltage depends on the facility with which the material can dissipate its heat, and on the temperature of the surrounding medium.

(b) As the stress is increased, a point is finally reached where heat is developed at a greater rate than it can be carried away, and the temperature then rises until the material chars and breakdown results. This necessarily applies to fibrous materials and those affected by heat, this class forming the greater part of our commercial insulation.

(c) Moisture in the material causes the temperature to rise much more rapidly than in well-dried stock. The heat generated tends to dry out the material and the temperature may fall as the drying proceeds.

(d) Local heating usually results from stress on large quantities of dielectric, and injury may occur at these points, while the larger part of the material remains unharmed. Breakdown invariably occurs at those places injured by local heating.

(e) The final breakdown in fibrous materials usually results from the burning of the material and not from mechanical rupture. An electromotive force far in excess of the dielectric strength of the material may be applied to produce almost immediate rupture. With a sufficiently low electromotive force and an appreciable time interval before the breakdown, it is probably due to burning caused by the heat generated in the material. The lower the electromotive force, the longer the time required to produce breakdown under a given set of conditions.

(f) It follows from (e) that if the temperature is kept low, either by providing good ventilation or by artificial cooling, the stress required to cause breakdown in a time-test will be much greater than if the material is not so cooled.

(g) The actual temperature measured in most fibrous materials before breakdown occurred (tests by Mr. Charles Edward Skinner, *Elec. Review*, N. Y., Vol. 1, 1902 pp. 82–87) was usually 175° C., or more.

(h) With a given stress, the initial and surrounding temperature has much to do with the rise. This is due to the fact that the loss in the material increases rapidly with temperature; and a much greater rise would result with an initial temperature of 80° than with 20°. Tests have shown that breakdown frequently results under the former conditions from a stress that would not injure the material under the latter.

In Fig. 1 are shown some characteristic curves of temperature rise. Curve A shows the effect of moisture, the temperature rising very rapidly at first, reaching a maximum, and then falling, finally becoming constant as the material is dried out. Curve B shows the effect on the same material after very thorough drying. Curve C shows the increased temperature due to slight increase in the stress. Curve D shows the rise in temperature in treated material when poorly ventilated, the test being continued until breakdown resulted. This curve shows the tendency of the temperature to become constant, but at a point slightly over 100° C. the loss becomes so great that the heat cannot be dissipated as fast as generated; hence the change in direction of the curve and final breakdown. In numerous tests the material was found to be badly charred on the interior, without breakdown having resulted.

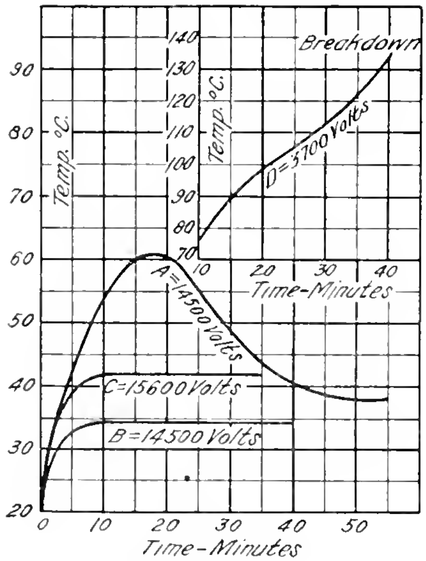


Fig. 1. Increase of Temperature in Insulating Material due to Stress

Variation of Loss Due to Variation of Temperature

Mr. Skinner's series of tests has shown that:

The energy loss in fibrous material increases at a greater rate than the temperature.

Local heating, occurring in a mass of poorly ventilated material, is due to a greater initial loss in one portion, causing increased heating, this in turn causing greater loss, etc., until the temperature finally reaches a point at which charring and breakdown result.

Fig. 2 shows some characteristic curves of the increase of loss due to temperature. These curves show that the rate of increase of loss is greater at high temperatures, thus giving the reason for the greater rise in temperature with a given stress when the initial temperature is high than when it is low.

Losses as great as 5 watts per cubic inch have been measured in fibrous material before serious injury resulted, due to charring. A considerably less loss than this will, however, char the material in time unless special means are taken to dissipate the heat generated.

It follows that a long continued test at high stress may seriously injure the insulation of a piece of apparatus without its being made apparent by the test. This has been called "straining the insulation," and it is probably always due to charring.

Variation of Loss Due to Variation of Voltage

As stated before, the loss is proportional to the square of the voltage, other conditions remaining constant. With increasing temperature, the loss increases more rapidly than the square of the voltage. The wave-form of the applied electromotive force also affects the loss.

Variation of Loss Due to Variation of Frequency

The rate of variation is in proportion to the frequency at low temperatures. From Fig. 2 it will be seen that the rate of variation follows a different law at higher temperatures.

Comparative Losses in Different Dielectrics

The amount of loss varies considerably in different materials. The smallest loss in all the solid dielectrics tested, except paraffine,

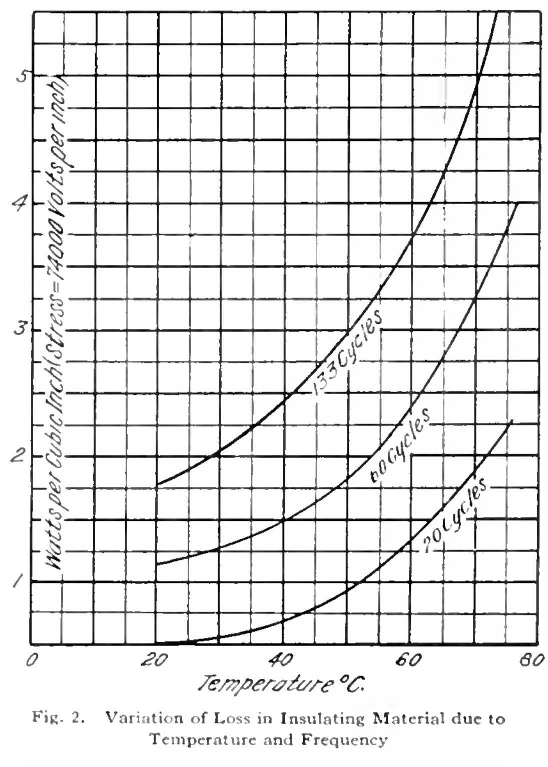


Fig. 2. Variation of Loss in Insulating Material due to Temperature and Frequency

was observed in flint-glass: (Dr. Monasch, London *Electrician* 1907, Vol. 59); while the loss in the cable insulated with rubber and impregnated jute was but slightly greater. The paraffine used as dielectric in one of the condensers tested showed no appreciable loss. For condensers subjected to high voltages, air was found to be the only dielectric giving negligible loss. Fibrous materials on the other hand have comparatively high losses, as shown in a previous example, where a loss of 5 watts per cubic inch was measured. Fluid dielectrics are said to have no appreciable loss. Information on different materials is so meagre, however, that no definite conclusions have as yet been reached concerning the relative losses in them.

In extensive high-tension cable net-works the amount of energy wasted in the dielectric is by no means negligible. In the case of short or medium lengths, it affords by far the greater part of the no-load loss, and only in very long uninterrupted cable lines can it be neglected in comparison with the copper loss.

Energy Loss in the Insulation of Large Transformers

A couple of examples from recent tests made on some large, high voltage transformers, will serve to illustrate the variation of the dielectric losses with the variation in voltage.

Fig. 3 shows this variation in a 60 cycle, 1200 kw., 60000-120000-138000Y 12000 volt transformer, the curve representing the difference between the measured core losses:

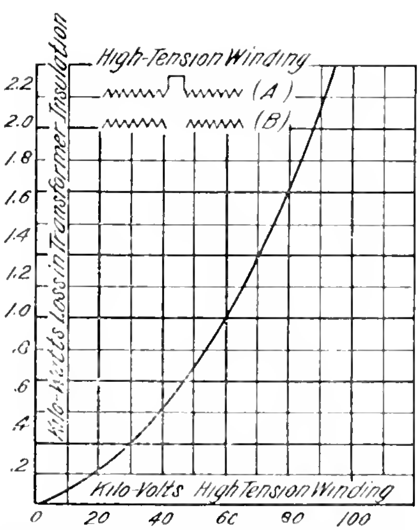


Fig. 3. Variation of Loss in Transformer Insulation due to Stress, WC-60 3750-60000/120000 138000 V 12000

(1), with the two halves of the high-tension winding in series; and (2), with the series connection broken. Unfortunately this curve does not reach the maximum operating voltage of the transformer. It shows, however, the general law of variation of the loss with the potential applied.

In Fig. 4 is shown a curve giving the difference in the exciting currents, with windings open and in series, on a 60 cycle, 3750 kw., 102000-92400 6800-6200 transformer. The ordinates of this curve, although in reality expressed in amperes, are still approximately representative of the dielectric losses under these particular conditions.

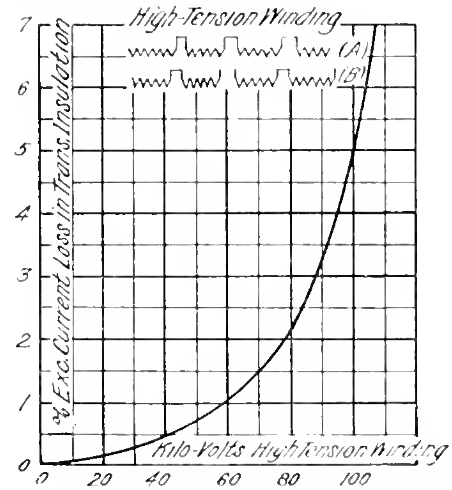


Fig. 4. Exciting Current used in Supplying Losses by Transformer Insulation due to Stress VC-60 1200 102000 92400 6800 6200

Conclusion

Several evident applications can be made from the principles thus far discovered. The most apparent is the requirement of thorough ventilation in high potential apparatus. The insulation of transformers for operation at high voltages should be of a character to provide ready dissipation of heat. Thus, it appears that fibrous insulation in thick layers should be avoided, and oil relied upon for insulation strength and dissipation of heat by circulation and conduction. There would seem to be an advantage, also, in thus decreasing the condenser effect due to many layers of tape, paper or varnished cambric, and substituting an equivalent strength of oil of little capacity. In cases where quantities of pressboard are used to increase the puncture voltage across distances through oil, practice has shown that it is necessary to space several thin sheets with ducts for oil circulation between them, if an advantage is to be gained. To insert an equal amount of material in a single compact mass is detrimental when the thickness is so great as to prevent dissipation of the heat.

J. M. HORTON ICE CREAM COMPANY

By W. D. Bearce

The electrical equipment of the J. M. Horton Company's new factory is an unusually good example of the economies possible in the isolated plant operation of refrigerating machines, and especially of the flexibility, cleanliness and reliability of operation accompanying electric drive in a plant of this character.

The use of gas producers in connection with gas engines for the operation of refrigerating machinery is at present limited to some half dozen plants in this country, of which, the following are typical installations: St. Louis Refrigerating and Cold Storage Co., St. Louis, Mo.; The Washington Market Co., Washington, D. C.; and the installation herein described. In the first named plant the equipment consists of large high speed gas engines direct connected to refrigerating machines, while the Washington Market Company employs gas engines of normal speed, with rope drive for speed reduction. The J. M. Horton Company employs gas engines direct connected to continuous current generators, which in turn drive the adjustable speed motors belted to the refrigerating machines.

The gas engine operates most efficiently when run at its rated speed and under full load, and for this reason is not suitable in most cases for the direct driving of refrigerating machines, which operate most economically at speeds proportionate to the demands made upon them usually variable. This drawback and the fact that other power is needed for auxiliary apparatus in a plant of this kind have limited the use of the gas engine in this respect.

In order to obtain the required flexibility the J. M. Horton Company has employed electricity as a medium of power transmission, with motors for driving the several machines and supplementary equipment.

Reliability of operation is especially important, since the connection to the three-wire mains of the local power company has only sufficient capacity for lighting the building. This connection is used regularly for night lighting when the generating units are shut down, and also insures lights in case of accident.

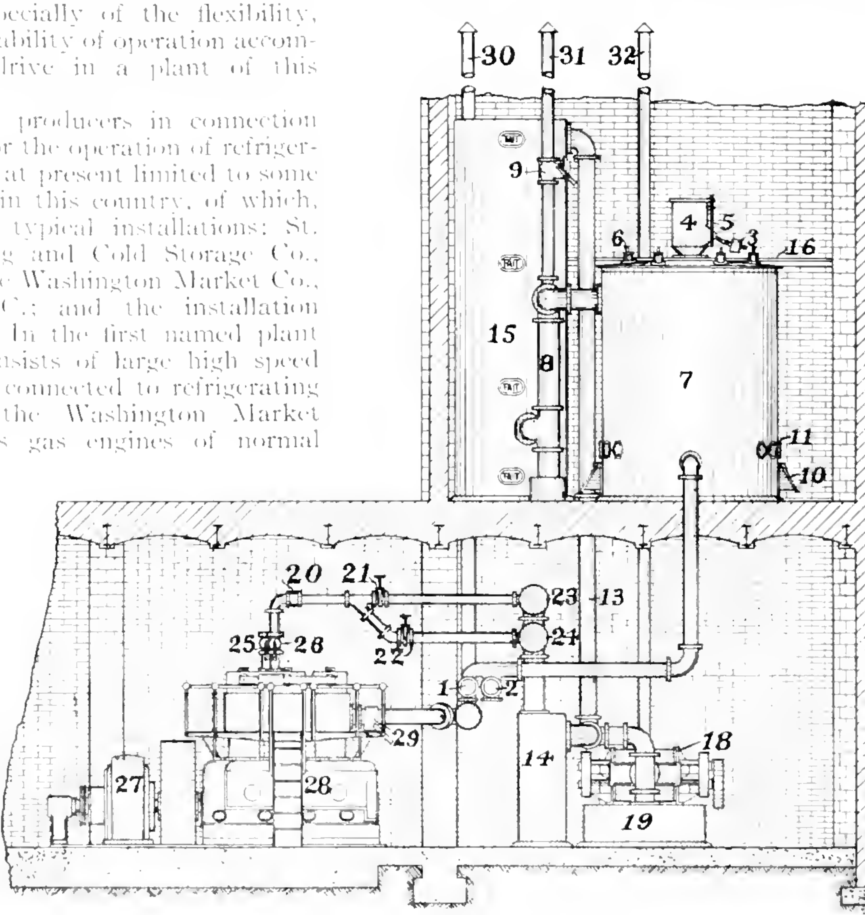


Fig. 1. Elevation, Showing Gas Producer Arrangement of Piping, and 150 Kw. Gas Engine Generating Set

Gas Producers

The gas generating equipment consists of two up-draft suction producers with scrubbers and dryers, furnished by the Tait Producer Company. The dryers are located in the basement in the engine room, while the remainder of the apparatus is installed on the main floor.

These producers are especially designed for the consumption of No. 1 Buckwheat coal and operate on a "balanced draught." They are rated at 350 h.p., with 50 per cent. overload capacity, and will operate for long periods without renewal of fires. Fig. 1 is a vertical section of the generating equipment showing one producer, arrangement of piping, and one of the 150 kw. gas engine generating sets. The gas is delivered from the producers to the motor-driven gas booster, by means of which it is supplied to the engines at a predetermined pressure.

The engine exhaust is piped back to the producer, where part of the burned gas is utilized as a draft diluent combining with the necessary amount of free air; the remainder being used to produce a pressure in the ash pit proportional to the suction above the fuel bed, thus giving the so-called "balanced draft." Each producer is supplied with pilot flame burners which indicate the condition of the fires.

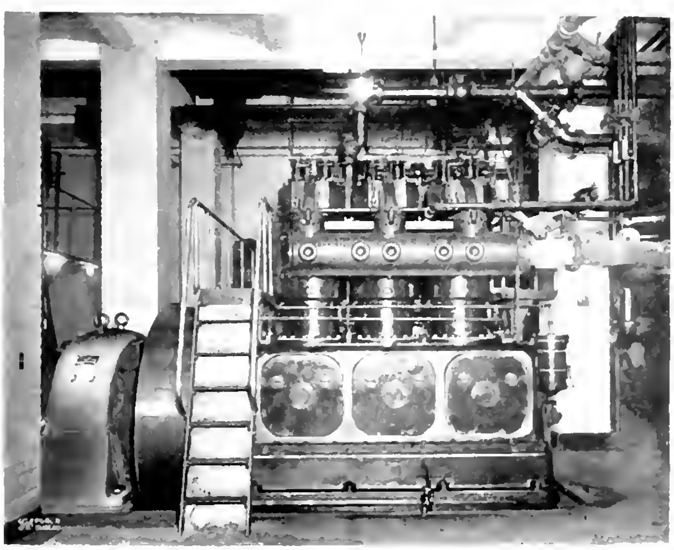


Fig. 2 150 Kw. Gas Engine and Generator Set

Gas Engines

The two generator sets consist of 3-cylinder Rathbun-Jones gas engines of the vertical type, direct connected to 150 kw. General Electric generators. One of these sets is shown in Fig. 2. Ignition is obtained from a

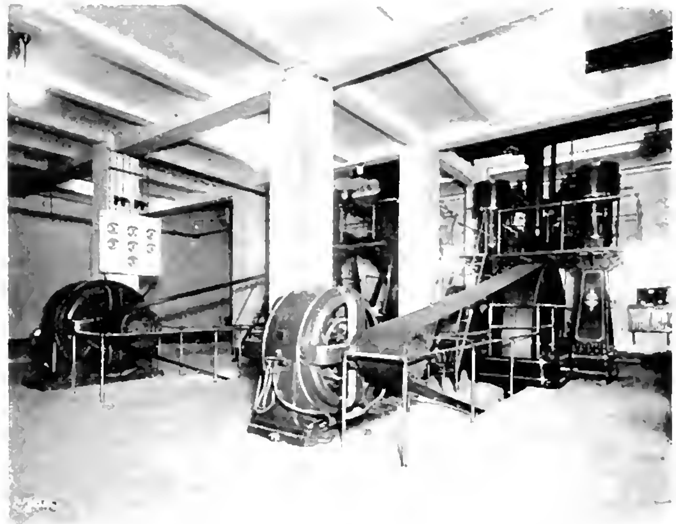


Fig. 3. One 90 H.P. and One 125 H.P. Motor Driving Ammonia Compressors

battery of storage cells charged from a small motor-generator set.

The generators are standard engine type direct current machines, each with a normal rating of 150 kw. at 250 volts and 257 r.p.m. Single-phase slip rings are provided for the derivation of a neutral wire, which is obtained through a compensator rated for 25 per cent. unbalancing.* This connection supplies current at 125 volts for the incandescent lighting system, while all of the motors operate at full generator voltage.

Switchboard

A seven panel slate switchboard (Fig. 4) controls the distribution of electric power, and is an illustration of the compact arrangement possible in locations where the available space is limited. Reservation is made in the engine room for another generating set and also for a third refrigerating machine, in anticipation of future requirements for additional power. The board is designed for the ultimate capacity of the plant and has

*See Fig. 17, page 86, February, 1911, REVIEW, article on "Compensators," by W. W. Lewis.

three generator panels (shown on the left) and wiring on the motor starting panel (fifth panel from left of illustration) for the

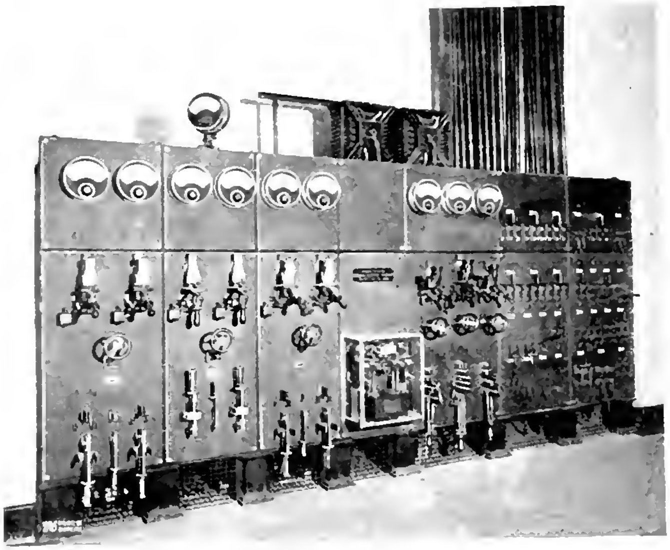


Fig. 4. Power Plant Switchboard

driving motor of the third refrigerating machine. This panel carries starting switches, ammeters, circuit breakers and rheostats, while resistance for starting the motors is mounted on a frame just above the panel.

The two panels on the extreme right carry switches for controlling the motor and lighting circuits in different parts of the factory. Circuits controlling the small motors on the second and third floors are equipped with signal lamps which are illuminated only when the motor is in operation, enabling the engineer in the basement to see at a glance just what motors are in use on these floors.

The recording wattmeter on the center panel measures the entire output and, together with the record of coal consumption, affords an accurate means of calculating the overall efficiency of the installation.

Refrigerating Machines

The present equipment comprises two compressors built by the York Manufacturing Company, one of which is belt connected to a 90 h.p. motor and rated at 50 tons refrigeration; the other being belt connected to a 125 h.p. motor and rated at 75 tons refrigeration (Fig. 3). The motors are equipped with commutating poles and are designed for a speed variation ranging from 250 r.p.m. to 500 r.p.m.; the change in speed being effected by field control. At the higher speed the compressors deliver full rated output at 65 r.p.m. The 50 ton machine has a 14 in. bore and 21 in. stroke and the 75 ton machine a 16 in. bore and 24 in. stroke. As in most commercial plants, ammonia vapor is employed to abstract the heat from the water. Free ammonia gas is first compressed by the refrigerating machine to a pressure of about 150 lb. per square inch. This operation increases the temperature of the gas and necessitates the employment of cooling coils, by means of which the temperature is again reduced to the condensing point. The liquid ammonia thus obtained is allowed to evaporate under reduced pressure in a coil of pipe placed in a tank containing brine for the circulating system.

Pumps are required for circulating the cold brine, and these are also motor-driven. Fig. 5 shows an adjustable speed 35 h.p. motor driving an 800 gallon turbine pump. This pump supplies brine for cooling one of the large chill rooms, in which the ice cream is set to harden after leaving the freezers. The diagrams of Fig. 6 show the general scheme of piping used

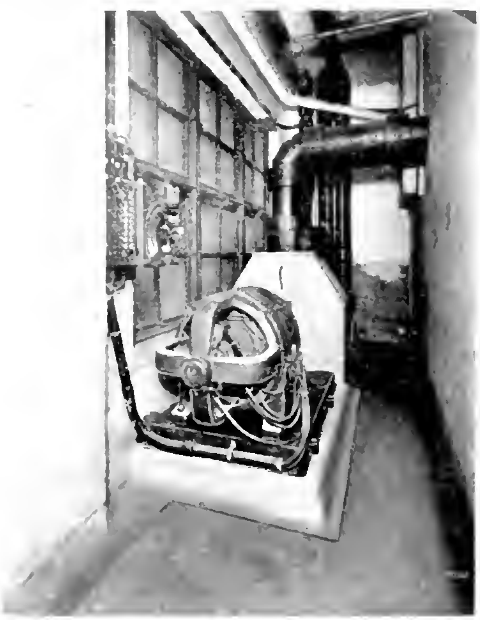


Fig. 5. 35 H.P. Motor Direct Connected to 800 Gal.-per-min. Brine Pump

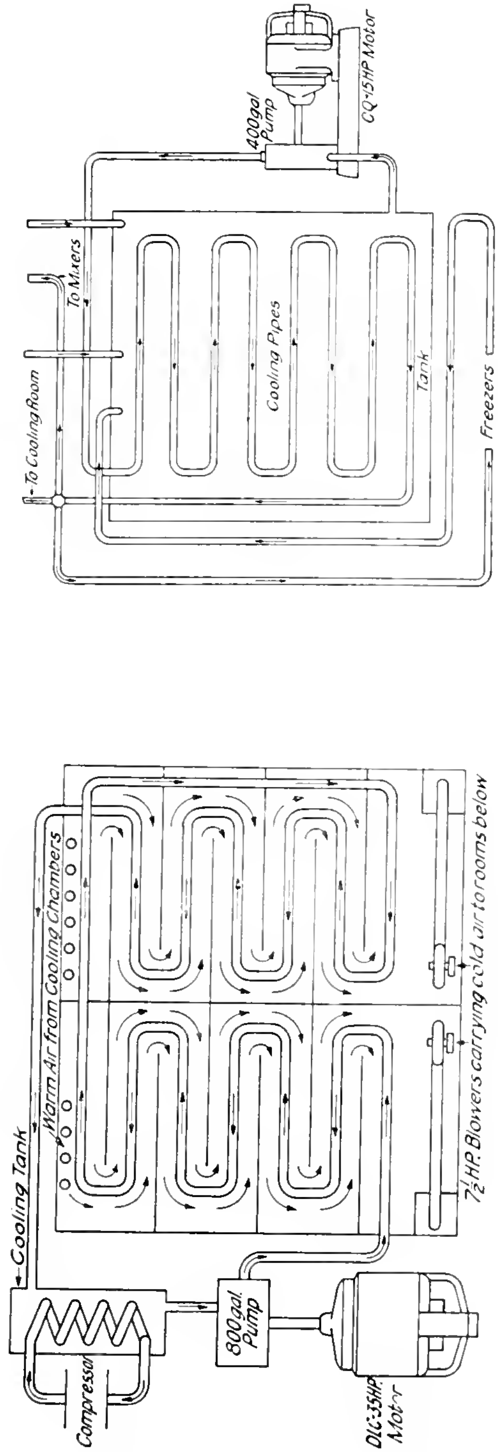


Fig. 6. General Arrangement of Piping for Circulating Brine

for circulating the brine. The 800 gallon pump takes the brine from the cooling tank and forces it through the coils in the large chill room on the second floor, while the 400 gallon pump supplies brine to the mixers, freezers and the third floor chill room. Fig. 8 shows the method of driving the brine-cooled freezers, which are each provided with a clutch on the main shaft for individual control, the whole group being driven by a 20 h.p. motor.

Other illustrations show applications of the adjustable speed motor to operations performed in the factory. In Fig. 9 a $7\frac{1}{2}$ h.p. motor is shown driving a countershaft belted to several ice cream mixers. Experience has demonstrated that motor-driven

MOTORS OPERATING AT 230 VOLTS

No. Motors	Horse Power	Speed	Application
			Engine Room
1	90	250-500	50 ton refrigerating machine
1	125	250-500	75 ton refrigerating machine
1	10	1500	Water pump for circulating water in jackets of gas engines
1	5	1100	Root blower for gas exhaustion
1	5	1700	Worthington pump
			Main Floor
1	$7\frac{1}{2}$	225	Ice crushers
			Second Floor
1	35	500-1000	Brine pump (800 gallon)
1	10	450	French freezers
1	10	450	Ice crushers and conveyors
1	$7\frac{1}{2}$	825	Ice hoist
1	20	925	Ice cream freezers
2	$7\frac{1}{2}$	825	Bunker room fans in cold storage
			Third Floor
1	20	1400	Turbine pump for condenser and jacket water, third floor to cooling tower
1	15	1500	400 gallon turbine pump handling brine from third floor tank
1	$7\frac{1}{2}$	310-620	Ice cream mixers
1	5	375-750	Cream beaters

apparatus, aside from affording improved sanitary conditions and ease of control, produces a cream of superior quality on account of the uniformity of speed attained. Fig. 7 shows the application of motor drive to cream beaters in the baking department.

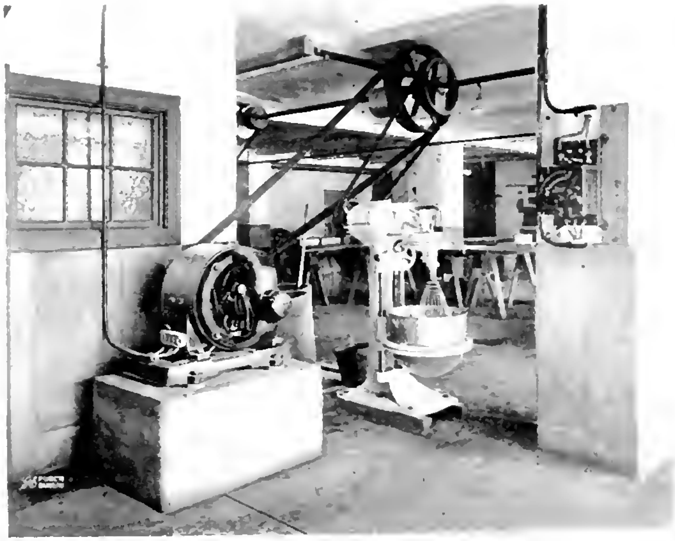


Fig. 7. Cream Beaters Operated from Line Shaft Driven by Electric Motor

Aside from the applications already mentioned, motors are used for elevators, ice crushers and conveyors, exhaust fans for cold storage, and pumps for condenser and cooling water. The list of motors used in various parts of the factory is given on previous page.

The plant is lighted, as may be seen from the illustrations, by tungsten lamps equipped with holophane reflectors.

The electrical equipment, with a few exceptions, was furnished by the General Electric Company and includes the apparatus listed on page 223. Mr. Karl W. Schantz, president of the Wegner Machine Company, acted as consulting engineer, and made recommendations for the installation. While the plant has been in operation only a few months it has already shown results which have not been duplicated in steam or direct-driven gas-engine-operated plants. It has remarkably high economy, requires a very small amount of attention, and is thoroughly sanitary.

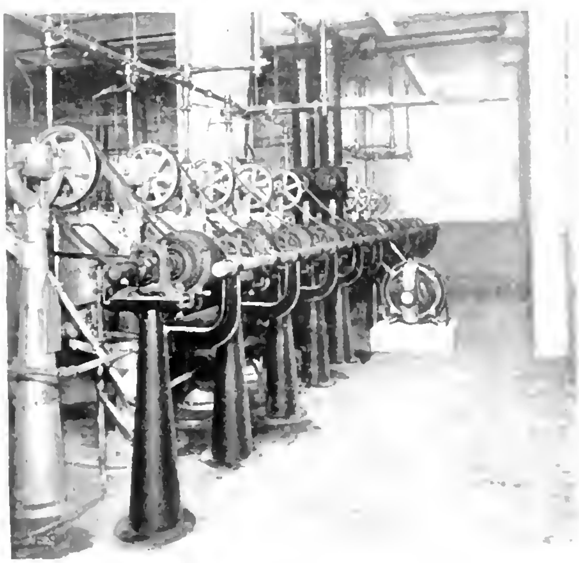


Fig. 8. Brine-cooled Freezers Operated from Line Shaft through Clutch

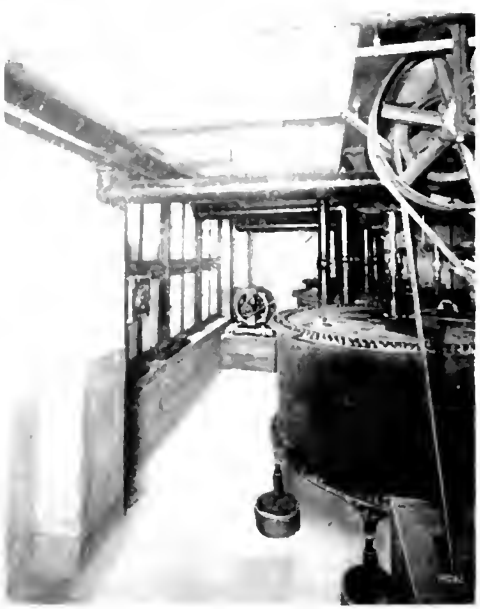


Fig. 9. Ice Cream Mixers

ARC HEADLIGHTS FOR ELECTRIC CARS

By P. S. Bailey

Beginning with the pioneer installations of trolley systems in this country, it was decreed that each car should be equipped with a light at the forward or driving end. Not only was this deemed necessary for the appropriate illumination of the track ahead, but also to meet with the requirements of the law in establishing visible evidence of the new vehicle to other nightly users of the thoroughfares.

Intensity of illumination was not at that time striven for. The reasons for this are obvious: cars were small, motive-power inadequate, rails short, and road-beds hazardous; consequently speed, as compared with that of modern methods of electric railway transportation, was low. The incandescent headlight, which was generally set into the dasher of the car, answered practically all the requirements of that period.

As the popularity of the new method of transit grew apace, it soon became necessary for the railways to enlarge their cars, provide motive power of greater capacity, use longer rails, lay better road-beds, and enlarge the generator output of their central stations. Then, too, more frequent trips and increased speed to keep up running schedules were the natural sequences. This condition of affairs made the use of a more brilliant illuminant imperative, with the result that the enclosed carbon arc headlight soon appeared.

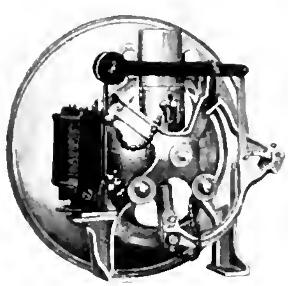


Fig. 1 Mechanism of Non-regulating Lamp

Several different types of enclosed carbon lamps were promptly put on the market, and this business, though now on the wane, has been of considerable magnitude. The carbon lamps were all of similar design, consisting of a cylindrical casing, enclosing a mechanism upon which was mounted a single or double solenoid that controlled an armature with a clutch attached. This solenoid separated the upper, or positive of two vertical carbons from the lower or negative, which was held rigidly in a carbon holder attached directly

Fig. 2. Lamp Fitted with Parabolic Reflector and Shield for Cutting Off Undesirable Rays of Light

to the frame. The carbons were connected in series with a resistance, usually made in the form of several units wound with high resistance wire. Sometimes, however (involving less loss of illuminative efficiency), a series-multiple arrangement of suitable incandescent lamps was installed in the car interior, in series with the carbons. These lamps answered very well the purposes for which they were designed and are still popular for certain classes of service. However, they may be considered more or less anachronistic from the modern standpoint.

The rapid growth of the cities and towns throughout the country, together with the high passenger and freight rates maintained by the steam railroads and the frequent inadequacies of schedules and connections—in the latter case often due to the topography of the country traversed—opened the way for the ever-increasing mileage of the interurban electric railroad. Competition was also distinctly beneficial, both to the proletariat and the capitalist.

The increase in speed required for the proper operation of interurban cars soon necessitated increased track illumination, both for the safety of the public and the protection of the owners.

To fulfill these requirements, a line of luminous arc headlights has been developed and placed on the market by the General Electric Company, which embody extremely high efficiency, long burning electrodes with consequent economy of operation, and simple

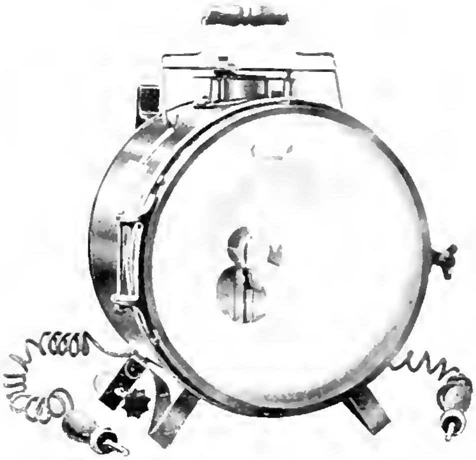


Fig. 3. Lamp with One 16 C.P. Incandescent Bulb for Subdued Lighting

and rigid mechanical construction. Eight different styles, which are essentially of the same basic mechanical principle throughout, differing only in details conducive to the best applications for particular optical requirements, are now manufactured.

Fig. 4. Lamp Equipped with Special Reflecting Mirror and Chimney Shield

The well-known characteristics of the luminous (magnetite) arc, which have already revolutionized systems of street illumination, are employed to great advantage in the headlights. Details of arc control, electrode composition, and lamp mechanism have been perfected, producing units of merit.

The mechanism (Fig. 1) is of the non-regulating type, being designed to strike an arc of fixed length. Slow electrode consumption provides opportunity for sufficient natural interruptions of the circuit, incidental to regular operation, to maintain the arc

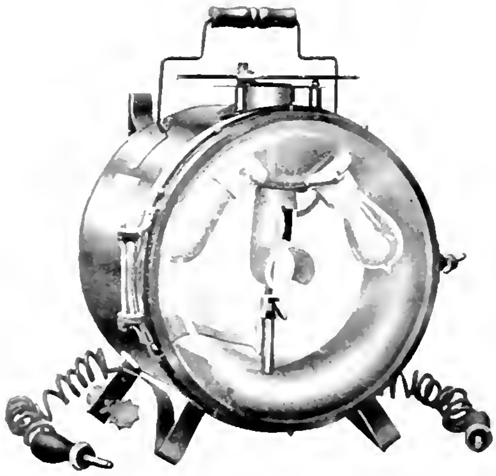


Fig. 5. Lamp Similar to that of Fig. 4, but with Two 16 C.P. Incandescent Bulbs for Subdued Lighting

within safe voltage limits. This ensures a simple and staunch construction, suitable for all classes of service. The moving elements of the mechanism are mounted on a sliding galvanized iron frame which is secured to the casing by means of a wing-nut and stud, the latter being attached to the central portion of the frame and projecting through the casing back. Contact is made at the back of the casing, to terminals on the back of the frame. Thus the lamp may be easily removed for inspection or repairs.

A solid convex heat-resisting glass window is provided for the doors of all lamps, reliance being made solely upon reflectors for light distribution; but where extreme concentration of the beam is required, the railway semaphore signal lens is introduced. The latter is, in fact, a moulded plano-convex lens with a series of circular sections so arranged as to avoid excessive weight and to secure the best optical results. It is exceptionally strong and has the advantage, due to its long focus, of remote location with respect to the arc, and consequently is affected but slightly by heat radiation.

The luminous arc is maintained at the foci of highly efficient reflectors or semaphore lenses according to the requirements of the service. The positive electrode, or anode, is a stationary copper forging over which is drawn a non-oxidizing metal sheathing; the life of this electrode being from 2,000 to 3,000 hours. The negative electrode, or

Fig. 6. Headlight Fitted with Semaphore Lens and Spherical Mirror

cathode, consists of a thin welded steel tube containing an efficient mixture of iron oxide and other suitable ingredients and attaining a life of 50 to 75 hours.

The volume of light from the luminous arc emanates entirely from the arc stream, in which the vapors from the negative electrode are heated to high incandescence. The

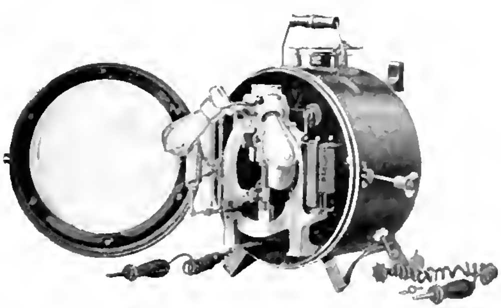


Fig. 7. Lamp Similar to that Shown in Fig. 6, but with Two 16 C.P. Incandescent Bulbs

principle of operation is different from that of the carbon arc, since the intrinsic illuminating value of the latter is very low, the luminosity of the carbon lamp depending upon the incandescence of the carbon tips. The luminous arc with the same wattage dissipation is approximately one hundred per cent more efficient than the carbon arc.

Unless otherwise ordered, all lamps are adjusted to operate on a nominal 550 volt direct current railway circuit, with an 80 volt arc and a current of 4 amperes.

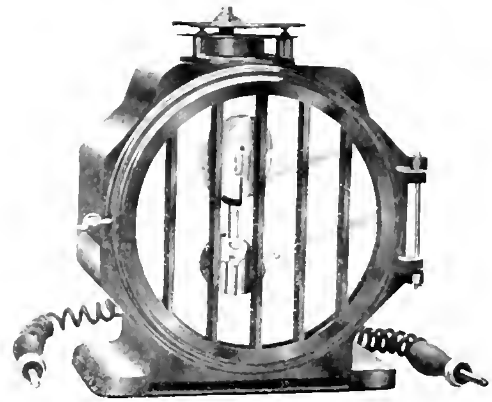


Fig. 8. Form E-1 Headlight

Fig. 2 shows the Form D-1 headlight with parabolic reflector, and chimney shield for cutting out undesirable direct rays. This lamp gives a comparatively wide angle of light distribution, varying in intensity from the maximum at the center to the minimum at either side of an angle of about 100 degrees. It is very popular with suburban railroads where speeds are comparatively low and

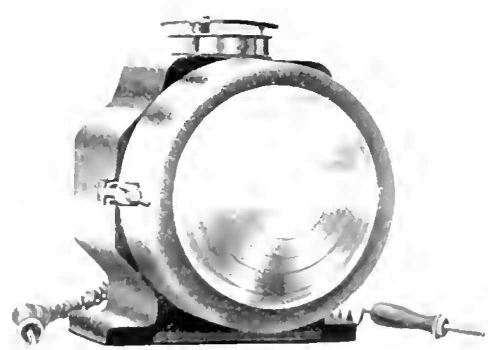


Fig. 9. Form E-2 Headlight

where curves and cross roads are frequent. The width of the beam enables the motorman to see partly around the curves and sufficiently far ahead to detect obstructions on the track, as well as to locate the approach of vehicles from intersecting thoroughfares.

Furthermore, he is given ample time in which to stop his car to take on waiting passengers.

One of the characteristics of the luminous arc is its reduced luminosity when reversed.

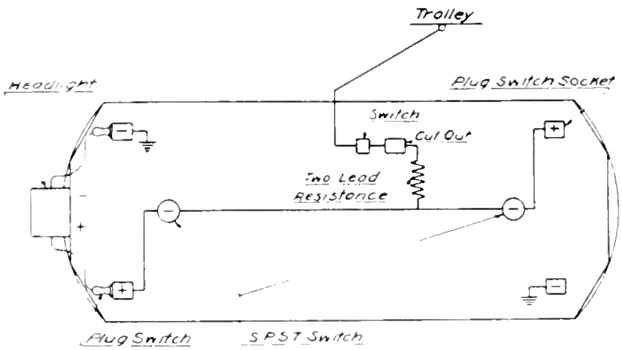


Fig. 10. Connections of Luminous Arc Headlight with Two-Lead Resistance for Street Railway Service

This feature is taken advantage of for dimming purposes inside of city limits where the regulations of certain municipalities require subdued illumination. This is a distinctly novel feature and eliminates the use of antiquated mechanical screens. By simply throwing a switch the driver is enabled to secure intense or radically diminished illumination at will.

Some companies prefer to use incandescent lamps for dimming purposes and therefore the Form D-3 lamp (Fig. 2) has been designed. This headlight is similar to the one shown in Fig. 2, but contains a single 110 volt, 16 candle-power incandescent lamp connected in series with a suitable resistance contained inside the casing, so designed as to operate across the nominal railway potential.

In Figs. 4 and 5 we have the Forms D-2 and D-8 units equipped with Mangin mirror and a chimney shield similar to that previously described in connection with the Form D-1 lamp. When it is desired to secure a beam of moderate width to carry a long distance and to brilliantly illuminate the roadbed directly up to the front of the car, this lamp has much to recommend it. The Form D-2 may be reversed for dimming, while the Form D-8 is fitted with two 110 volt, 16 candle-power incandescent lamps for the purpose.

Fig. 6 illustrates the Form D-6 lamp equipped with semaphore lens and spherical reflector. This is the latest development in the field of interurban car lighting, and is admirably suited for the purpose. It is the result of broad engineering and operating experience. The semaphore lens is admirably designed for intense concentration of the light rays, thus emitting a beam of great penetrating power. By contrast with surrounding darkness, the motorman is enabled to pick out objects within the small, intensely concentrated zone of light at a distance of approximately 2000 feet.

It is estimated that a regulation interurban limited car, traveling at the rate of 60 miles an hour, can be brought to a stop, with good braking, within a distance of 1750 feet; thus it will be seen that the use of this lamp is attended with an ample factor of safety. The lamp may be operated reversed for dimming inside city limits.

The Form D-7 headlight (Fig. 7) is similar to the Form D-6, but has two 110 volt, 16 candle-power incandescent lamps added, where this method of dimming the light is preferred. Both the Forms D-6 and D-7 types employ a small spherical reflector located at a suitable radial distance from the arc, which increases the total useful illumination about ten per cent.

Many of the leading mining companies are reporting satisfactory results from the Forms E-1 and E-2 headlights. These lamps are equipped with the standard mechanisms, the former with parabolic reflector and the latter with semaphore lens. Both mechanisms are enclosed in cast iron casings which amply protect them from the rough service which they might naturally be expected to receive. Figs. 8 and 9 show the Form E-1 and Form E-2 lamps, respectively. The distribution of light is the same as that of the Form D-1 and the Form D-6 lamps, previously described. Both lamps may be operated with polarity reversed for dimming purposes.

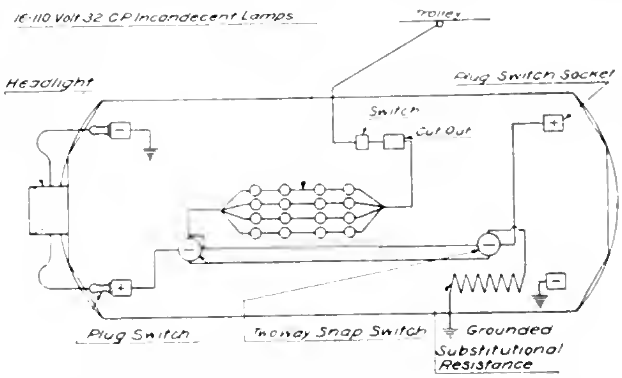


Fig. 11. Connections for Street Car Lighting System with Luminous Arc Headlight and Substitutional Resistance for Incandescent Lamps

if desired. Fig. 10 shows the simplest method of connection for the lamp and resistance, when the reversing feature is not required. Fig. 11 shows the connections of the headlight when placed in series with a multiple arrangement of incandescent lamps located in the car interior. This is the most efficient method, inasmuch as the surplus energy is used for lighting purposes. A substitutional resistance is shown, which may be used when it is desired to operate the incandescent lamps without the headlight.

Fig. 12 is a diagram of connections used for headlights equipped with incandescent lamps for dimming purposes. The negative sides of both arc and incandescent lamps are grounded to the casing, which is in turn grounded through the car dasher. A single-pole double-throw switch may be used to operate either arc or incandescent lamps.

Fig. 13 shows the connections required for reversing the polarity of the arc, thereby obtaining brilliant or subdued illumination. It will be noted that when the polarity is reversed an additional resistance is thrown into the circuit, thus securing a still further reduction in the intensity. A double-pole double-throw switch is essential and may be located as in the diagram.

It is the practice to send out all lamps in which the arc alone is relied upon for illumination, equipped with two leads, one positive and one negative. Lamps can be furnished with only one lead if so desired, with the negative side grounded to the casing. All lamps employing both arc and incandescent lamps are furnished with two positive leads, the negative sides of both arc and incandescent lamps being grounded to the casing. Whenever desired, a third, or negative, lead can be furnished. Fig. 16 is an actual night photograph of the track illumination furnished by the Form D-6 headlight when equipped with a 12 in. semaphore lens and assisted by a small spherical reflector. The photograph speaks for itself, and inspection will show the clearness with which objects at a considerable distance appear.

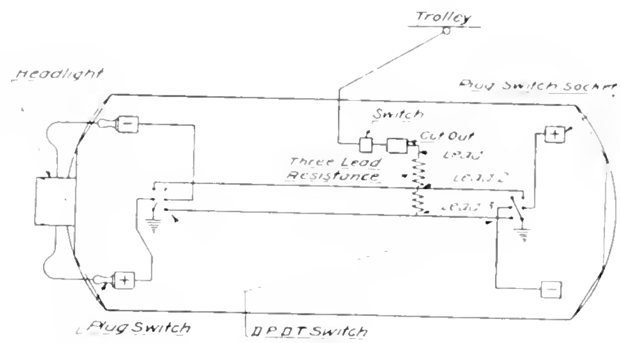


Fig. 13. Connections for Luminous Arc Headlight for Normal Operation, and for Operation with Reversed Polarity for Subdued Illumination.

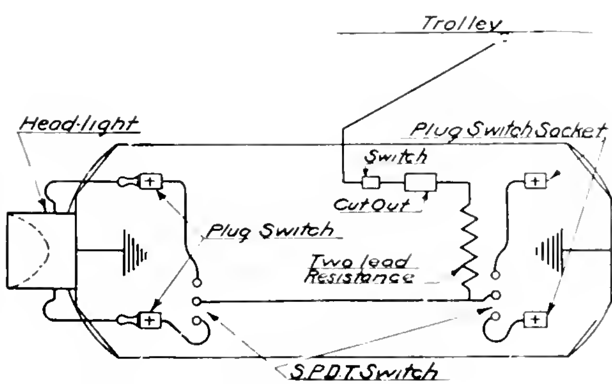


Fig. 12. Connections for Luminous Arc Headlight with Two-Lead Resistance and Incandescent Lamps for Dimming Purposes

The salient features of the lamps just described may be summarized as follows:

Simplicity and symmetry of design.

Substantial construction, combined with minimum weight

Long life and high efficiency of electrodes, combined with ease of trimming and low maintenance cost.

Absence of inner enclosing globes, thus further reducing cost of maintenance.

Focusing feature of the arc, insuring permanent concentration and direction of light rays.

Solid or heat-resisting glass doors that eliminate trouble from breakage due to expansion and contraction of the glass by adverse conditions of temperature.

The facility of control of both arc and incandescent lamps, thereby insuring the obsolescence of antiquated mechanical screens for dimming purposes.

Lastly, the adaptability of the units herein described for the requirements of all classes of direct current street railway lighting. All cases can be satisfactorily handled by some one of the foregoing combinations.

THE MANUFACTURE OF P-3 PORTABLE ELECTRICAL INSTRUMENTS

By C. C. Eaton

If an infinite attention to details and a capacity for taking pains are the distinguishing and characteristic features of genius, an investigation of instrument manufacturing at the Lynn Works of the General Electric Company must compel any thoughtful visitor to conclude that the company should properly be classed as a genius among industrial organizations.

The making of a successful electrical measuring instrument depends upon three factors: First, the choice of and adherence to sound theoretical principles; next, the adoption of a good design; and lastly, but of no less importance, the exercise of infinite patience and pains in the smallest details of work and workmanship.

The fundamental principles upon which the numerous measuring instruments of the General Electric Company are based are not new. Many persons assume that instruments employing these principles had reached their highest point of development some little time ago. Why there should be such wide divergences in price, quality and utility among the various makes of instruments utilizing these principles is not at once clear to the minds of the uninitiated; but this is one of the interesting problems which a visit to the instrument department of the Lynn Factory unfolds.

Here it is found that, in spite of the large production required, man has seemingly turned his mind into a microscope for the perfection of little things. One recalls the story of the smallest needle in the world, sent as a present from Queen Victoria to the Empress of China who, after a brief interview with her royal jewelers, returned the present to her Britannic Majesty, but with the needle converted into a needle case, which upon the removal of the cover was found to contain a half dozen smaller needles, each perfect as to finish and taper and each with its small eye precisely drilled. And so at Lynn, the instrument department is found busy, not metaphorically, but actually splitting hairs, dividing seconds into hundredths or working accurately to the ten-thousandths of an inch. But here, unlike the needles of the Chinese Empress, unlike the Microscopic cloisonné of Japan or the inlaid feather enamel of China, the product belongs to the realms of practical utility rather than to art. Instead of being blazoned forth in vivid and picturesque colors on the sides of a delicate piece of ceramic art; or displayed in the soft and mellow tinting of an Oriental rug knotted seven hundred times to the inch, the skill of the workman, expressed in the finely turned threads or the delicately shaped and polished jewel, is hidden beneath the unassuming wood or metal cover of an electric meter—unseen and only demonstrating its presence by its perfectly accurate working.

The P-3 class of alternating current portable instruments includes self-contained voltmeters, ammeters and wattmeters up to 600 volts and 200 amperes. Their convenient size and portability make them invaluable for many classes of work where a laboratory instrument would not be practicable, for instance, in the test room or on line work. The readings can then be checked in the laboratory with the permanently placed instruments of a larger size.

The principle employed in the voltmeter and wattmeter is a modification of that of the dynamometer, while in the ammeter the Thomson inclined coil system is used. In the dynamometer proper—an instrument used in the laboratory—one coil is fixed permanently and the other coil is hung at right angles thereto, with its ends suspended in mercury cups and controlled by a spiral spring and a torsion head. When the current passes, the movable coil turns towards a position parallel to the fixed coil. By turning the torsion head, and thus twisting the spiral spring, which thereupon balances the torque, the reading of the instrument is obtained.

In the P-3 instrument a set of fixed coils surround a pivoted coil, the latter with its attached needle being free to move within certain limits when acted upon by the current. In the case of the wattmeter the line current flows through the outer coil or field while the potential or the voltage current passes into the moving coil through a small spiral spring, which serves to produce a counter torque and at the same time to return the needle to the zero mark upon the shutting off of the current. The current is limited by a high non-inductive resistance connected in series with the moving coil.

The damping of the swing of the needle is secured by means of an aluminum disc, which swings between the poles of two astatically arranged permanent magnets, and in which Foucault currents are generated upon the cutting of the lines of force of the damping magnets. The instrument is by this means rendered extremely "dead beat," while the aluminum disc is so mounted as to balance with its weight that of the needle arm and pointer.

These principles are not new or distinctive and are found in instruments of varying styles, makes and standards of workmanship. The superiority of the P-3 portable instruments depends upon the ingenious applications of the principles, together with an advantageous design and an extreme refinement of material and construction. In the design an axiomatic simplicity has been attained by a particularly simple and effective method of support for the movable parts, and the attachment between them of the magnet, scale plate, and stationary coils.

Fig. 1. Pivot on Shaft of P-3 Portable Instrument Magnification, 30 Diameters

The current and potential coils are supported by the central frames. These are the torque-producing elements, which are necessarily kept in fixed relations to each other. Any force affecting the instrument will therefore have its effect on each and every part alike, and the danger of separating by mechanical strain any one part from its exact relationship with every other part is successfully eliminated; even the coefficient of expansion with change in temperature being regulated to an identical point for the entire mechanism. The frame and all other subordinate fixed or movable parts of the instrument are surrounded by a laminated iron shield protecting the interior coils from magnetic fields. This arrangement also serves, when the instrument is used on direct current, to prevent errors due to the projected fields of the damping magnets. Every effort is made to guard and protect the two moving coils, upon which, more than upon any other feature, depends the accuracy of the instrument.

The magnets employed in these instruments have received a great deal of care and attention. The material has been selected of such quality and grade as to assure the strongest and most permanent fields. To this has been added a study and a refinement of the process of treatment and handling, which also assures permanency and strength. After hardening they are subjected to several artificial aging processes.

The same care and precaution that is manifested in the preparation of these details is expended also in the selection and preparation of the small coil springs which control the actions of the scale needle. These

Fig. 2. Ordinary Pin. Magnification, 30 Diameters

are selected from the most perfect springs that can be purchased on the market. They are then subjected to a most rigid examination, test and finishing process. The cutting of threads on a brass bolt of a diameter of 0.030 inches and the making of a nut of similar size, to such an accuracy that the nut when screwed on would neither bind nor play loose, also offered difficulties that were surmounted through persistent effort. These bolts are used as adjustable balances on the P-3 instruments. Their preparation was made doubly difficult by the propensity of the metal to "flow" or "swedge" under the die; an error of 1/10000 of an inch rendering a bolt or nut valueless, while an error of one thread to an inch, or an error in the pitch of the threads for a distance of 5/100 of an inch in a screw of 180 threads to the inch, would render impossible the free interchange of bolts and nuts.

It is, therefore, to the small and seemingly insignificant parts of these instruments that the greatest attention and care in manufacture and selection of parts has been given, thus insuring that a finished product attains a degree of perfection almost incomprehensible in any device so delicate and fragile. Doubtless none of the small parts are of such

Fig. 3. Ordinary Watch Screw. Magnification, 22 Diameters

importance as the jewels. These are made of Ceylon sapphires, which are imported directly, without limitations as to selection. Only that portion of the shipment is used which upon microscopic inspection shows itself to be perfect; the rest is freely rejected. These jewels are then cut with diamond dust and given an extremely high polish—the highest which it is possible to obtain. Each jewel is worked upon, repeatedly inspected, again worked upon, again inspected, until it is brought to a perfect degree of polish and curvature or rejected.

The importance of this careful cutting and polishing becomes apparent upon examination of the shafts which are balanced on the jewels. These are made of drawn phosphor bronze tube with pivotal points of glass-hard steel swedged into their extremities. In the history of instrument manufacture no greater point of interest has been developed than the exact treatment of these pivots to produce a pivoted suspension of such delicacy of adjustment as to insure practically absolute accuracy. The pivots are made of especially selected steel, which is ground, polished and burnished under a microscope, and is subjected to the same rigid inspection that is given to the jewel. The radius of curvature at the end must not be more than 0.0015 nor less than 0.00125 of an inch, and the polish must show no flaw or blemish when inspected under a binocular microscope having magnifications of not less than 50 diameters. Actually, the weight supported upon these points is extremely small, almost immeasurable and insignificant, but the area of contact is correspondingly small, which results in high pressure, so that only the highest quality of workmanship and material will insure low friction. For this reason it is necessary to shape both the pivot points and the cavity in the jewels containing them in the form of a "V," but with the apex precisely rounded. The diameter of the pivot has been given; that of the jewel cavity is made 0.007 of an inch, approximately. The radius of the curvature of the pivot is considerably smaller than the bottom of the jewel, so that the two shall touch at a point only. Too much friction would result if the surfaces fitted into each other exactly. In the upper jewel there is drilled a minute hole from the apex of the "V" through the jewel to allow for expansion of pivots and shafts without bending at the points.

The great care used in finishing and adjusting the pivotal points, as well as the "V" shaped jewels in which they rest, is well illustrated by Fig. 1, which shows the completely polished pivots used in the meters as compared with Fig. 2, an ordinary brass pin, photographed under the same magnification.

Very few jewel makers are ever able to develop the necessary skill for the manufacture of the P-3 jewels. Indeed, much of the success of these refined processes of workmanship have necessarily entailed a large amount of effort and time in the perfection of new machinery especially adapted for the work in hand. Microscopical workmanship requires microscopical tools, so that it is often questionable whether greater interest and wonder attaches to the small piece of steel that is polished to

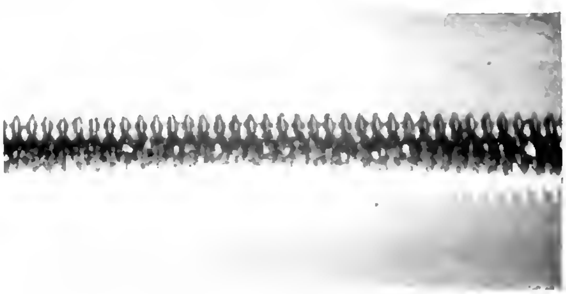


Fig. 4. Screw of Balance Arm P-3 Portable Instrument Magnification, 22 Diameters

an accuracy of one ten-thousandths of an inch, or to the mechanical means by which this result is accomplished. The precise method adopted in the setting of the jewels well demonstrates this point. They are attached to the central frame of the instrument by means of a brass screw into the end of which they are carefully swedged. It was formerly the custom to prepare the screw for insertion in its appropriate hole in the framework before setting the sapphire. It was found, however, that no matter with how much care the "V" of the jewel might

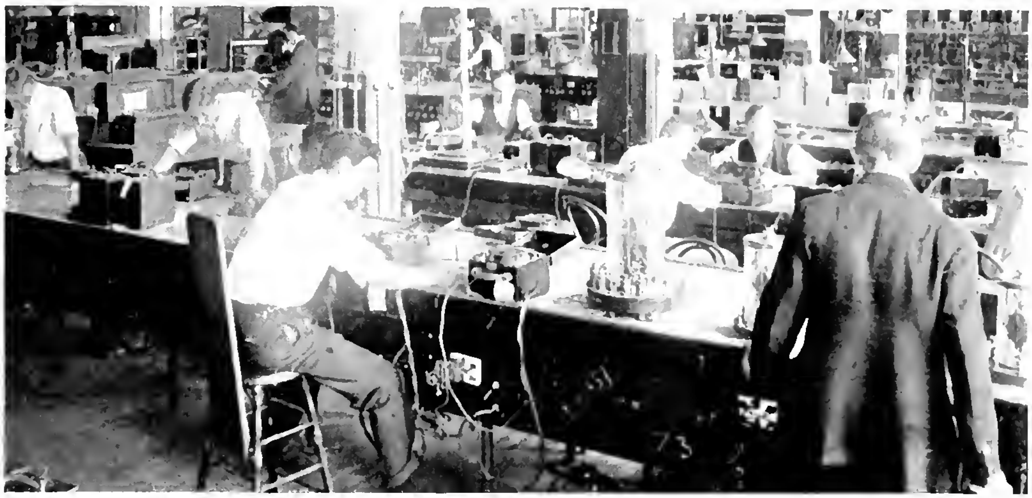


Fig. 5. Meter Standardizing Laboratory

be centered, the process of setting it in the screw was liable to throw the "V" center to one side. The process was therefore reversed. The jewel is first set in the blank screw, the threads of which are thereupon chased upon a specially designed lathe which employs the "V" of the sapphire for the turning center, the jewel being protected in the process by a revolving spindle.

The minuteness of this work is well illustrated by Fig. 3, which shows a screw extracted for the purpose from an ordinary watch, and Fig. 4, a bolt photographed beside it for contrast. This bolt and nut are those previously mentioned as used to adjust and balance the instrument. The extreme delicacy of the workmanship can, perhaps, be best appreciated by the statement that the routine of the work provides for the elimination of every bolt having an error of one ten-thousandths of an inch. Indeed, these minute parts are made with such accuracy that it is possible to detach and interchange the brass bolt or nut of any P-3 instrument issuing from the factory with that of any other instrument. Such a statement must not, however, be interpreted too broadly, as there are very few workmen, even among the skilled instrument makers employed in the factory, who are capable of taking high grade instruments apart and putting them together again without serious damage.

The attention devoted to even the smallest details that are used in the manufacture of these products, as well as in the machinery and appliances that are employed for their production, is demonstrated by the fact that the room in which much of the work of assembling and testing is carried on is sealed and ventilated in order that even the smallest particles of dust may be prevented from entering the instruments before they are sealed. The cracks in the wood floor of the room are carefully filled with a special compound which prevents the collection of dust and dirt.

In this room the various small parts of the instruments are inspected, tested and assembled. The elements are then carefully balanced and tested. The absolute straightness of the indicating pointer is assured and its exact pivoting in the origin of the radial lines. The pointer is also suspended over a mirror to avoid errors of parallax when using the instrument.

When assembled, the instrument is ready to be calibrated. Each detail is again checked and the instrument sealed. Not even then, however, is the process of "making sure" completed, for the product is again subjected to a thorough working test and the errors are recorded on a chart which is certified to and accompanies the instruments.

TYPICAL SYNCHRONOUS CONDENSER INSTALLATIONS

By John Liston

The growing appreciation of the saving which can be effected in operating expense and the high efficiencies rendered possible by the centralization of a generating equipment, the flexibility characteristic of alternating current distribution systems and the widespread adoption of the induction motor for power application, have in many instances resulted in conditions which necessitate the maintenance of a high power factor on systems having a large percentage of inductive load. The progressive engineer is fully alive to the improved service which can be given when the power-factor is maintained at the highest point compatible with a reasonable economy in the cost of equipment.

The technical press has recently displayed great activity in a thorough exposition of the theories involved in the problem of power-factor improvement, and as a result the relation of power-factor to the size and efficiency of prime movers, generators, conductors, etc., is now generally understood; the numerous installations of synchronous condensers on alternating current systems having an inductive load indicating that their value in improving the power-factor is now fully recognized.

The following pages contain illustrations and descriptions of some typical synchronous condenser installations that cover a great variety of conditions, and indicate the methods of installation and operation that it has been found advisable to adopt in order to meet most successfully the requirements of actual service. Before describing these equipments, it might be well to recapitulate briefly the salient points of the theory on which their operation is 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 on the other hand, a non-inductive load, such as incandescent lamps, takes current wholly in phase with the voltage, and as a result, operates at 100 per cent. power-factor. When transformers operate at full load their effect on the power factor is practically negligible, but as they require magnetizing current they may seriously affect the power-factor when unloaded, or partially loaded. The relative cost of synchronous condensers for the correction of power-factor, as compared with the increased investment in generators, conductors, etc., caused by low power-factor,

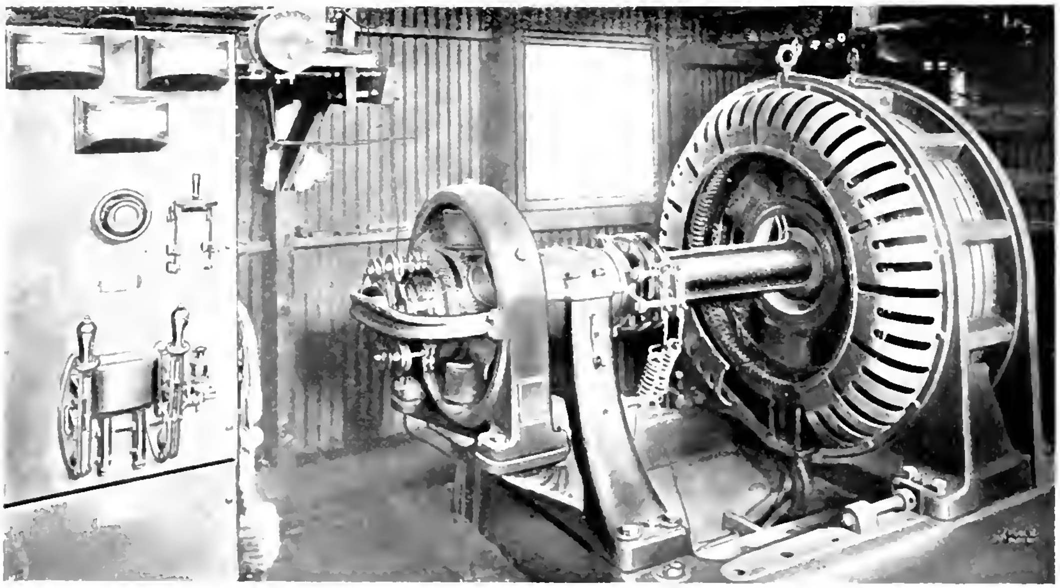


Fig. 1. 400 kv-a 550 volt, 600 r.p.m. Synchronous Condenser with Direct Connected Exciter installed in Substation No. 1 Colorado Light & Power Company, Cripple Creek, Colo.

will, of course, depend upon the percentage of the inductive load of the system and the possibility of locating the synchronous condenser where it can be effectively used to supply the required leading current.

When an alternator is delivering rated output at normal voltage the losses in field and armature are greater at a low power-factor than at unity. Loss of efficiency is therefore unavoidable at low power-factor due to the increased energy input for a given output.

The effect of low power-factor on regulation is often of vital importance as the average modern alternator at unity power-factor is capable of carrying 25 per cent. overload with a regulation of approximately 8 per cent., whereas at 0.7 power-factor (lagging current), the regulation is about 25 per cent.

In regard to the effect of low power-factor on the size and capacity of conductors, the results can be clearly demonstrated by an analysis of the following hypothetical conditions: Assume a distance of five miles and a load of 1000 kw., which is to be delivered at a potential of 6000 volts, three-phase, with an energy loss of 10 per cent. In order to do this, each conductor at unity power-factor has to be of 79,200 cir. mils area at 0.9 power-factor, 97,533 cir. mils and at 0.6 power-factor, 218,000 cir. mils; in other words, at the lower power-factor, the investment in copper alone would be 2.8 times that required for unity power-factor. If the same size wire were used at both unity and 0.6 power-factor, the energy loss at 0.6 power-factor would be 2.8 times the loss at unity power-factor. Low power-factor, therefore, will generally mean diminished kilowatt capacity of generators, transformers and conductors, and augmented energy losses; at the same time the regulation of the entire system will be adversely affected.

The synchronous motor when used as a 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 made to deliver leading current, which compensates for the inductive load on other parts of the system. The synchronous condenser, therefore, can supply magnetizing current to the load on a system while the power component is supplied by the generators.

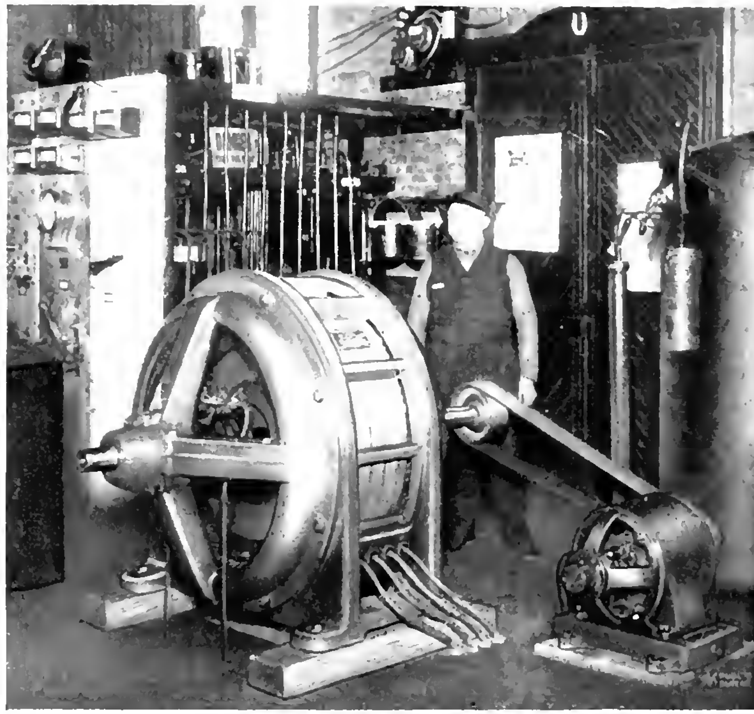


Fig. 2. 200 kv-a., 2300 volt, 900 r.p.m. Synchronous Condenser with Belted Exciter Jamaica Substation of the New York & Queens Electric Light & Power Co.

The most desirable location for a condenser is, of course, near the inductive load in order to avoid to the greatest extent the transmission of the wattless current. It often happens that a system is so interconnected and the inductive load so distributed that one large condenser cannot economically meet the conditions, in which case it may be better to install two or more smaller ones. The question of suitable attendance should also be considered and, for this reason, it may be necessary to compromise on the location.

In the case of a central station providing synchronous condensers for the benefit of distant commercial circuits, the consumer is, as a rule, aware of the improvement effected in the operation of this plant by reason of the improved regulation, and is usually willing to supply the ordinary attendance required by the condenser, so that the amount of work devolving on the central station force is ordinarily limited to that involved in periodical inspection.

Most of the synchronous condensers shown herewith are equipped with direct connected exciters, this combination constituting a compact, self-contained unit, as shown in Fig. 1; but they can be arranged for excitation from other sources with suitable means of control or provided with a belt driven exciter as shown in Fig. 2.

The generating station is located in South Chicago and the condensers in a sub-station at the plant of the Universal Portland Cement Company at Buffington, Ind., where they operate on the low tension circuit which serves the induction motors.

Current for Buffington is generated at 2200 volts, three-phase, 25 cycles, and is stepped-up for transmission to 22,000 volts by two banks of transformers, each consisting of three 2000 kw. water cooled units. The transmission line is 10 miles long, and consists of three No. 0000 copper conductors. At the Buffington sub-station the transmittal voltage is stepped-down to 480 volts through three banks of transformers, two of these consisting of three 750 kw. units, and the third of three 1500 kw. units, all the transformers being connected delta on both the high and low tension sides.

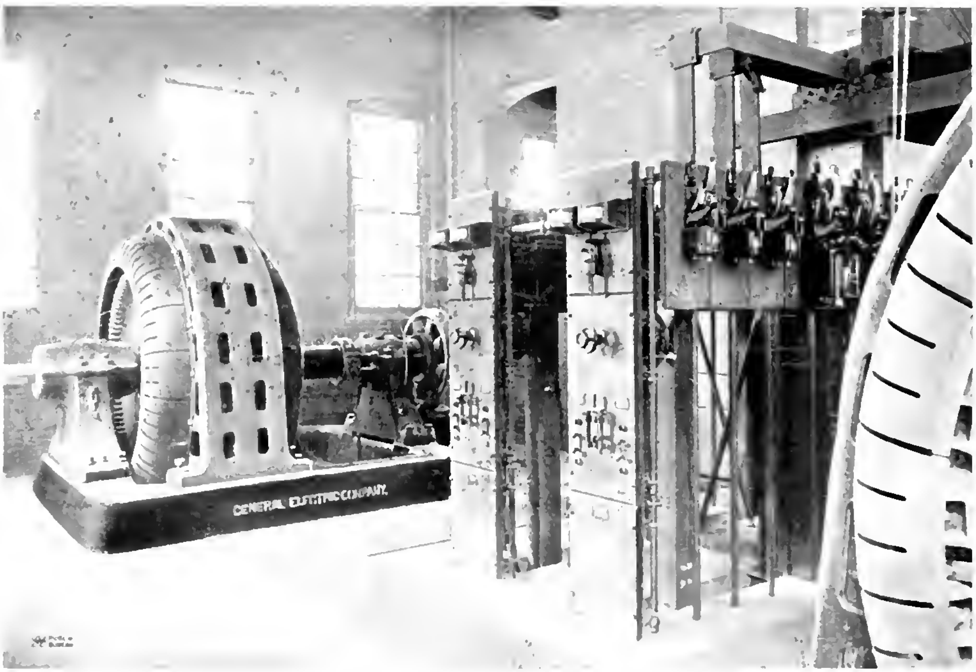


Fig. 3. Two 1650 kv-a., 440 volt, 500 r.p.m. Synchronous Condensers and Control Panels Substation, Universal Portland Cement Company, Buffington, Ind.

While the accompanying illustrations show only horizontal shaft machines, the vertical shaft type has been used in some instances to meet special conditions, but the requirements of the average distribution system are such that they can usually be met by the adoption of machines of the standard horizontal shaft type.

Illinois Steel Company, South Chicago, Ill.

The synchronous condenser equipment of this company affords a good example of the effects obtained by installing this type of machine on a feeder system serving a single plant of large capacity.

Two synchronous condensers are installed at Buffington, each rated at 1650 kv-a. and provided with direct connected exciters and control panels as shown in Fig. 3.

The load at the mills is practically all induction motors and inductive; it is fairly steady and is on practically continuously 24 hours a day. The condensers do not carry any mechanical load, being connected in the line solely for the improvement of the power-factor, and the results obtained are indicated by the following readings taken simultaneously at both ends of the transmission line.

With the condensers cut out of service:

6100 kw., at 0.74 power-factor on 2200 volt bus at South Chicago. 5800 kw., 450 volts low on tension bus at Buffington.

With the condensers in operation and taking exactly full load current from the low tension bus at Buffington:

6400 kw., at 0.917 power-factor on 2200 volt bus at South Chicago.

6150 kw., 475 volts on low tension bus at Buffington.

With 25 per cent. overload on the condensers:

6400 kw., 0.934 power-factor on the 2200 volt bus at South Chicago.

6050 kw., 485 volts on low tension bus at Buffington.

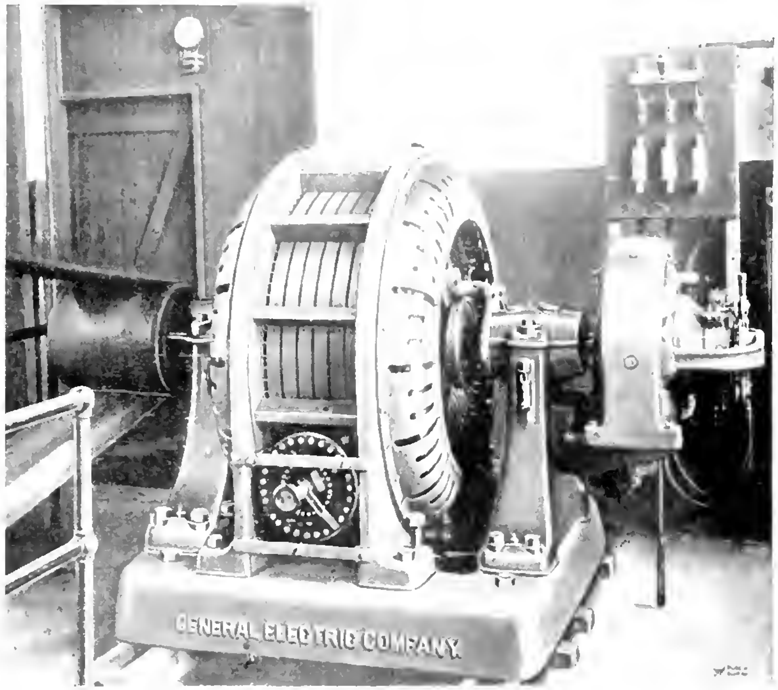


Fig. 4. 300 kv-a., 230 volt, 720 r.p.m. Synchronous Motor driving Air Compressor Chalmers Motor Company, Detroit, Mich.

Edison Illuminating Company, Detroit, Mich.

Among the customers of this company is the Chalmers Motor Company of Detroit. Current is received at a sub-station and from there transmitted at 4600 volts, three-phase, 60 cycles to the consumer's plant, where it is stepped-down to 220 volts for the power-circuit. Primary current is purchased by the Chalmers Motor Company, which owns the step-down transformers; the synchronous motor shown in Fig. 4 being connected on the secondary circuit of these transformers.

As transformers are all rated in kv-a. output, a 100 kv-a. transformer is supposed to deliver 100 kw. at unity power-factor at normal voltage and at normal temperatures; but, if the power-factor should be 0.6, the rated energy output of the transformer would be only 60 kw. and yet the current, and consequently the heating, would be approximately the same as when delivering 100 kw. at unity power-factor.

Prior to the installation of the synchronous motor the Chalmers Company complained of great secondary drop, and to overcome this the Edison Company installed a 68 kw. boosting transformer loaded to about one-half of its capacity. Although the voltage was in this way brought up to normal, conditions were still unsatisfactory. It was therefore decided to install a synchronous motor having a rating of 300 kv-a. which was operated at partial load by being belt connected to an air compressor; in which service it displaced a 100 h.p. induction motor, at the same time eliminating the boosting transformer.

The operation of this motor has served to relieve conditions on the illuminating company's lines and has improved the regulation of the transformers by minimizing the secondary drop. The load carried on this portion of the system consists almost entirely of induction motors and other inductive apparatus, and the benefit derived from the use of the synchronous motor is shown by the fact that before it was installed the power-factor was about 62 per cent., whereas it is now maintained at 95 per cent.

Witherbee, Sherman & Company, Mineville, N. Y.

The distribution system of the Company is at present provided with three synchronous motors, the relative positions of the generators and motors being shown on the accompanying chart, Fig. 5. The system includes two hydro-electric, one turbine driven, and one engine driven generator plants; from three of these current is transmitted to the fourth, which is located in Mineville, at the point indicated by Fig. "A" on the chart, the current being distributed to the motor circuits from the points "A" and "B." The transmission to the central station at Mineville is over three-phase circuits at 6600 volts.

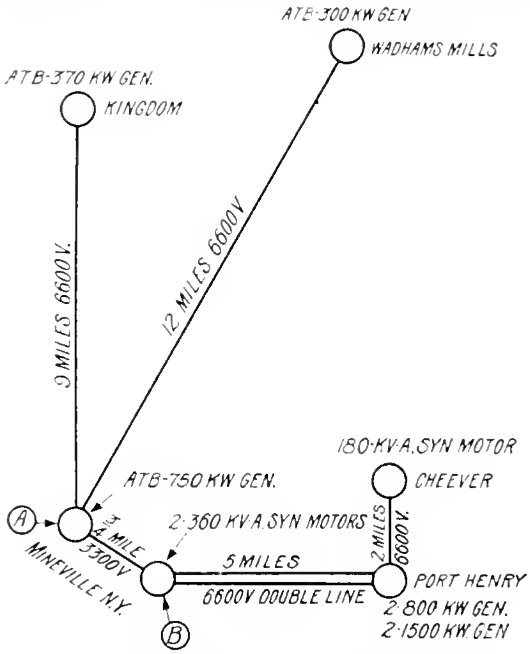


Fig. 5. Diagram showing relative location of Generators and Synchronous Motors
Witherbee, Sherman & Company, Mineville, N. Y.

For the operating of the mine at Cheever, current is transmitted direct from the generating station at Port Henry. The distribution from "A" and "B" is all at 3300 volts, being stepped-down to 440 volts for the operation of the motors, which have a total rated capacity of 4762 h.p. Except for the three synchronous motors, the load is practically all inductive, there being less than 10 kw. required for lighting.

The actual power demand ranges from 60 to 65 per cent. of the rated motor capacity, and prior to the installation of the synchronous motors, the power-factor was approximately 68 per cent., the condenser effect of these motors making it possible to maintain an average of about 90 per cent. power-factor at the present time, in spite of the fact that a considerable portion of the induction motor load is very widely distributed. The three synchronous motors are partially loaded, each motor driving an air compressor through belting.

The 180 kv-a. motor at Cheever takes about 150 kw. for the operation of a 1250 cubic foot compressor, while the two 360 kv-a. machines take about 300 kw. each, for the operation of two 2500 cu. ft. sets. The

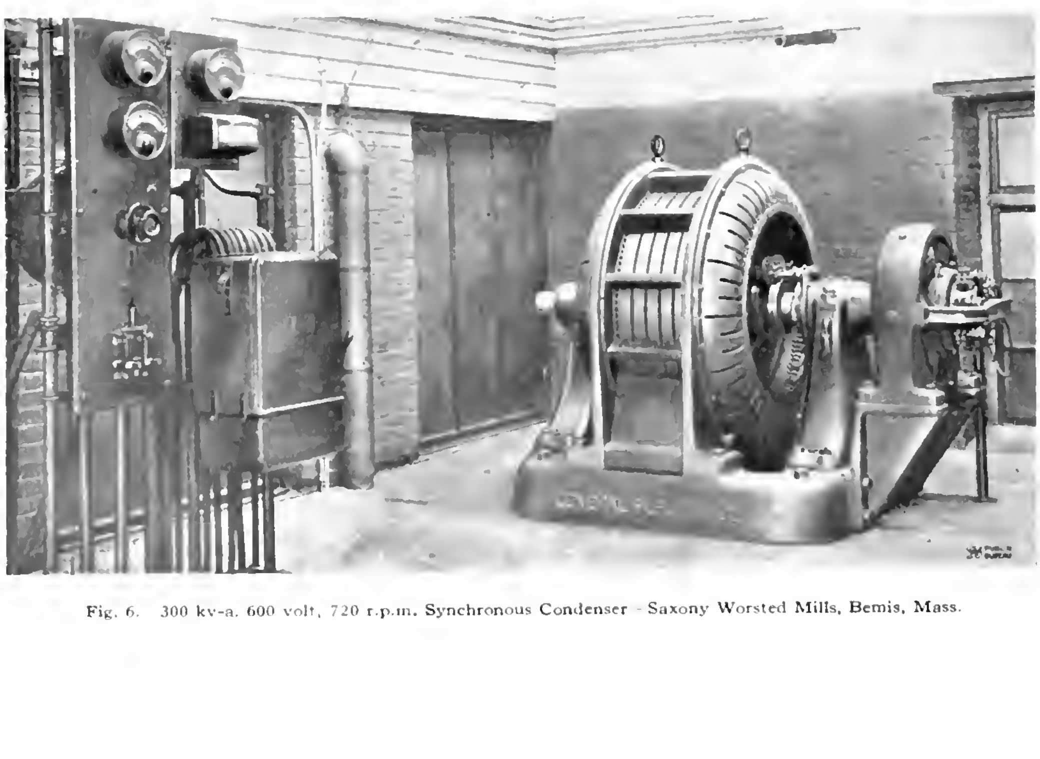


Fig. 6. 300 kv-a. 600 volt, 720 r.p.m. Synchronous Condenser - Saxony Worsted Mills, Bemis, Mass.

operation of these compressors affords an ideal method of utilizing a portion of the motor capacity mechanically, inasmuch as the load on the motors is practically constant during the time the mines are in operation, and thereby permit the motors to be run at approximately 80 per cent. power-factor. So successful has their operation proved that provision has already been made to install a fourth machine of 360 kv-a. capacity, and it is the intention of the engineers of the Witherbee-Sherman Company, when providing for additions to the electrical equipment, to so proportion the amount of the inductive and non-inductive loads that a high power-factor will be maintained under all conditions of operation. This result can be readily accomplished by providing synchronous motors for the operation of air compressors which would ordinarily be driven by induction motors.

At the time the motors now in operation were first installed more power was needed than could be supplied by the generating equipment available at that time, but the reduction in losses which resulted from the use of the synchronous motors as condensers increased the capacity of the system to such an extent that additions to the generating capacity were not required for a considerable time, during which the operation of the various induction motor equipments was maintained at normal load.

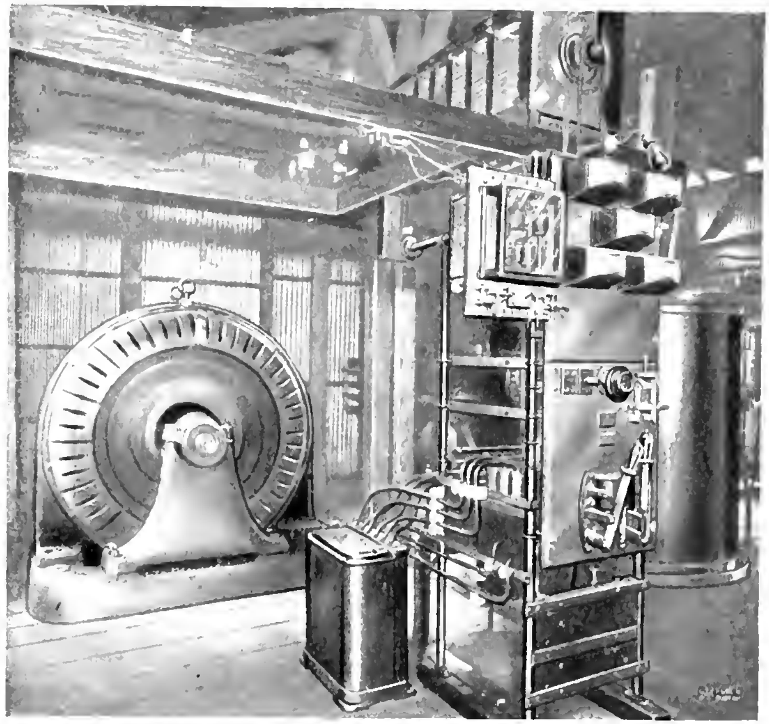


Fig. 7. 1000 kv-a., 2300 volt, 720 r.p.m. Synchronous Condenser and Control Panel with Voltage Regulator—Northern California Power Company, Kennett, Cal.

The Saxony Worsted Mills, Bemis, Mass.

This installation differs radically from those previously described, as the synchronous condenser is located close to the generator. Current is generated in the power station at the mills and is all used within a radius of a few hundred feet. The power station equipment includes one 600 kw. and one 450 kw. alternator, while the synchronous condenser, which is, in this case, unloaded and simply floated on the line for the improvement of the power-factor of the system, is rated at 300 kv-a. The load consists almost entirely of induction motors and the varying power demands of the particular service to which they are applied are such that before the synchronous condenser (shown in Fig. 6) was installed, the average power-factor was approximately 64 per cent.

The deleterious effects of low power-factor loads on alternating current generators are evidenced by decreased kilowatt capacity, the necessity for increased exciter capacity, decreased efficiency, and impaired regulation. If we assume the case of a 100 kv-a. generator operating at 100 kv-a. (0.6 power-factor), 60 kw. output, it is probable that normal voltage could be obtained only with difficulty, unless the alternator was especially designed for low power-factor service. The lagging current in the armature sets up a flux which opposes the flux of the fields and in consequence tends to demagnetize them, resulting in low armature voltage.

In the case of the Saxony Worsted Mills, the operation of the synchronous condenser, by supplying leading current to the system, has raised the power-factor from 64 per cent. to about 85 per cent.

Northern California Power Company, Kennett, Cal.

The synchronous condenser shown in Fig. 7 is installed on the distribution system of this Company at Kennett, which is served by transmission lines from generating stations at Kilarc and Volta, located, respectively 28 and 38 miles from the point at which the condenser is operated.

The extent of this portion of the transmission system, and the ratings and relative location of the generators and synchronous condenser are shown in the diagram (Fig. 8). The local load demand amounts to about 1500 kw., and before the installation of the synchronous condenser the power-factor was about 79 per cent.; the resulting improvement being indicated by the fact that the power-factor can now be maintained at about 96 per cent., while the voltage at the point where the synchronous condenser is installed is raised approximately 10 per cent. during the change from no load to full load.

In order to obtain the closest possible voltage regulation, a regulator (see Fig. 7) is used in connection with the synchronous condenser and holds the voltage at the

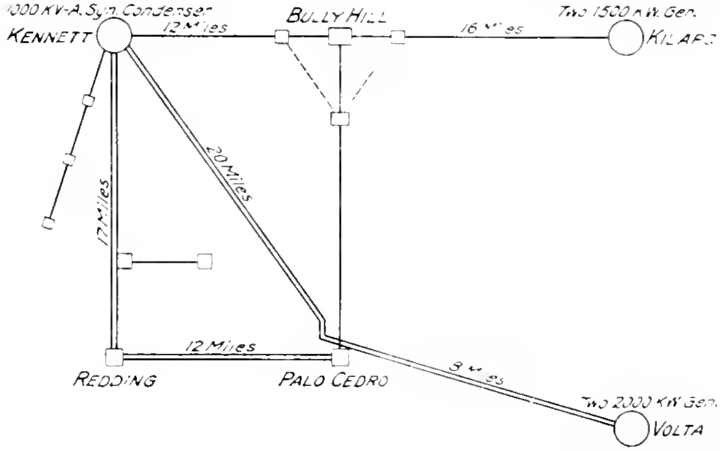


Fig. 8. Diagram of a section of the Northern California Power Company's Transmission System showing relative location of Generators and Synchronous Condenser

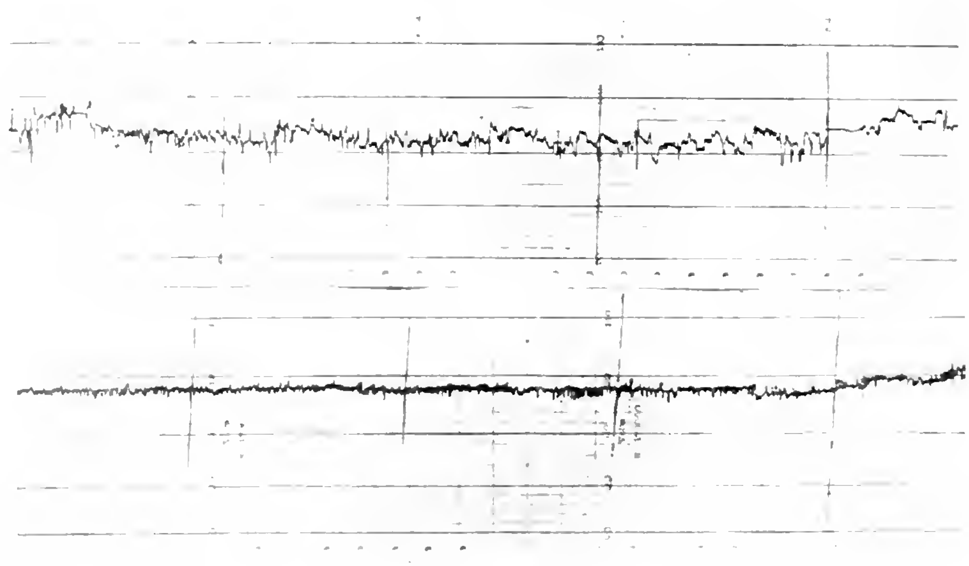


Fig. 9. Curve Drawing Voltmeter records at Kennett, Cal. Upper curve shows voltage regulation with Synchronous Condenser out of service—lower curve with Synchronous Condenser in operation

center of distribution, within 2 per cent. The regulator is mounted on the side of the control panel and connected in the field of the synchronous condenser to automatically change the excitation and compensate for voltage variations.

A graphic demonstration of the improvement in voltage regulating, which has been secured in this case, is given by the curve-drawing voltmeter records reproduced in Fig. 9.

Cadillac Motor Car Company, Detroit, Mich.

Where the motor equipment of a plant receiving energy from an alternating current system includes direct current motors which are served by a motor-generator set, it will frequently be found advisable to utilize a synchronous motor for driving the direct current generator and to so proportion the load that part of the capacity of the synchronous motor may be devoted to improving the power-factor. A set of this type is employed by the above company, the synchronous motor being rated at 170 kv-a., and the generator at 100 kw.

Current is supplied to the Cadillac Motor Car Company by the Detroit Edison Company at 4600 volts and is stepped-down through three 250 kw. transformers to 220 volts for the induction and synchronous motor circuits, the lighting circuit being provided with a separate transformer. The motor-generator set feeds a 250 volt Edison three-wire circuit, and the excess capacity of the synchronous motor is such that the power-factor, which is about 65 per cent. when the motor-generator set is not in operation, is raised to approximately 85 per cent. when the synchronous motor is supplying leading current to the induction motor circuits.

The demand on the system is about equal to the rated capacity of the transformers, so that if the power-factor had not been raised it would have been necessary to provide additional transformers to take care of the induction motor load. As direct current was necessary for the operation of variable speed machinery, the required service for both alternating and direct current circuits was secured most economically by the adaption of the synchronous motor-generator set.

In the description of the foregoing installations, it will have been noted that where synchronous motors could be effectively utilized for carrying a mechanical load, they have been connected up with generators to form motor-generator sets, or have been arranged for driving air compressors under conditions conducive to uniform expenditure of power, or for other service where the energy demand was practically constant. The most economical results, when following this method, can be obtained by having the motors deliver approximately 70 per cent. of their rated kv-a. in energy, as they can then take about 70 per cent. in leading wattless kv-a., and in this way be made to provide the required condenser effect.

In cases where these machines are used as synchronous condensers only and are simply floated on the line for the improvement of the power-factor, it is evident that their mechanical construction can safely be made somewhat lighter than if they are required to carry a mechanical load.

In order to minimize the cost of an installation of this kind the General Electric Company has designed and standardized a complete line of comparatively inexpensive high speed machines especially adapted for the service. These machines have a smaller air gap than a standard synchronous motor, and have comparatively high temperature reaction constants, these characteristics permitting of a considerable reduction in the amount of construction material required, while at the same time their value as condensers remains unaffected. They are ordinarily arranged for operation at 2300 volts, but can, of course, be wound for any commercial voltage.

These synchronous condensers are designed for alternating current starting and the compensators are provided with three taps to meet various starting requirements. When starting by means of this compensator, the amount of current taken from the line will range from 60 per cent. to 100 per cent. of normal current.

The entire success with which the synchronous condenser can be used to correct conditions of low power-factor, on even the most extensive central station distribution systems, or on the shorter lines of isolated plants, as indicated by the typical installations described herewith, should appeal strongly to every central station manager and to the engineers of isolated plants having an inductive load. Their use will in many cases obviate the necessity for additional generator capacity and will always conduce to the maintenance of the highest possible efficiency for the generator plant and distribution system.

THE HARWOOD ELECTRIC COMPANY, PENNSYLVANIA

At Harwood Mines, Luzerne County, Pennsylvania, there is a large deposit of anthracite coal which was known until recently as the Pardee mines, after the owner. These mines have been profitably worked for a period of some forty years, and at present are shipping over 250,000 tons of coal annually. During this time an immense quantity of waste coal and culm was accumulated, amounting in all to approximately 2,000,000 tons. There is but a limited market for this fuel, which, nevertheless, possesses relatively high calorific, or heat-producing properties when proper methods are employed for its combustion. With the intention of utilizing this large amount of waste coal, a company was organized about four years ago and after acquiring control of the mine property, consisting of approximately 900 acres of coal land, undertook the building of a steam-electric power station and a transmission system. This Company ultimately became the Harwood Electric Company, which was incorporated under the laws of the State of Pennsylvania, June 30, 1909.

The Harwood Electric Company does a wholesale and retail electric power and lighting business and, as shown by the map (Fig. 1), serves at present the following cities and towns: Harwood, Hazleton, West Hazleton, McAdoo, Lattimer, Milnesville, Park View, Coloraine, Beaver Meadow, Bunker Hill, Audenried, Jeanesville, Harleigh, Cranberry, Berwick, Espy, Lime Ridge, Almedia, Bloomsburg and Danville.

The population of the surrounding country within a radius of 25 miles is approximately 375,000, and some 425,000 h.p. in steam boilers is required to supply power for lighting, traction, coal mining and other industrial purposes. The prospects for the extension of the efficient and reliable power of the Harwood Electric Company are therefore very favorable.

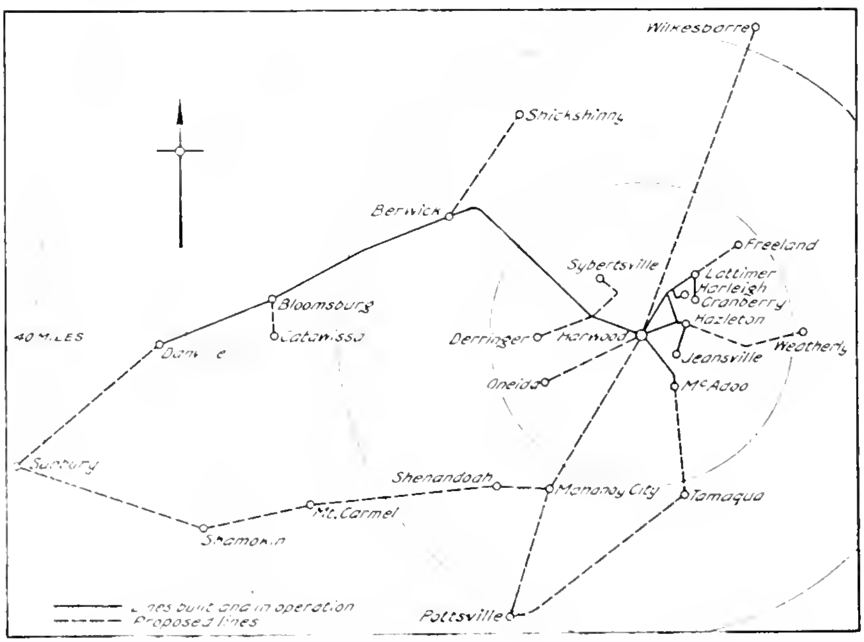


Fig. 1. Map of the Harwood Electric Company's Transmission Lines

In the several cities and towns named above, with the exception of Berwick, Espy, Lime Ridge, Almedia, Bloomsburg and Danville, the Company has more than 3500 incandescent and power customers. The towns just named are indirectly served by the Harwood Company through the Columbia Power, Light and Railway Company. Current is supplied to this concern over a 15 mile transmission line, extending from the Harwood station to a point near Nescopeck, on the east side of the Susquehanna River, where it is connected with the lines of the

Columbia Company. The span across the Susquehanna, which is about 2200 feet in length, is made by steel cables suspended from 65 ft. steel towers. The voltage on this branch of the system is 25,000.

Some of the more prominent manufacturing concerns supplied with power by the Columbia Power, Light and Railway Company are the McGee Carpet Works, of Bloomsburg, the American Car and Foundry Company, of Berwick, and the Danville Tube Works, of Danville. In addition to its other business this Company also furnishes power for operating 20 miles of trolley line between Danville and Berwick.

The power now purchased from the Harwood Company by the Columbia Power, Light and Railway Company supplants that formerly produced by five steam plants. These plants have been shut down and a large saving in operating expenses thereby effected.

The street lighting for the city of Hazleton and for the boroughs of McAdoo and Beaver Meadow is furnished directly by the Harwood Electric Company. A considerable power load has also been built up in Hazleton, amounting in all to something like 2500 h.p. in motors. This power is supplied to silk mills, iron works, lumber mills, ice plants, printing offices, laundries, garages, etc., etc. Seven or eight passenger and freight elevators in Hazelton also are operated by electric motors.

The Company further supplies about 1500 h.p. in current for the operation of collieries located in the towns of Harleigh, Harwood, Cranberry, Audenried and Lattimer Mines, and some 300 h.p. for water works in Humbolt, Harleigh and West Hazleton, and for an ice machine at Lattimer Mines.

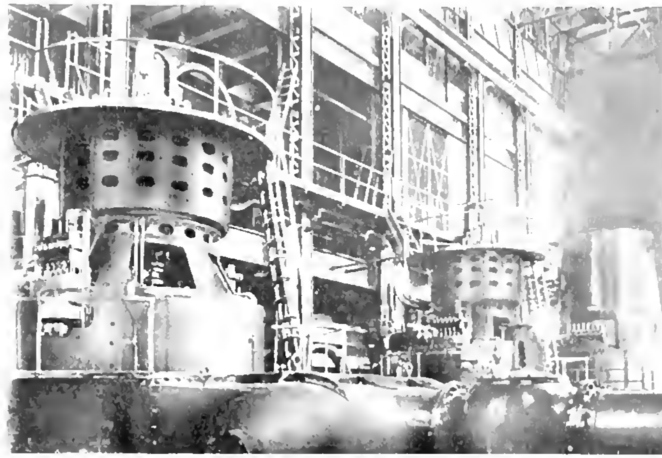


Fig. 2. Generator Room, showing One 5000 Kw. (in background) and Two 1500 Kw. Curtis Steam Turbines

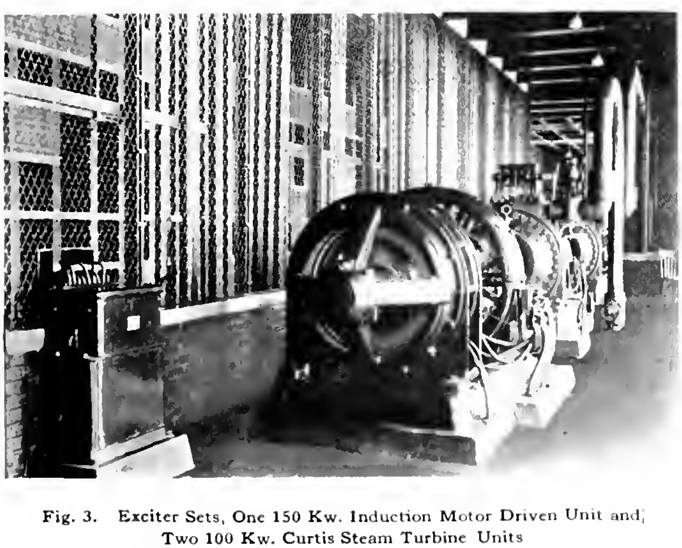


Fig. 3. Exciter Sets, One 150 Kw. Induction Motor Driven Unit and Two 100 Kw. Curtis Steam Turbine Units

Power Plant

The power house is located at the mines, adjacent to the culm piles, and is a thoroughly modern structure in every respect. It is built of steel and brick and consists of two main divisions, a boiler and a generator room, separated from one another by a brick wall. Work was begun on the building November 1, 1908, and after a short period of inactivity during the winter of 1908-09, construction was resumed on the plant and every effort made to complete it at the earliest possible date. Because of the urgent requests from the nearby towns for lighting and power, the station was put in service in November, 1909, although not actually completed at that time.

The coal is taken from the banks, and from the "breaker" and coal piles, and carried by electrically driven conveyors to the top of the coal tower. Here it is thoroughly mixed, dried and weighed, and finally automatically loaded into another electrically driven conveyor which carries it to the boiler room coal bunkers. The coal is handled entirely by machinery from the time it leaves the waste coal and culm piles until it is

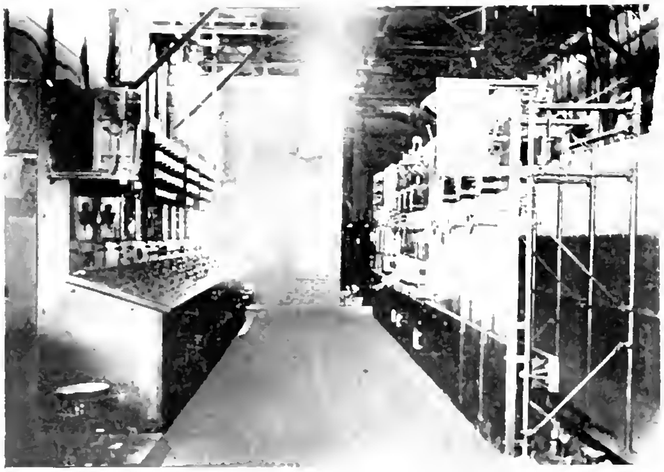


Fig. 4 Control Benchboard and Switchboard

delivered at the boilers. In a similar manner the ashes are flushed out of the pits below the boilers and carried to the outside ash bunker, being finally loaded into ash cars by the same conveyor that handled the coal in the first place.

The boiler room contains ten boilers, each rated at 650 h.p. As previously stated, special means are necessary for effecting the proper combustion of the fuel, and to this end forced draft fans are installed which drive 200,000 cubic feet of air per minute through the grates, producing an intense heat that will melt all but the most refractory of fire brick.

The water for the boilers is obtained from artesian wells about a mile distant from the station. It is pumped to a reservoir on a neighboring mountain by electrically driven pumps located at the wells, the pressure due to the elevated position of the reservoir being sufficient to deliver the water to the top of the power house, 85 feet above the ground. Before being fed to the boilers the water is heated to the boiling point by means of the exhaust steam from the station auxiliary pumps. The supplying of water to the boilers is automatic and no attention to this detail is required from the firemen.

The steam from the boilers is passed through superheaters and raised to a temperature of more than 500 deg. nearly hot enough to melt lead whence it is carried directly to the turbines. From the turbines the steam is conveyed to the condensers, which are of the Le Blanc type. The condensing apparatus is operated by horizontal steam turbines of 225 h.p. each. About 600,000 gallons of cold water per hour are required to condense the steam necessary for the generation of 10,000 h.p. After passing through the condenser, the cooling water is discharged into long pipe lines leading to spray nozzles located at a slight distance above ground level. The water is here converted into a shower 15 ft. high, and in falling to earth is cooled to normal temperature. It is then drained into a 6 acre cooling pond, where it is further cooled and then returned to the condensers. This pond will hold nearly 30,000,000 gallons, or sufficient water to run the plant at full load day and night for three months, should the regular water supply fail. The building of this cooling pond entailed some of the most difficult work encountered in the construction of the plant, as the formation of the soil at this point consisted of earth alternating with layers of hard rock, and required an immense amount of dynamite for its removal.

There are at present installed in the generating room one 5000 kw. (maximum rating) and two 1500 kw. (80 per cent. rating) vertical Curtis steam turbine generator sets. These sets are shown in Fig. 2. The generators are three-phase, 60 cycle 11,000 volt machines and are operated in parallel. Provision is made for additional turbine-generator sets, and when finally completed the station will have an output of 50,000 h.p. or more.

In Fig. 3 are shown the exciter sets, two of which are 100 kw. machines direct connected to horizontal Curtis steam turbines, while the third is a 150 kw. induction motor driven unit.

The switchboard and control benchboard are located upon a gallery extending along one side of the generating room. A view of these two boards is shown in Fig. 4.

Six 1000 kw. oil and water-cooled step-up transformers are placed at one end of the exciter gallery and enclosed in fireproof compartments. These units supply current to the transmission line to Nescopeck and Berwick, transforming from the generator potential of 11,000 volts to 25,000 volts.

The transmission lines from the station are protected from lightning and other static disturbances by aluminum cell lightning arresters.

GENERAL ELECTRIC REVIEW

VOL. XIV, No. 6 JUNE, 1911

CONTENTS

Illumination of Copley Square, Boston, with Boston Flame Arcs

(See page 269)

GENERAL ELECTRIC REVIEW

THE ELECTRIC VEHICLE

The paper by Mr. J. E. Kearns on the use of the electric automobile by gas companies deals with one phase of a question of great interest to the central station community as well as to manufacturers of electric vehicles. To say that the question contains the solution to the problem of profitable central station operation is probably overstating the case, but there is no doubt that there is a wealth of profitable day load to be obtained in this direction.

According to a table of figures presented by Mr. Hermann Spoehrer before the Missouri Electrical Association, the estimated annual consumption of electric vehicles in kilowatt-hours will be, say 2400 for a pleasure car, 7500 for a two-ton truck and 11,000 for a five-ton truck. It is therefore a simple matter to compute the effect which would be produced on the off-peak demand on a central station by the sale of, say, one hundred light delivery trucks to the merchants of any town.

Full profit will not be made out of these possibilities without close co-operation between the manufacturers of vehicles and the power companies, as there are obstacles which can only be overcome by concerted action: misapprehensions exist in the popular mind as to charging rates and maintenance costs; the majority of cities are totally unprovided with garage accommodation; in many places traffic regulations forbid the waiting of vehicles at the curb and therefore call for special provision for waiting cars; charging voltages of various cells range over such wide limits as to militate against economical garage operation; while there are a number of other difficulties which, until successfully negotiated, will adversely affect both the manufacturer and the power company.

In order to give point to this view, mention should be made of the way in which the situation has been met by the interested parties in the city of Boston. The Boston Edison Company have undertaken to supply electricity free of charge to dealers in electric automobiles for the purpose of sign advertising, and will also provide free illumination of a large sign to be erected for the display of advertisements representing all the local electric vehicle agencies. The commodious new garage which has been erected by the Edison Company will be placed under the direct supervision of the Electric Vehicle Association of America, and expert technical advice and assistance will thus be obtained on the spot; a capable staff of salesmen has been organized to make a thorough canvass of the merchant houses of the city; an extensive newspaper advertising campaign has been inaugurated; and, in short, no stone has been left unturned to insure the wholesale introduction of the electric vehicle into the city.

Mention should also be made of a very enterprising move on the part of the Anderson Electric Carriage Company, of Detroit, who have made an offer to sell one hundred electric automobiles at factory cost to any power company in the New England field, in order to assist in the development of the business in this area.

A further difficulty which has been encountered in the past has been due to the lack of organized experimental and research work on the machine and on the battery equipment, together with well-collated operating data. To meet this need, the Boston Edison Company have come to an arrangement with the Massachusetts Institute of Technology, whereby the latter will undertake laboratory research work with regard to technical electric vehicle questions, as well as an investigation of factory and garage economy. It is to be hoped that one of the first points to receive attention will be the standardization of voltage rating of the various batteries wherever possible.

The manner in which the situation has been handled in Boston is entirely suited to the peculiar difficulties and needs of the position, and should serve as an example which might be profitably followed throughout the country.

In a number of large cities, of which Cleveland, St. Louis and Minneapolis are notable examples, garages for the accommodation, maintenance and charging of electric vehicles have also been erected, and there is no doubt that as this example is more widely followed, so will one of the greatest obstacles to the adoption of the electric vehicle disappear. At these institutions any number of cars may be handled from 20 up to 80 or 100, and the usual system is to charge a flat rate of $25 or $35 a month for storage, delivery, maintenance, charging and small repairs.

In Mr. Kearns' paper will be found much useful information with regard to the use of the electric vehicle for a variety of commercial purposes.

OZONE

The article by Dr. M. W. Franklin on ozone and the ozonator presents much useful information regarding the use of ozone for such purposes as deodorizing and cleansing storage rooms, kitchens, public halls, etc., and gives a detailed description of a device called the ozonator for generating this gas on a commercial scale. Parts of this article have already appeared under Dr. Franklin's name in the New York *Medical Journal* of April 8th last, and are reprinted now through the courtesy of the editor of that paper.

Dr. Franklin mentions that carbon dioxide, if breathed into the lungs, is not, itself, in any sense poisonous, and is only to be objected to in so far as it replaces oxygen in the air. That the danger from this source is not deadly is shown by the fact that a human being may continue to breathe at high altitudes where the normal proportion of oxygen is very much reduced, the rate of breathing naturally being increased to make up for this deficiency.

Carbon monoxide, on the other hand, is a dangerous poison, the explanation of its action on the human system being found in the effect which it produces on haemoglobin. Haemoglobin is the main constituent of the red corpuscles of the blood and serves as the agent for carrying oxygen from the lungs to the general tissues of the body. It readily combines with oxygen to form oxyhaemoglobin, this combination taking place as the haemoglobin passes through the lungs. The compound is an unstable one and the loosely-combined oxygen is given off again as the corpuscles pass through the capillaries, thereby reducing the oxyhaemoglobin to haemoglobin.

With carbon monoxide, however, an exceeding stable compound known as carboxyhaemoglobin is formed, which, owing to its stability, will continue to circulate through the system without in the least serving as an oxygen carrier, and with a resulting impoverishment of all the tissues to be nourished. In extreme cases of carbon monoxide poisoning, it is necessary to resort to transfusion of blood in order that the supply of haemoglobin, necessary to carry the oxygen from the lungs to the other tissues, may be maintained.

Carbon dioxide possesses no such deleterious effect on the oxygen-carrying capacity of the blood, and it is therefore the function of the ozonator to prevent the inhaling of the poisonous carbon monoxide into the lungs by converting it into the innocuous carbon dioxide.

The study of the whole question is being pursued in various quarters, and it is probable that a great deal of new and interesting matter will shortly come to light. Experiments are also being carried out with regard to the application of ozone as a cure for various affections of the respiratory tract, and the results of these investigations will be published at a later date through the proper channels.

DIELECTRIC STRESSES FROM THE MECHANICAL POINT OF VIEW*

By W. S. Franklin

The object of this paper is to discuss dielectric stresses from what may be called the mechanical as distinguished from the atomistic or electronic point of view. The discussion is based on two ideas, namely: (*a*) That dielectric breakdown occurs at a definite electric field intensity; and (*b*) that the line of dielectric breakdown is a conducting path.

The present paper discusses dielectric stresses only in so far as they are modified by variations of inductivity and shapes of metal parts; fatigue effects (and other effects involving time), the peculiar breakdown characteristics of very short air gaps, the corona discharge, and so on, will be discussed in a second paper which will be based almost wholly upon the electron theory.

The ordinary practical units, ampere, ohm, volt, coulomb, farad, volt-centimetre, volt per centimetre, etc., are used exclusively in this paper.

A familiarity with the condenser is taken for granted. The equation of the condenser is:

$$Q = CE \qquad (1)$$

in which E is the electromotive force applied to the condenser plates, Q is the amount of charge drawn out of one plate and forced into the other plate, C is the capacity of the condenser.

The capacity of a parallel plate condenser with air as the dielectric is

$$C = 881 \times 10^{-16} \frac{a}{x} \qquad (2)$$

in which a is the area of one of the plates (sectional area of the dielectric) in square centimetres, and x is the thickness of the dielectric in centimetres.

To substitute oil or any other dielectric for the air increases the capacity of a condenser in a certain ratio k, so that the capacity may then be expressed by the equation

$$C_{oil} = 881 \times 10^{-16} \frac{ka}{x} \qquad (3)$$

The factor k is called the *inductivity* of the dielectric (also sometimes called *specific capacity* of the dielectric). Thus the inductivity of kerosene is about 2, which means that the capacity of an air condenser is doubled if kerosene is substituted for the air dielectric.

In the following discussion the letter B is used to designate the factor 881×10^{-16}.

Gauss's Theorem

A theorem of fundamental importance in electrostatic theory is as follows: The total electric flux Φ emanating from a charged body is equal to $Q \div B$, or the total charge on a body is equal to $B\,\Phi$, where Q is the charge in coulombs and Φ is electric flux expressed in volt-centimetres in air. (An electric field intensity is expressed in volts per centimetre, and the product of this field intensity by an area in square centimetres gives electric flux in volt-centimetres, the area being perpendicular to the field.)

When applied to a parallel plate air condenser, Gauss's theorem may be derived by multiplying both members of equation (2) by E (the electromotive force between the plates), giving:

$$CE = Q \qquad = Ba\frac{E}{x};$$

but $E \div x$ is the electric field intensity between the plates in volts per centimetre, so that $a \times E \div x$ is the electric flux from plate to plate in volt-centimetres and therefore, $a \times E \div x = \Phi$ whence we have

$$Q = B\phi \qquad (4)$$

Gauss's theorem may be derived for a parallel plate condenser with any dielectric by multiplying both members of equation (3) by E (the electromotive force between the plates), giving:

$$CE = Q = B.a.k\frac{E}{x}$$

but $E \div x$ is, as before, the electric field intensity between the plates and $k \times E \div x$ may be defined as the *electric flux density* in the dielectric, so that $a \times kE \div x$ is the total flux, and we thus arrive again at equation (4).

MAGNETIC AND ELECTRIC PARALLEL

$$B = \mu H$$

Where H is intensity of magnetic field in gausses, μ is the permeability of the medium, and B is the magnetic flux density.

$$F = kf$$

Where f is intensity of electric field in volts per centimetre ($E \div x$), k is the inductivity of the medium, and F is the electric flux density in volt-centimetres per square centimetre.

* Reprinted from the *Journal of the Franklin Institute*.

ELECTRICAL STRESS AND MECHANICAL STRESS

The stretching force per unit of sectional area of a rod is called the *stress* on the rod, and the elongation of unit length of the rod is called the *strain*; and the strain is proportional to the stress. That is, strain = constant × stress.

This constant is the reciprocal of what is usually called the modulus of elasticity, and it is large in value for a substance like rubber, which is greatly stretched by a moderate stress.

The intensity of an electric field in volts per centimetre (or the volts per centimetre in a layer of dielectric between metal plates) is frequently called *electrical stress*, and the electric flux density kf in the dielectric is frequently called the *electrical strain*. Therefore we have

electrical strain = k × *electrical stress*.

The inductivity of a dielectric is analogous to an elastic constant (reciprocal of what is called modulus of elasticity). The product kf, which we call electric flux density or electric strain, was called *dielectric polarization* by Maxwell.

In some cases electric flux density (or strain) is given instead of electrical field intensity (or stress) when it is desired to specify the condition of a dielectric. Now electric flux can be expressed in coulombs according to equation (4), B being a numerical factor. Therefore electric flux density (or strain) may be expressed in coulombs per unit area. Thus electric strain is sometimes expressed in coulombs per square inch.[1]

Electric Stresses in Plane Layers of Different Dielectrics

Consider two metal plates with equal thicknesses of air ($k=1$) and of glass ($k=6$)

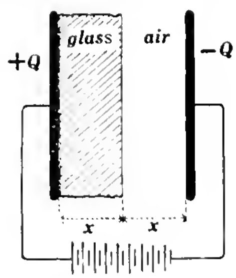


Fig. 1

between them as shown in Fig. 1. The thing which is constant throughout the region between the metal plates, that is, the thing which has the same value in glass and air, is electric flux density, kf, because there are equal and opposite charges on two plates and, therefore, according to Gauss's theorem the total flux passing out from the positively charged plate ($+Q$) is equal to the total flux passing in towards the negatively charged plate ($-Q$). Now since kf is the same in the glass and in the air, and since $k=1$ for air and $k=6$ for glass, therefore electric field intensity or stress in volts per centimetre (f) is six times as great in the air as in the glass.

[1] In a recent paper before the American Institute of Electrical Engineers an author states that this method of specifying electrical strain is so little understood that he deems it justifiable to give a full discussion of the matter and he arrives by a confused argument to the wrong result "coulombs per inch cube."

Consider the special case in which the glass and air are of equal thickness, as indicated in Fig. 1. Then six-sevenths of the battery voltage is impressed on the air layer and one-seventh on the glass layer. If glass and air are each 1 centimetre thick, and if the total voltage is 35,000 volts, then, assuming the air not to break down, the voltage across the air will be 30,000 volts, and the voltage across the glass will be 5000 volts.

If the glass plate is removed, leaving 2 centimetres of air, then the electrical stress

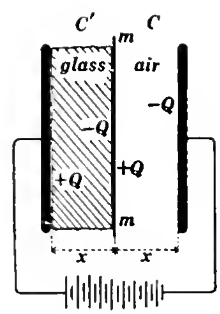


Fig. 2

on the air will be 17,500 volts per centimetre. Therefore the electrical stress in the air between two plates 2 centimetres apart is increased from 17,500 volts per centimetre to 30,000 volts per centimetre by filling half of the space between the plates with glass of inductivity 6.

This effect can be shown in a very beautiful manner by connecting two metal plates to a high-voltage transformer and adjusting the plates to a distance such that the intervening air layer is barely sufficient to sustain the voltage. Then if a glass plate be introduced between the metal plates, the electrical stress in the remaining air will be increased sufficiently to break the air down at each reversal of the alternating voltage, as shown by the bluish luminosity of the air layer.

The above discussion of the stresses in layers of glass and air as based on Fig. 1

can be simplified as follows: Imagine a thin sheet of metal *m m* to be placed between the air and glass as shown in Fig. 2. We thus have two exactly similar condensers, C' and C, of glass and air, and the capacity of the glass condenser is six times as great as the capacity of the air condenser, according to equations (2) and (3). But the charges on C' and C are the same because they have been charged in series. Therefore the voltage across the glass condenser is one-sixth of the voltage across the air condenser, according to equation (1).

The concentration of the greater part of the voltage upon the air layer in Figs. 1 and 2 is exactly analogous to the concentration of the greater part of the magnetomotive force of a dynamo field-winding upon the air gap in the magnetic circuit; only a small portion of the magnetomotive force is required to force the magnetic flux through the highly permeable iron, and a large portion of the magnetomotive force is required to force the magnetic flux through the less permeable air layer. A small portion of the battery voltage is required to force the electric flux through the highly inductive glass in Fig. 1 and a large portion of the voltage is required to force the electric flux through the less inductive air.

Mechanical Analog of Fig. 1

A difficulty in obtaining a simple mechanical idea of the concentration of the greater part of the battery voltage on the air layer in Fig. 1 arises from the following fact: the glass and the air are *in series* in Fig. 1 (and the electric flux density or *electric strain* or

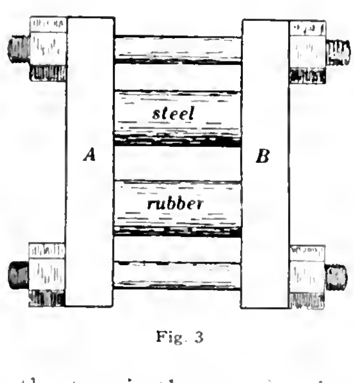


Fig. 3

yield, in the two is the same), whereas two mechanical elements have the same *stress* when they are in series; to have the same strain or yield, two mechanical elements must be *in parallel*. Thus Fig. 3 shows a column of steel and a column of rubber equally compressed between two bars A and B (the steel and rubber columns are in parallel); the easily yielding rubber (high inductivity) supports a small part of the compressing

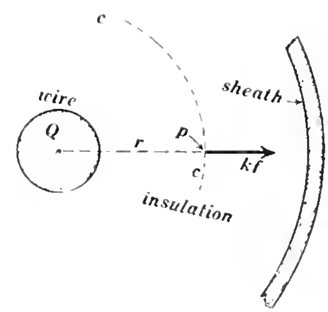


Fig. 4

force, and the stiff steel (low inductivity) supports a large part of the compressing force.

The Graded Cable Insulation

Influence of Variation of Inductivity on Electrical Stress.—Consider unit length of the wire core of a cable and let Q be the amount of electric charge thereon. Let f be the electric field intensity in volts per centimetre at the point p in the insulation distant r from the axis of the cable and let k be the inductivity of the insulating material at p. Then kf (see Fig. 4) is the electric flux density at p, and $2\pi r \times kf$ is the flux across the cylindrical surface cc (of unit length); that is, $2\pi rkf$ is the flux emanating from Q and, therefore, according to equation (4), we have

$$Q = B \times 2\pi rkf$$

or

$$f = \frac{Q}{2\pi B} \cdot \frac{1}{rk} \tag{5}$$

Therefore, if k decreases as r increases so that the product rk is constant, then the electrical stress f, in volts per centimetre, will be the same in value throughout the cable insulation.

There is an interesting mechanical analogy to the graded cable insulation. If a thick walled steel tube is subjected to internal pressure as in a cannon, the material next the bore is stretched to its stress-limit before the outer portions of the steel are brought into full action. If easily yielding (high elastic like rubber) steel could be used for the inner portions of the gun tube, then the greater yield of the inner material would tend to bring all of the material of the tube up to the limiting stress simultaneously. There is in fact but little variation in the elastic coefficient of various kinds of steel, and this method of gun construction is therefore impracticable. There are, however, great differences in the inductivities of different insulating materials, and therefore the grading of cable insulation is to some extent practicable.

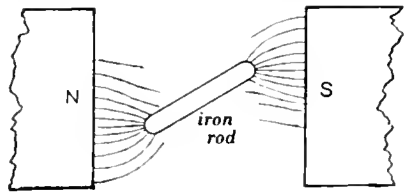


Fig. 5

Experimental Effects Dependent upon Inductivity

The lines of force in an electric field converge upon and pass through a glass rod (high inductivity), and the lines of force in a magnetic field converge upon and pass through an iron rod (high permeability). A glass rod suspended in an electric field oscillates to and fro through an equilibrium position parallel to the field in the same way that a suspended iron rod oscillates in a magnetic field. (Figs. 5 and 6.)

A glass plate is drawn into the intense electric field between positively charged metal plates in the same way that a piece of iron is drawn into the intense magnetic field between two opposite magnet poles, as shown in Figs. 7 and 8. In the same way oil and especially water is drawn into the most intense part of an electric field.

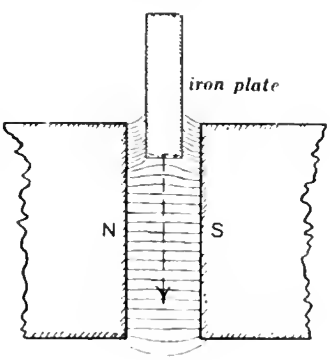


Fig. 7

A thin glass cell partly filled with oil and provided with metal terminals *A* and *B* is placed in a lantern and the terminals *A* and *B* are connected to a Toepler-Holtz machine, as indicated in Fig. 9. The oil (high inductivity) is drawn up as shown, and eventually a column of oil is formed reaching up to terminal *A*. In the same way a magnetic liquid (permeability greater than unity) would be drawn up to a magnet pole.

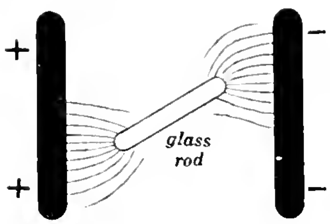


Fig. 6

Bubbles of air rising in oil in front of a blunt metal terminal (charged) are repelled.

A gold-leaf electroscope is placed in a lantern, and the plate of the electroscope is connected by a fine wire to an insulated plate *PP* on the lecture table, as shown in Fig. 10. When a slab of paraffin wax *W* is placed in the region *CC*, the electroscope leaves fall slightly. The capacity of the condenser *CC* has been increased by the paraffin slab and a greater portion of the charge on the insulated system flows into *PP*, thus decreasing the charge on the electroscope leaves. If we had two inflated rubber bags connected by a tube, and the walls of one bag were made more yielding by dissolving off a portion of the rubber (if that were possible), then the weakened bag would swell and the other bag would shrink. The plate of paraffin makes the dielectric around *PP* more yielding and some charge flows from *EE* into *PP*.

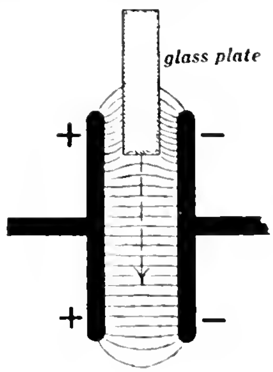


Fig. 8

Dielectric Hysteresis

The most prominent kind of dielectric hysteresis is a kind which is closely analogous to what is technically called *elastic lag* in mechanics. Glass, for example, when subjected to a mechanical stress takes on a certain amount of strain (deformation) quickly, after which the strain slowly increases for a time; and when the stress is removed, a remnant of the strain persists for a time. This kind of hysteresis is sometimes called *viscous hysteresis*, and it is very different from the magnetic hysteresis in iron or steel, although a slight amount of viscous hysteresis does exist in very soft iron.

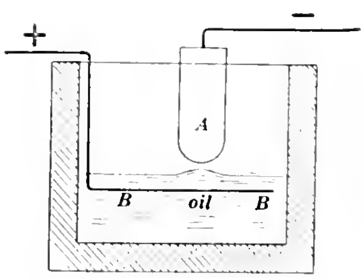


Fig. 9

Dielectric hysteresis of the viscous type has long been known to exist, and it is the cause of the so-called "residual charge" which accumulates in a Leyden jar when the jar is completely discharged and allowed to stand.

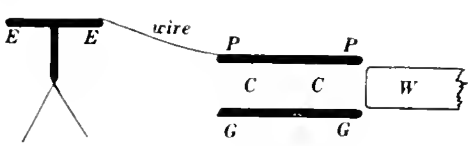


Fig. 10

A Leyden jar is charged. The coatings of the jar are then momentarily connected by wire, and then the jar is left standing on open circuit. After a time the coatings are again connected and a second slight discharge is obtained.

A rubber tube is stretched. This stretch corresponds to the electrical strain of the glass walls of the Leyden jar. The end of the tube is momentarily released, and the end is then clamped fast in what seems to be its equilibrium position. After a time the end is again released and a second slight "discharge" or movement takes place.

Gleitfunken

Everyone who has used Leyden jars is familiar with the fact that a spark will often jump seven or eight inche over the edge of a jar from tin-foil to tin-foil, when the coatings are connected to a spark-gap of an inch or an inch and a half. A surface of contact of two dielectrics of different inductivities is electrically very weak, even when it is free from dirt and dust. The explanation of this fact for the simple case of the Leyden jar is as follows: Consider the dotted line in Fig. 11 (a tube of electric flux) partly in air and partly in glass. The voltage between the tin-foil coatings is concentrated in the air portions of the tube of flux because of the high inductivity of the glass, and the air portions break down. Tubes of flux then pass between the charged fringes beyond the edges of the tin-foil, and the action is repeated, and so on until a spark jumps over the edge of the jar. A strip of window glass placed edgewise in the spark-gap of a Toepler-Holtz machine causes a spark to jump one and one-half or two inches when a one inch spark-gap (without a glass strip) is connected in parallel with the spark-gap of the machine.

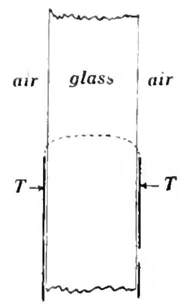


Fig. 11

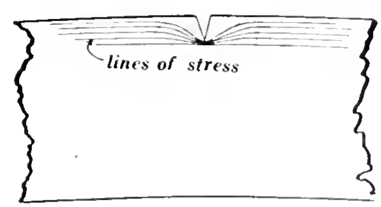


Fig. 12

Concentration of Electrical Stresses by Points

The ease with which a bar of hard toolsteel can be broken when a sharp-bottomed nick is made in one side of the bar is well known. Fig. 12 shows the lines of stress passing around the bottom of a sharp groove in a bent bar. The stress is very greatly concentrated near the bottom of the groove, and the groove deepens by the formation of a crack. The stress is then concentrated at the edge of the crack, and the crack is extended farther and farther until the bar is broken in two.

It is perhaps not universally known that the glass-cutting diamond does not make a scratch. Such a scratch would be a shallow flat-bottomed groove, and no very great concentration of stress would occur at the bottom of such a groove when the pane of glass is slightly bent. The end of a cutting diamond is a perfectly rounded "corner" of a natural diamond crystal (the diamond is a crystal with curved faces), and when a cutting diamond is drawn properly across a pane of glass a minute crack is formed under the diamond on account of the excessive local compression. This crack causes a very great concentration of stress when the pane of glass is subjected to a very slight bending action, and the result is that the crack runs through the pane. When a diamond is drawn heavily across a pane of glass a very considerable exertion is required to break the glass and the crack does not always follow the groove. When a diamond is drawn properly across a pane of glass only a very slight bending movement is required to break the glass, and the break nearly always follows the minute crack produced by the diamond.

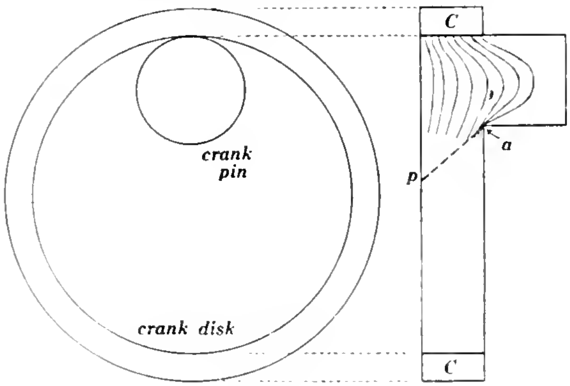


Fig. 13

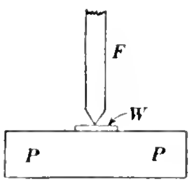


Fig. 14

A very interesting accident occurred at the Bethlehem Steel Works a number of years ago when an attempt was made to strengthen a crank-disk by shrinking a collar upon it. The disk had a crank-pin on one side, and the disk sheared off along the dotted line *ap* in Fig. 13 on account of the excessive concentration of stress at the re-entrant angle *a*. The fine curved lines show the approximate trend of the stress lines in the disk due to the collar *CC*.

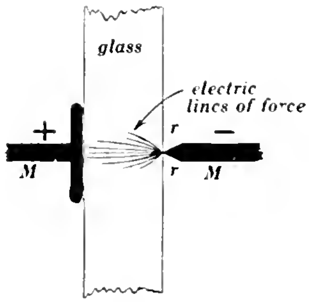


Fig. 15

An interesting experiment is to place a small piece of window glass on a flat plate of steel (or plate glass) and press a sharp-pointed file against it as shown in Fig. 14. The stresses in the window glass are very greatly concentrated at the sharp point of the file, and it takes but little force on the file to break the glass to pieces. If, however, a bit of soft copper is placed under the point of the file, one cannot push hard enough to break the glass; the copper yields (breaks down mechanically) and distributes the stress.

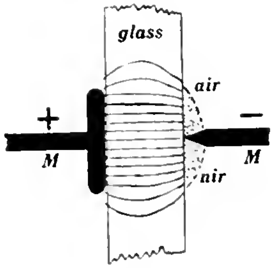


Fig. 16

When a voltage is applied to the metal terminals *MM* in Fig. 15, the electric lines of force (the electrical stress lines) converge upon the sharp metal point and the electrical stress is very greatly concentrated near the point. Indeed a comparatively low voltage will rupture the glass plate in Fig. 15 because of the starting of an electric rupture by the excessive concentration of the stress near the metal point. To produce this result, however, the region *rr* must be filled with a substance of great dielectric strength like turpentine or wax. If the region *rr* is filled with a substance of low dielectric strength like air, the portion in the immediate neighborhood of the metal point breaks down electrically and becomes a conductor, and the resultant distribution of electrical stress in the glass plate (which is shown in Fig. 16) is the same as if the glass plate were between two flat metal plates as shown in Fig. 17. Under these conditions the electrical stress in the glass is nearly uniform, and a very high voltage is required to puncture the glass plate because there is no region of concentrated stress to start the electrical breakdown.

Having air around the metal point in Fig. 15 is like having a bed of soft copper around the point of the file in Fig. 14. The copper

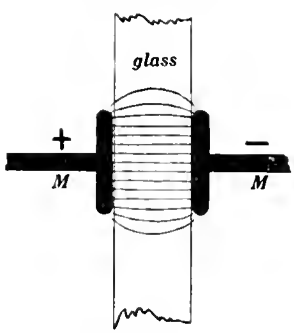


Fig. 17

breaks down mechanically and distributes the stress, thus preventing excessive concentration of stress near the point of the file and the starting of a crack thereby. The air breaks down electrically and distributes the stress, thus preventing excessive concentration of stress near the metal point and the starting of an electric puncture thereby.

An electrical breakdown in a solid dielectric (and usually in liquid and gaseous dielectrics also) is always in the form of a puncture, that is, the breakdown occurs along a line, and this line of breakdown is an electrical conductor. Therefore the electrical stresses in the dielectric are concentrated at the end of an incipient puncture, as at a metal point, and the puncture is thus carried through the dielectric or into regions where the electrical stresses were far below the breakdown value before the puncture started. These details were first definitely studied by Jean [2] in 1858; in describing his results, however, Jean does not, of course, use the language of mechanical analogy which is here employed.

Fig. 18[3] shows the electric lines of force between two metal balls, and Fig. 19 shows

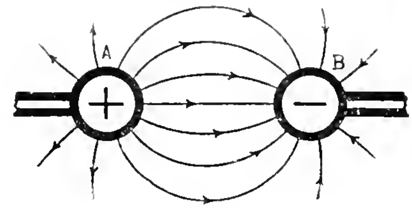


Fig. 18

how the electric lines of force rearrange themselves when an electric puncture starts.

The voltage required to puncture a homogeneous layer of dielectric is very nearly proportional to the thickness of the layer, when the electrodes are flat metal plates as shown in Fig. 17; but the concentration of stress near metal balls as shown in Fig. 18 and near a metal point as shown in Fig. 15 introduces a complication, the sparking voltage being far from being proportional to the thickness of the dielectric between balls or points.

Many dielectrics are very heterogeneous, containing moisture in the interior, for example, and the voltage required to rupture such a dielectric between flat plates is far from being proportional to the thickness.

For very small sparking distances in air at normal atmospheric pressure the breakdown stress in volts per centimetre becomes very great. That is, the proportional relation between voltage and sparking distance does not hold for very short spark gaps in air and

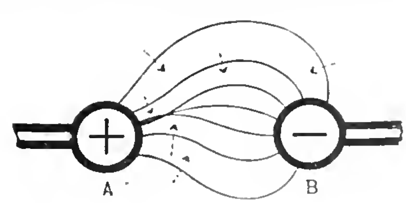


Fig. 19

perhaps the same thing is true of liquid and solid dielectrics. The peculiar breakdown characteristics of short air gaps will be considered in a second paper in which the electron theory will be prominently used.

[2] Compt. rend., xlvi, 186, 1858.
[3] Figures 18 and 19 are taken from Nichols and Franklin's "Elements of Physics," vol. ii (Electricity and Magnetism). The Macmillan Company, 1896.

ALTERNATING CURRENT APPARATUS TROUBLES

Part I, By D. S. Martin

INTRODUCTORY

In this series of articles it is proposed to deal with the following alternating current apparatus:

Alternators
Synchronous Motors
Induction Motors
Transformers
Rotary Converters

Each of the above sections will be dealt with separately and an attempt made to enumerate some of the chief troubles which may be encountered when setting these various types of apparatus to work, as well as faults which may develop after the apparatus has been operating in regular service. The list of troubles will be followed by a detailed analysis of the various causes which may be responsible for each particular trouble under notice, together with the procedure which should be followed in order to determine which of these causes is the origin of the difficulty. Finally, a few notes will be added as to the remedy which should be applied in order to overcome the trouble. Thus, if it is necessary to locate and remedy a defect in any given piece of alternating current apparatus, it is suggested that some hypothetical cause be assigned for the trouble and the various tests made to determine the correctness of this hypothesis. If incorrect, experiments will be made for the next hypothetical cause, until the source of trouble is exactly determined, and the approximate remedy for overcoming the defect may then be applied.

We do not propose to consider troubles due to mechanical causes, such as heating of bearings, excessive vibration, etc., but shall devote our attention to troubles which may be experienced in regard to the electrical operation and behavior of the apparatus.

ALTERNATING CURRENT GENERATORS

An alternator may be subject to any of the following troubles:

Defect (A) Failure to generate
Defect (B) Undue heating of
(a) Stator, or armature
(b) Rotor, or field
(c) Collector rings
(d) Bearings
Defect (C) Bad regulation
Defect (D) Noise and vibration
Defect (E) Defective insulation

A consideration of defect (A), failure to generate, brings us at once to troubles which may develop in the exciter, and since failure of the excitation voltage renders it impossible for the alternator to generate, it is essential that such failure of the exciter be analyzed in detail. It will therefore be most convenient to first consider all exciter troubles (other than mechanical) which may be met with, although these may not directly affect the excitation voltage furnished to the generator at the collector rings, and in this manner finally dispose of the exciter question and make the way clear for alternating current matters proper.

For the present, therefore, we must put aside purely alternating current questions for an investigation of the exciter, and consider the troubles which may be experienced, both as regards the failure of an exciter to build up voltage when first set to work and its failure to operate efficiently and satisfactorily under actual service conditions.

EXCITER TROUBLES*

(1) Failure to Build up Voltage

Cause 1. Residual magnetism too weak or destroyed.

Before the electro-magnetic reaction between armature and field can take place, a flux (of a certain strength) must be provided by the iron of the field pole itself, and this is sometimes so weak as to be incapable of providing any terminal voltage when cut by the armature conductors. Even though the machine when shipped from the factory was possessed of sufficient residual magnetism in the poles, clumsy handling in transit, resulting in jars and shocks to the apparatus, may be sufficient to kill this magnetism. The same effect may be produced by placing the machine in close proximity to other electrical machinery, which may also destroy its residual magnetism; but in any case and by whatever means this destruction of residual field is produced, it will be impossible

* The analysis of exciter troubles is based on the arrangement adopted by Prof. Crocker and Dr. Wheeler in their valuable treatise, "Practical Management of Dynamos and Motors."

for the machine to build up its own full field by electromagnetic action without the help of the magnetic field at the outset.

Symptom. Test the pole pieces with a bar of iron or a compass. Little or no attraction will be observed.

Remedy. The only means of overcoming this trouble is to pass a current from some external source through the field windings. Any voltage may be used, up to the full field voltage, though a relatively small percentage of full voltage will probably be sufficient. If a higher voltage than normal is the only supply available, this may be reduced as desired by any resistance at hand, such as lamps, rheostats, etc. When once this current has been passed, sufficient magnetism should thereby be given to the iron to provide a residual field strong enough for the machine to build up when connected in circuit; but in order to determine whether this is the case, the machine should be run up to speed (on open circuit if shunt or compound wound) and a voltmeter placed across the exciter terminals. If no voltage is then indicated on the meter, the cause of the trouble must lie elsewhere.

Cause 2. Shunt field of exciter connected so as to oppose residual field.

Here the failure to build up does not depend upon the direction of the residual field of the machine, so that the separate excitation method mentioned under Cause 1 cannot be applied in this case. The reason for this is that if the field induced by the current provided by the residual magnetism tends to weaken the residual, then if the direction of the latter be reversed, the direction of the field current will be reversed as well, resulting in again weakening the residual field, though in the opposite direction.

Symptom. Little or no attraction will be shown for a bar of iron or compass when exciter is running.

Remedy. (a) Reverse the field terminals, keeping armature connections the same; or (b) reverse armature terminals, keeping field terminals the same; or (c) reverse direction of rotation. The three remedies, a, b, and c all act with the same effect, i.e., each course will have the effect of changing the direction of the induced current flowing in the field, and thus giving the induced field the same polarity as the existing residual field. In certain cases, however, it may be found that the original trouble in the machine, viz., reversed direction of current in field, has resulted in killing the residual field, and in this case, after the remedy has been applied, resort must be made to the separate excitation method mentioned under Cause 1.

Cause 3. Reversed connection of one or more of the field spools.

The field poles of the exciter should be alternately N and S around the frame of the machine, and any reversal of one of the poles will tend to prevent the exciter from building up.

Symptom. Separate source of field excitation will again be required in this case, and the polarity of all poles tested with a compass. It will be found that the correct alternation of the N and S poles is not observed, but that the N of the compass will be attracted or repelled by adjacent poles. Failing a compass, the test may be made with a bar of iron, a long nail, etc. Each individual pole will attract the bar, by itself, but when the iron is placed in the field of both poles at once, the attraction will be much weaker, although when actually placed against the spools the iron will be held in place.

Remedy. The connections of the faulty pole or poles should be remade to give the correct sequence of poles around the frame. The compass or iron bar test should then show alternate N and S poles.

Cause 4. Rough or dirty surface of commutator, uneven bearing surface of brushes, and incorrect tension adjustment of brushes.

These will all be grouped under one heading, as their effect is to cause a partial break between the commutator and the external circuit. This may cause trouble when a machine is first set to work, as the increased resistance may considerably reduce the voltage applied to the field windings, and thus prevent the flow of a current in the field winding sufficient to excite the machine and thus build up full voltage.

Symptoms. The symptoms in this case are all visible and may be detected by close inspection of the commutator and brush rigging.

Remedy. Commutator should be stoned or sandpapered, brushes should be bedded true to the curvature of the commutator, and the tension of all brush springs adjusted to the correct value.

Cause 5. Incorrect brush position.

In the list of troubles enumerated, no mention has been made of failure to excite through incorrect position of the brushes. No hard and fast rules can be laid down for this, but machines nowadays are shipped from the factory with the correct brush position marked on the brush-rocker, and this marking should be adhered to. Adjustment may sometimes be necessary to secure the best operation and this may be made as required.

Note on exciters fitted with compound winding or commutating poles, or both

Shunt wound machines have been referred to, no mention having been made of compound winding or commutating poles, but the procedure for machines fitted with these additional field windings is substantially the same. The exciter may still be considered as a shunt wound machine and built up for the first time on the shunt winding only. Some external load may then be applied and careful note made of the operation and of any variation in the terminal voltage. The series winding may then be connected in circuit, and if it is found that the terminal voltage falls rapidly when the external load is applied, it may be assumed that the compounding is wrongly connected.

Similarly for a machine fitted with commutating poles: the operation at all working loads should be virtually sparkless, and if it is found that the operation of the exciter becomes worse instead of better when the commutating field is connected in circuit, this is an indication that the commutating field is incorrectly connected.

Some differences in behavior between shunt wound and compound wound exciters will be noted, such as may be seen when the machine is connected to an external circuit possessing a partial or dead short circuit. In this case a shunt wound exciter would fail to build up, while the effect on the compound wound machine might be to cause the exciter to build up very rapidly. The simplest course, as we have indicated, would probably be to consider the machine as shunt wound when going through the various steps of procedure in locating and remedying the trouble.

(2) Exciter Builds up, but no Voltage is Indicated at Generator Collector Rings

We are now free to assume that all troubles connected with the failure of an exciter to build up its voltage have been dealt with. In practice it may be found that although full voltage may be read across the terminals of the exciter, no voltage or a less voltage will be indicated on the generator collector rings. Mention should therefore be made next of two causes that would be responsible for this.

Cause 1. Open circuit in connections between exciter terminal board and collector rigging.

Symptom. Voltmeter held across slip rings will show no voltage or reduced voltage, although full voltage is read across terminal board. This will point to the fact that connections are open circuited, and proof of this may be obtained with magneto or battery and bell.

Remedy. In the unlikely event of there being an actual break in the connecting cable, a fresh lead should be run, but the trouble is more probably due to dirty or loose connection on exciter terminals or brush rigging. These connections should therefore be cleaned and tightened up.

Cause 2. Short circuit in connections between exciter terminal board and collector rigging.

Symptoms. If the exciter is giving its full voltage on open circuit, the effect of connecting the machine to an external circuit having a partial short circuit will be to cause a fall in terminal voltage. If the exciter (shunt wound) is started up on a dead short circuit, it will fail to build up, while sometimes a comparatively small external load or a partial external short circuit will have the same effect. Shunt wound exciters should therefore be started up on open circuit wherever possible.

Remedy. Here again it is unlikely that the fault occurs in the connecting cables. Accidental short circuits at the collector brush rigging are usually due to carelessness, and careful inspection will point out the remedy.

(To be Continued)

OZONE

By Milton W. Franklin

Although the application of ozone to the arts and sciences is of comparatively recent date, the field for speculation with regard to its commercial application in the future would seem to be virtually boundless. It is proposed to give here a brief description of the properties of ozone and their bearing on its practical value, together with some details of the method of manufacture of the gas and a description of an apparatus which has recently been developed and placed on the market for the supply of ozone on a commercial scale.

Physical Properties of Ozone

Ozone is a colorless gas with a sharp penetrating odor. In high dilutions the odor is similar to that of chlorine, but when the gas is more concentrated the odor closely resembles that of moist phosphorus. The gas is an unstable one under most conditions, though it decomposes slowly, even at temperatures approximating 45° or 50° C. In the pure state it is probably stable at temperatures up to about 260° C. At a pressure of 125 atmospheres at —103° C., ozone becomes a mobile, dark blue liquid, which is highly magnetic and less active chemically than the gas.

Chemical Properties of Ozone

Ozone is an endothermic compound, i.e., it is formed with the absorption of heat. Most endothermic compounds cannot be formed directly from their elements, and in such cases, the heat of formation is determined by calculation. Ozone, on the other hand, is formed directly from oxygen, and the endothermic heat has been determined directly. Berthelot has determined the endothermic heat of ozone by oxidizing arsenious to arsenic acid by oxygen and by ozone, and, by comparison, found that the endothermic heat is 29,600 calories to each gramme molecule. Still more recently, van der Meulen, by decomposing platinum black by means of ozone, has calculated the heat at 36,200 calories to each gramme molecule. The figure given by Berthelot is generally accepted, the reaction formula for ozone being given by:

$2\ O_3 = 3\ O_2 + 2 \times 29{,}600$ calories.

Like all endothermic compounds, ozone is highly explosive, but only when in the liquid state, and this explosiveness and chemical instability are indices of the great activity which renders ozone useful and valuable.

The chemical symbol for ozone is O_3 and in the presence of oxidizable or, in general, organic substances, the gas readily decomposes into O_2, while the third atom forms a more stable compound with the substance attacked. This chemical instability in the presence of oxidizable substances renders ozone the most active oxidizing agent known.

The action of ozone in destroying organic substances is so certain and rapid that it cannot exist except momentarily in air containing organic matter; hence its presence in air is an indication that the air is not only sterile, but that gases and products of putrefaction have been converted into stable oxides, i.e., inert matter; and the gas in consequence of this great oxidizing activity is a powerful and rapid disinfectant.

Ozone in Offices and Public Halls

The ozonator described below gives a flow of about 4250 cu. ft. per hour, which, on account of the rapid diffusion of the ozone, will sterilize and deodorize a room of considerable dimensions, the completeness of this depending on the purpose for which the room is used and upon the ventilation afforded. It must be understood that the ozonator is an adjunct to the usual system of ventilation. Any room or building used for the habitation or congregation of human beings should have a plentiful supply of fresh air, which must be supplied to furnish the oxygen necessary for sustaining life and to replace the burned out air from the lungs. It is, however, usually impossible to furnish enough fresh air thoroughly to replace the air which has been consumed, so that the most that may be hoped for is to dilute it. There always remains the decaying and putrefying organic matter; matter from the lungs, bronchial passages and mouth, and the product of incomplete combustion, carbon-monoxide. Ozone does not take the place of fresh air, but it oxidizes—"burns up"—the products of respiration, changes the harmful carbon-monoxide into the harmless carbon di-oxide (harmless except in so far as it replaces good air), and makes the room fresh, clean-smelling and habitable.

Under usual conditions, one ozonator should be sufficient for a room of at least 50,000 cubic feet, such as large offices, banks, hotel kitchens, theaters, churches and other public halls of medium size. For larger spaces the number of ozonators may be increased until the desired result is obtained. The ozonator is a powerful ozone producing machine, so that a multiplication of units will seldom be found necessary unless the space is very large or conditions very bad.

Ozone for Storage Rooms

For deodorizing rooms used for the storage of substances giving off strong odors, a larger amount of ozone can and must be used than for habitations. Odors from cheese, fish, meat, etc. are due to extremely small particles of the substances floating in the air. The ozone attacks these organic particles and immediately oxidizes them, "burns them up," thereby rendering the air free from odor. Where the substances have been stored for some time, stronger and longer ozonizing is necessary. Undoubtedly, ozone will perform this task, but the quantity and time necessary for deodorizing will have to be determined to a certain extent by experiment.

Ozone in the Factory

For use in factories where foul smelling odors abound, such as glue factories, abattoirs, fertilizer factories, etc., similar conditions have to be met. As an instance of the value of ozone for such purposes, a case may be cited in which an ozonator was installed in one of the shops of a firm of manufacturing engineers. In the particular room, known as the varnish or pasting room, considerable trouble was caused by the offensive character of the fumes and vapor emitted by various oils and varnishes. On one occasion, the whole force of girls was obliged to leave owing to nausea resulting from the conditions.

The problem of keeping air pure and tolerable and at the same time maintaining the temperature at a comfortable point was difficult and expensive. It was found necessary to keep the steam heating appliances operating at maximum capacity and to have the windows open. In addition an elaborate system of ventilators for the various machines was designed and partially installed. The advent of the ozonator solved the problem in an inexpensive and simple manner. The air was rendered almost entirely without odor and the windows kept open only as much as is required in an ordinary room. The heating requirements and consequent expense were thereby greatly diminished and the health, and hence the efficiency, of the employees was in no way jeopardized.

Similar conditions exist in almost every factory in the land and similar improvements can be made with manifold benefit to the employees and the employer.

The Preparation of Ozone

If a pointed conductor is raised to a very high electrical potential, the electricity flows out through the point and a so-called electrical wind is formed. The discharge is oscillatory, as may be proved in many ways, e.g., by means of a revolving mirror and by the evidence of a hissing sound. In the dark the discharge is distinctly visible as a small, whitish ball of fire at the point and a violet effluvium extending from the ball. The discharge, when in air, gives rise to the characteristic smell of ozone. The reaction which takes place around a distinct spark discharge differs from that of the silent discharge only in degree, the greater intensity of the spark discharge producing more intense reactions. The point of difference between silent and spark discharge is more or less ill defined.

There are characteristic reactions in gases other than air, when the electrical charge on the conductor is sufficiently intense, e. g., if the discharge reaches a certain critical intensity, nitric acid as well as ozone is formed in the air. It is thus essential, in the design of ozone generators, that the electric intensity be kept below that value at which nitrogen is ionized. Disregard of this point, in an effort to increase the production of ozone and to keep the dimensions of machines small, has rendered some forms of ozonizers useless.

The ideal method for the production of ozone is to employ two plates or curved surfaces of large area, between which the air to be ionized is passed. When the electrical intensity of surface charge upon these plates reaches a certain definite value, the electricity will leak into the air between the plates and the energy thus absorbed by the air will cause the molecules of oxygen to become ionized.

The resulting ions will possess an electrical charge and become the centers of aggregates of atoms and thus form the molecules of ozone. This is most simply explained on the following hypothesis:

There exists at all times in air a small number of free ions possessing, say, a negative charge. When an electrostatic stress is applied to this air these ions begin moving toward that pole which possesses a charge opposite to their own. The rapidity of this motion is a direct function of the potential gradient, and when the velocity has reached so high a value that the kinetic energy of these ions is sufficiently great, they will ionize molecules that they strike in their passage across the field. In this way the number of ions in the electric field is increased. This results in the presence of free atoms of oxygen, each possessing a charge of electricity, and these atoms are continuously moving in one direction or the other with great rapidity. They are incessantly colliding with each other and with unaffected molecules of the gas present, and in consequence are continually causing new ionizations and combinations.

There are three such ways in which they can combine, viz., two oxygen atoms can recombine and form a new molecule of oxygen, or an atom of oxygen may combine with a molecule of oxygen and form a molecule of ozone, or three atoms may form a molecule of ozone.

The Ozonator for the Supply of Ozone on a Commercial Scale

The ozonator illustrated in Fig. 1 is the concrete result of investigations and experiments extending over a period of many years. Every factor entering into the design of an ozonator was carefully considered theoretically and practically, and every facility has been employed to make the device a success.

In the lower part of the case is placed a transformer which changes the supply voltage to a value sufficiently high to produce ozone when applied to the generating units. Above the transformer is a horizontal wooden partition upon which rests the ozonator proper. This consists of a number of glass tubes to the outside of which is applied a coating of copper and through the inside of which, separated therefrom by a small air gap, are placed aluminum tubes. One high voltage lead from the transformer is connected to the outer coatings of the glass tubes and the other to the inner aluminum tubes.

When current is applied a violet electrical discharge takes place between the inner side of the glass and the aluminum tube. This discharge through the air in the small annular air gap transforms the oxygen of the air into ozone. The small but powerful centrifugal blower mounted on the top of the case blows air into the ozone chamber, through the generating unit, thence through the screen and into the room. The blower insures a flow of air through the tubes and a thorough expulsion of the ozonized air into the room, increasing greatly the effectiveness of the machine.

One of the small switches shown on the top of the case is for putting the entire machine in or out of service. The other switch is a three point switch in the transformer circuit. At the off point the transformer and hence the ozonator are disconnected entirely from the circuit. At the first point only a comparatively low voltage is applied to the ozone units, resulting in the production of a small amount of ozone. At the second point a larger amount is produced, and at the third point the full capacity of the machine is obtained. This easy method of varying the amount of ozone adds materially to the usefulness of the machine, as the amount of air can thereby be regulated according to the time of day, congestion, humidity, etc.

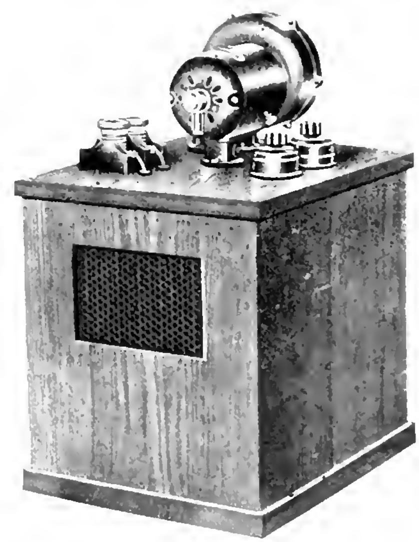


Fig. 1. General Electric Ozonator

The connections are such that the blower will always be running when ozone is being produced. Connections to the interior are made by means of spring contacts so that should it ever become necessary to remove the cover, the connections would be automatically opened. By placing the blower on the top of the case, the necessity for removing the cover for oiling is avoided.

ESSAYS ON SYNCHRONOUS MACHINERY

Part V

By V. Karapetoff

PHASE CHARACTERISTICS OF SYNCHRONOUS MOTOR UNDER LOAD

The practical significance of phase characteristics is explained in the preceding article. The upper curve of Fig. 3 shows the general shape of a phase characteristic when the motor carries a considerable load. The variations of the armature current in this case are much less pronounced than at no load, because the current comprises a comparatively large energy component which remains constant for all the points of the curve (constant kilowatt input). For the same reason, the power-factor curve also shows lesser variations than the no load curve.

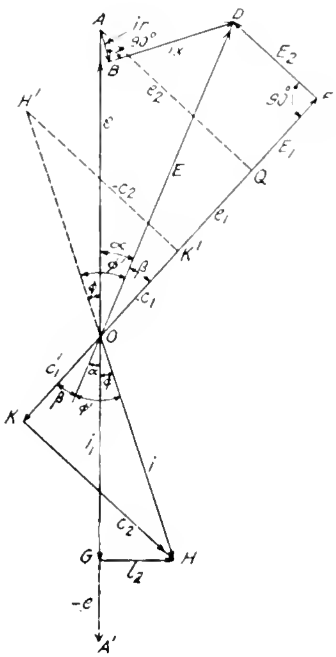


Fig. 6. Vector Diagram of Loaded Synchronous Motor

The purpose of this article is to show how to calculate phase characteristics for a given machine under load. The vector diagram of a loaded synchronous motor is shown in Fig. 6, which is similar to that of a loaded alternator (Review, April 1911, p. 195), except that the energy component i_1 of the current is reversed. This is evident because a motor takes power from the line, while an alternator delivers power to the line. The motor is assumed to be over-excited so that the armature current i leads the line voltage $OA'(=-e)$ by an angle ϕ. As in Figs. 4 and 5, $OA=e$ is the terminal voltage, equal and opposite to the line voltage; OA corresponds to the terminal voltage, e, of the alternator in Fig. 2.

The induced counter-e.m.f. E of the motor is obtained by adding the ohmic drop ir and the inductive drop ix to the terminal voltage e. This induced counter-e.m.f. consists of two components, E_1 and E_2, at right angles to each other. The component E_1 is induced by the main flux, which is excited by the field coils f and by the fictitious coils (1) (Fig. 1, February 1911, Review, page 55). The e.m.f. E_2 is induced by the flux excited by the fictitious coils (2), which represent the cross-magnetizing action of the armature currents. It is explained on page 55 that in a motor the fictitious poles lead the actual poles; therefore E_2 is shown in a leading quadrature with respect to E_1.

The phase characteristic is supposed to be drawn for a constant input to the motor. Therefore the energy component i_1 of the current is known, and the problem consists in finding the values of the field ampere-turns for assumed values of the reactive component i_2. The solution is similar to that of voltage regulation of alternators, given in the third article of the series (April 1911, Review). As a matter of fact, Fig. 6 and the necessary formulae can be obtained directly from Fig. 2 by turning the vector i clockwise until the phase angle $\phi = AOH$ becomes larger than 90 degrees. It is more convenient, however, to consider the acute angle ϕ, between the line voltage and the line current to be the phase angle (Fig. 6) and to deduce formulae directly applicable to the synchronous motor.

By analogy with equations (10) (April 1911, Review, page 195) we have from the figure $OABD$.

$$\left.\begin{aligned} E\cos\alpha &= e - ir\cos\phi + ix\sin\phi = a_1 \\ E\sin\alpha &= ix\cos\phi + ir\sin\phi = b_1 \end{aligned}\right\} \quad (20)$$

Here a_1 and b_1 are introduced for the sake of brevity, to denote the known values of the right-hand side of equations (20). Replacing $i\cos\phi$ and $i\sin\phi$ by i_1 and i_2 we obtain

$$\begin{aligned} a_1 &= e - i_1 r + i_2 x \\ b_1 &= i_1 x + i_2 r \end{aligned} \quad (20a)$$

Squaring equations (20) and adding them together we get:

$$E=\sqrt{a_1^2+b_1^2} \qquad (21)$$

or very nearly

$$E=a_1+\tfrac{1}{2}\, b_1^2/a_1 \qquad (21a)$$

because b_1 is usually small as compared to a_1.

Dividing the second equation (20) by the first gives

$$\tan\alpha=b_1/a_1 \qquad (22)$$

Angle β can be determined from the triangle ODF. Thus we have

$$\sin\beta=E_2/E_1 \qquad (23)$$

where E_2 is determined by formula (7) (February 1911, REVIEW, page 58). The internal energy component c_1 of the current which enters into equation (7) can be determined from the triangle OHK:

$$c_1=i\cos(\phi'+\beta). \qquad (24)$$

The upper ampere-curve in Fig. 3 is plotted by using the calculated values of M as abscissae against the total armature current

$$i=\sqrt{i_1^2+i_2^2}=i_1/\cos\phi \qquad (29a)$$

as ordinates. The ordinates of the power-factor curve represent the values of $\cos\phi=i_1/i$.

Numerical Illustration. It is required to calculate the full-load phase characteristics (current and power factor) of the same synchronous motor that was used as an illustration in the preceding article. The computations for seven points on the curves are shown in the table below. The energy component of the current is $i_1=530/(6.6\times\sqrt{3})=$ about 47 amp. The following terms in equation (20a) have the same value for all the

FULL-LOAD PHASE CHARACTERISTICS

Reactive Component i_2 Amp	$\tan\phi = i_2/i_1$	Angle ϕ	$\cos\phi$ Per Cent	Total Current $i=i_1/\cos\phi$ Amp	a_1 Volt	b_1 Volt	E Volt	Angle α	Angle $\phi'=\phi+\alpha$	Ratio E/E_2'	Angle β	E_1 Volt	M_n Amp. Turns	Angle $\phi'+\beta$	M_1 Amp. Turns	Calculated field Excitation $M=M_n+M_1$ Amp Turns	Field Excitation from test, Amp. Turns
30 leading	0 64	32° 40′	84 18	55 8	6956	698	6990	5° 45′	38° 25′	6 66	6° 10′	6950	6400	44° 35′	1360	7760	7730
17 leading	0.36	19° 50′	94 07	50	6774	681	6810	5° 45′	25° 35′	7 24	6° 45′	6760	6000	32° 20′	930	6930	6930
10 leading	0.21	11° 50′	97 88	48	6676	671	6710	5° 45′	17° 35′	7 44	7° 0′	6655	5800	24° 35′	695	6495	6520
0	0.00	0	100	47	6536	658	6670	5° 45′	5° 45′	7.55	7° 25′	6510	5600	13° 10′	370	5970	6110
10 lagging	−0 21	−11° 50′	97 88	48	6396	645	6430	5° 45′	− 6° 05′	7 12	8° 5′	6370	5400	2° 0′	60	5460	5580
17 lagging	−0 36	−19° 50′	94 07	50	6298	635	6330	5° 45′	−14° 05′	6 73	8° 30′	6260	5200	− 5° 35′	170	5030	5140
30 lagging	−0 64	−32° 40′	84 18	55 8	6116	618	6150	5° 45′	−26° 55′	5 86	9° 20′	6070	4950	17° 35′	590	4360	4400

Substituting the value of c_1 from (24) into (7) and denoting the known part by E_2', we have

$$E_2=E_2'\cos(\phi'+\beta) \qquad (25)$$

where

$$E_2'=k_2 k_c k_f n\, Ti.\, v \qquad (26)$$

Substituting the value of E_2 from (25) into (23) and solving for β we obtain

$$\tan\beta=(\cos\phi')/[E/E_2'+\sin\phi']. \qquad (27)$$

Knowing angle β we find

$$E_1=E\cos\beta \qquad (28)$$

and

$$c_2=i\sin(\phi'+\beta). \qquad (29)$$

It is shown on page 55 that in a motor the leading reactive current demagnetizes the field. The demagnetizing ampere-turns M_1 can be calculated from formula (5). The required field excitation M is a sum of M_1 and of the net excitation M_n necessary to produce the voltage E_1 at no load. The value of M_n is obtained from the given no-load saturation of the machine. (See page 58 in regard to an increase in the magnetic leakage between the poles when the machine is loaded.)

points on the ampere curve: $i_1 x=658$ volts; $e-i_1 r=6536$ volts. From the no-load saturation curve we find $v=1.35$ volt per ampere-turn on the lower straight part of the curve. Consequently,

$$E_2'=0.30\times 0.966\times 1\times 3\times 16\, i\times 1.35$$
$$=18.8\, i \text{ volt.} \qquad (29b)$$

Formula (5) becomes

$M_1=0.75\times 0.966\times 1\times 3\times 16\, c_2=34.8\, c_2$ ampere turns, or, combined with equation (29),

$$M_1=34.8\, i\sin(\phi'+\beta). \qquad (29c)$$

The order of computations is as follows: First, various values of the reactive component of the armature current are assumed, both leading and lagging, as given in the first column of the table. From these the corresponding values of power factor and the total current are calculated. The values of E and α are found from equations (21a) and (22), using the values of a_1 and b_1 computed from equations (20a). Knowing α, the values of $\phi'=\phi+\alpha$ are determined. After this, the values of the angle β are calculated according to equation (27), using the values of E_2' from formula (29b). Knowing β, the induced e.m.f. E_1 is found from equation (28). The demagnetizing ampere-turns M_1 are determined from formula (29c), and the net excitation M, corresponding to E_1, is found from the no-load saturation curve. Adding M and M_1 together, the required field excitation M is obtained. The calculated values of i and $\cos \phi$ are plotted in Fig. 3 against M as abscissae.

For comparison, the last column of the table contains values of field excitation found from an actual test on the machine. It will be seen that the calculated results check quite well with the experimental values.

THE USE OF ELECTRIC DRIVE IN THE SHIRT AND COLLAR INDUSTRY

By W. D. Bearce

The facility with which electric drive may be adapted to almost any condition of service is so generally recognized by industrial authorities that all modern plants are now designed for electrical operation, and many others originally designed for mechanical drive are being rearranged for the use of the electric motor.

The manufacturing equipment of Cluett, Peabody and Company is of particular interest as an example of the application of electric drive to a variety of machinery requiring for its operation comparatively small quantities of energy. In installations of this kind cleanliness, reliability, and unobstructed workrooms are quite as important as the cost of energy transmission and consumption, since the cost of energy represents only a small percentage of the total cost of the finished product.

The firm of Cluett, Peabody and Company operates five plants engaged in the manufacture of shirts and collars, constituting the largest group of factories of this kind in the world. These plants are located at Troy, Rochester and Corinth, New York, and at Leominster, Mass., and South Norwalk, Conn.; they are all electrically equipped, and a new plant now being built at St. John, N.B., will also be electrically driven.

The Troy factory is the largest of the five and contains the most up-to-date electrical equipment. Ten large interconnected buildings containing 480,000 feet of floor space are devoted to the various manufacturing operations, store rooms and offices.

Ordinarily, central station power would be used for a small motor installation in preference to an isolated generating plant, but as steam is required for heating and for the various processes of shirt and collar manufacturing, this company generates its own electrical energy for both lighting and power.

The boiler room contains six large water tube boilers which supply steam at about 100 lb. pressure to the engine room. The main generating unit is a Curtis turbine set of the horizontal type (Fig. 1) using steam at 100 lb. condensing. The turbine has a rated capacity of 500 kw. at 3600 r.p.m., while the generator is capable of delivering

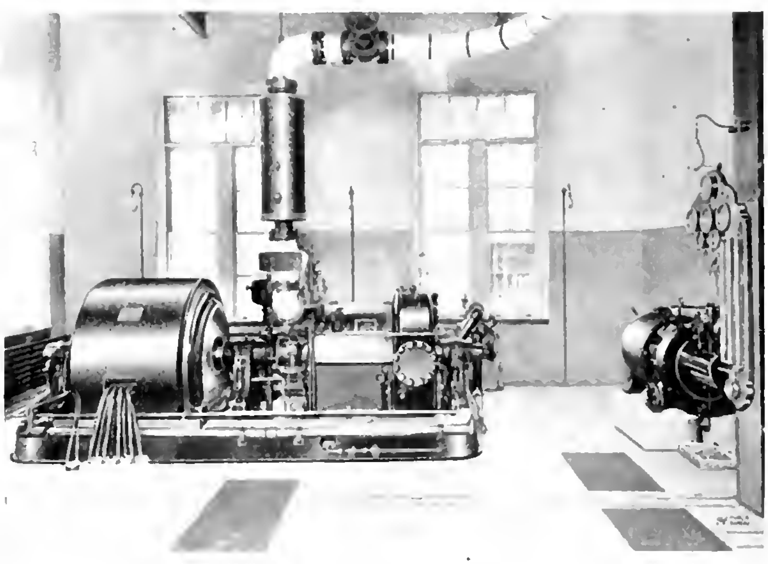


Fig. 1. 500 Kw. Curtis Turbine-Generator Set and Exciter

500 kw., or 625 kv-a., at a power factor of 0.8.

In addition to this unit the engine room contains a large reciprocating engine of the Corliss type direct connected to a 450 kw. General Electric alternator, and a 75 kw. generator of the same manufacture belted to a small engine. The former unit is held in reserve, while the latter is used when the main factory is not in operation. The 25 kw. Curtis turbine exciter shown in Fig. 1 is used for exciting the turbine unit when starting up, but a 20 kw. induction motor-generator set is used after the plant is in operation. A voltage regulator acting upon the exciter field insures constant voltage at the switchboard.

Three-phase 60 cycle current is supplied to the power circuits at 220 volts, while the lighting circuits are operated at 127 volts from the separate phases of the Y connected armature, the neutral of which is brought out. A black enamel slate switchboard controls the distribution of energy from the generators to the various parts of the factory; provision also being made to take power from the city mains for emergency lighting.

Wherever practicable, the transmission cables are carried to the various departments on the outside of the building in order to reduce the possibility of fire.

One hundred and forty-four motors, mainly in size below 10 h.p., are connected to the power circuits. The aggregate output of these machines is 662 h.p. With two or three exceptions the power required for the operation of individual machines is only a fraction of a horse power and group drive is employed in most departments. The squirrel cage induction motor is used as standard, as it runs at nearly constant speed and has no moving contacts; exceptions, however, are made in the cases of the large motors in the washing departments, which are designed with internal starting resistances, and some of the elevator motors, which are of the slip ring type designed for variable speed operation.

The cloth is first shrunk and dried, and then carried to the cutting departments, where it is unrolled on long benches. The cutting machines used for making collars are large presses, each of which forces several properly shaped steel dies through a large

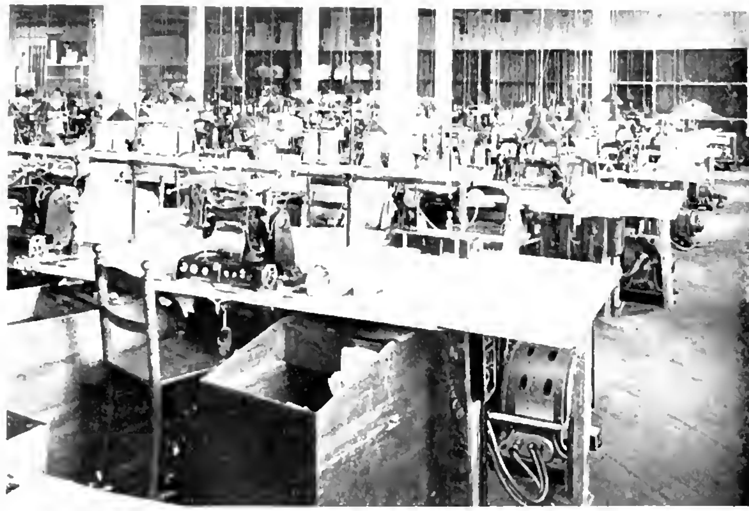


Fig. 2. Sewing Machines in Shirt Stitching Department

number of thicknesses of cloth. Seven of these machines are employed, and are driven in two groups by 5 h.p. motors suspended from the ceiling. The operation is intermittent, but the motor load is well regulated by large fly wheels on each machine.

Cloth for shirting is cut by a special machine, consisting of a rapidly moving knife directed by hand and operated by a small motor. The whole outfit is easily guided through the cloth, and by means of a flexible cord and sliding contact can be operated continuously across the entire length of the room. The capacity of the cutter is about 175 thicknesses of cloth at each cut, and one pattern, marked on the top breadth of cloth, is a sufficient guide for cutting the entire quantity. The pieces which go into the make-up of the completed shirts and collars are sorted by hand and sent in individual bundles to the stitching departments.

A typical motor arrangement in the shirt stitching department is shown in Fig. 2. Motors of 3 h.p. capacity are used as standard and are back-geared to a counter shaft which runs the length of the table. Twenty-five or thirty machines are driven from one motor, each sewing machine being controlled by the operator through a friction clutch.

A similar arrangement is followed in the collar stitching rooms and in the button-holing department. Although these operations necessitate several different types of machines, the power requirements differ very little. For stitching operations alone, fifty-five

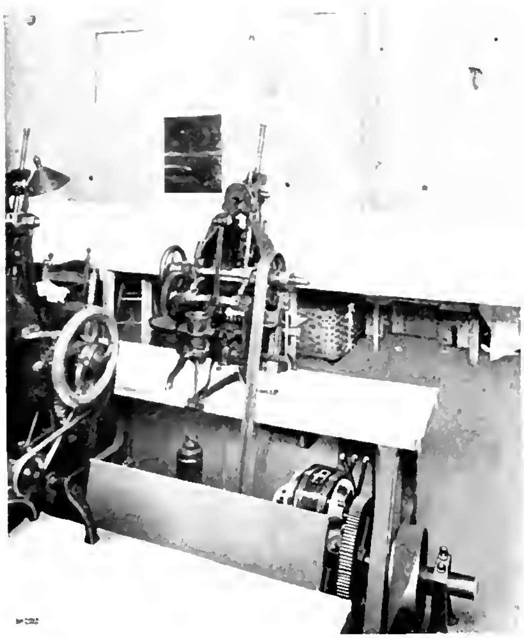


Fig. 3. Collar Stamping Machine Driven by 2 H P. Motor

2 and 3 h.p. motors are employed, driving about 1200 sewing machines of various types.

After the completed shirts and collars are properly examined for defects they are carried to the stamping departments, where the name, size, etc., are printed on each garment. Fig. 3 shows one of the 2 h.p. motors in the collar stamping department which serves to drive 16 stamping machines similar to the one shown in the illustration. These machines are driven from two line shafts, which, in turn, are connected to the motor by means of belts and a back gear.

Unlike the larger part of the apparatus used in shirt and collar manufacturing, the washing machinery requires a comparatively large amount of power. Fig. 4 shows one of the collar washing machines and the driving motor suspended from the ceiling. A 75 h.p. motor drives this group, which comprises washing machines and centrifugal extractors, while a similar motor rated at 50 h.p. drives the shirt washing section. These motors are equipped with an internal starting resistance which limits the current required to start the line and counter shafting.

After the washing operations are completed, it is necessary to exercise unusual precautions to prevent the goods from getting soiled, and the use of electric drive assists materially in maintaining clean rooms and machinery.

The starching room contains thirteen machines, all driven from the floor below by two motors rated respectively 1 h.p. and $1\frac{1}{2}$ h.p. The starched goods are first dried and then dampened for ironing. Fig. 5 shows the arrangement of the dampening machines, a 3 h.p. motor being geared to a countershaft from which six machines are driven.

Collar ironing is performed entirely by machinery, but shirt ironing is done largely by hand. However, one group of machines driven by a 3 h.p. motor is employed for ironing neck bands and cuffs. Fig. 6 is a view in the collar finishing department showing one of the ironing machines direct driven by a $\frac{3}{4}$ h.p., 1800 r.p.m. induction motor. The gear covering is removed to show the method of connecting the motor to the driving shaft. These machines were originally belt driven through a pulley which occupied the space now taken up by the gear and pinion. Fourteen machines are used, all equipped with $\frac{3}{4}$ h.p. motors.

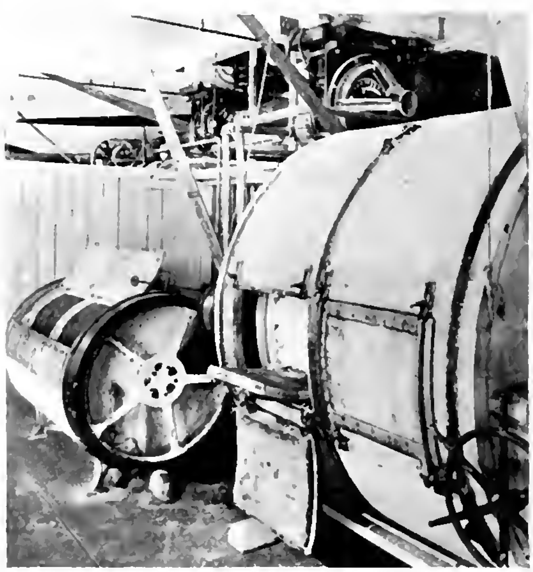


Fig. 4 50 H P. and 75 H.P. Motors in Washing Department

As a large proportion of the collars are of the turn-down style, it is necessary to iron the reverse side of the tips. This operation is performed very rapidly by the special ironers called "tipping machines." Twelve machines are group driven by a 10 h.p. motor arranged with intermediate countershaft for speed reduction.

The examination and packing of the finished materials play an important part in the production of a uniform quality of goods. Much of this work is necessarily done by hand, but the wrapping and labelling of boxes is largely taken care of by the box-wrapping machines shown in Fig. 8. Each of these machines has a capacity of about 9,000 boxes per day, completely wrapped and labelled. The motor is rated 3 h.p. and is back-geared to the countershaft from which the machines are driven.

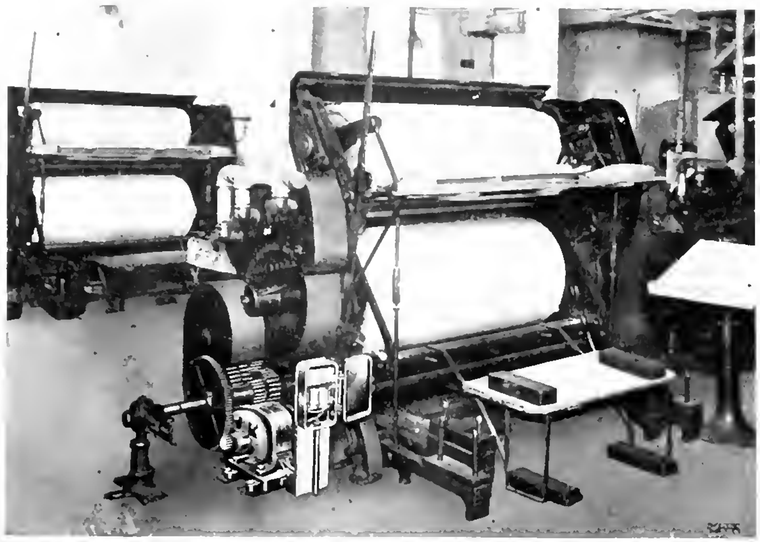


Fig. 6. Collar Ironing Machine Individually Driven by ¾ H.P. Motor

Fig. 7 shows a 1½ h.p. motor geared to a countershaft for operating the fold-shaping machines that perform the final operation before inspection and packing. This motor arrangement gives unusual freedom from dust and dirt and occupies a minimum amount of space; these features ac ounting for its general application to small group drives.

Fig. 5. Collar Dampening Machines in Laundry

Besides operating the machines engaged in the manufacture of shirts and collars, electricity is used for power for a variety of factory machinery. Ten motors totaling 88 h.p. are used for the operation of as many elevators. Two of these motors are of the slip-ring type arranged for electric control, while the remainder are in continuous operation with mechanical control.

The machine and carpenter shops are electrically driven, as well as the printing department. Ventilation is an important factor in a factory of this size, and approximately 70 h.p. in motors is employed in driving exhaust fans. A vacuum cleaner is installed in the engine room, with pipe connections to various parts of the factory, to facilitate the removal of dirt and inflammable dust. This outfit is driven by a 20 h.p. motor running at 1200 r.p.m.

The lighting is done almost entirely by tungsten lamps, in 60, 100 and 250 watt sizes. An interesting feature of the lighting arrangement is shown in Fig. 2. The sewing machines in the foreground are provided with adjustable brackets and five

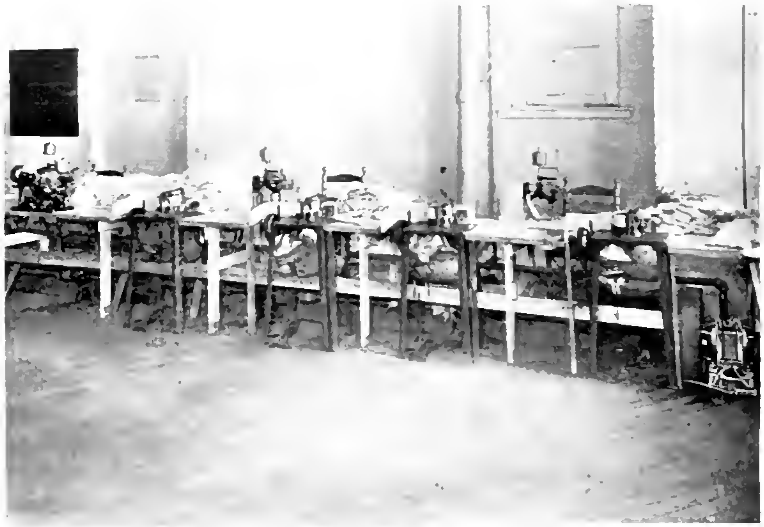


Fig. 7. ½ H.P. Motor Driving Fold Shaping Machines in Laundry

watt, 10 volt tungsten lamps, while the current is supplied by lamp transformers similar to those used in sign lighting. All sewing machines are to be similarly equipped, thus eliminating the swinging drop cords now used.

GENERATING UNITS

Rating	Volts	Driven by
ATB- 2-625-3600	240	Turbine
ATB-72-450- 100	240	Direct connected Harris Corliss
ATB- 8- 75- 900	240	Belted Fishkill Corliss
C- 2- 25-3600	125	Turbine
MPC- 6- 20-1200	125	Direct connected induction motor

INDUCTION MOTORS

Operating	Number	H.P.
Stitching	55	163
Washing machinery	2	125
Laundry machinery	22	35¼
Cutting machinery	5	18
Stamping machinery	3	6
Elevators	10	88
Printing and box making	7	26
Exhaust fans and blowers	19	71½
Wood working	4	31
Machine shops	4	16
Miscellaneous and spares	13	82½

The combination of a steam turbine unit with squirrel cage type induction motors gives unusually satisfactory service in a factory of this kind; the source of power is reliable and the motors maintain a uniformly constant speed particularly suited to factories where adjustable speed is not required.

The accompanying table gives in general the distribution of the motor equipments to the different departments. The electrical appa-

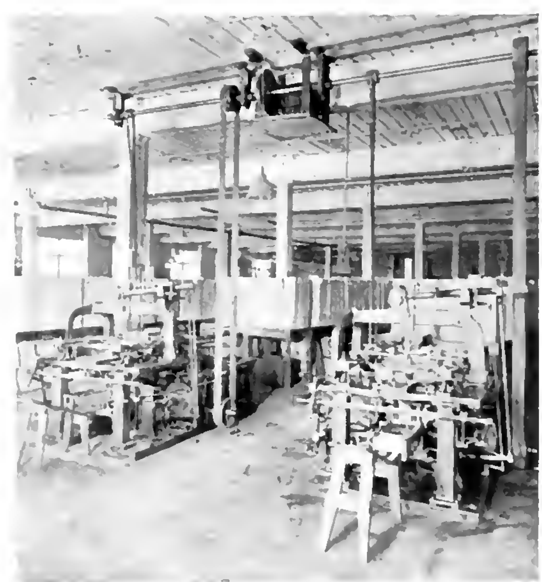


Fig. 8. Box Wrapping Machine in Packing Room

ratus throughout the factory, including the generating equipment listed below, was furnished by the General Electric Company.

LUMINOUS AND FLAME ARCS VERSUS OPEN AND ENCLOSED CARBON ARCS FOR STREET ILLUMINATION*

By W. D'A. Ryan

Illuminating Engineer, General Electric Company

I wish to present graphically the relative illuminating values of certain direct current series lamps available for street lighting, and to emphasize particularly the advance in the art through the introduction of the large unit luminous and the low amperage flame arc lamps.

The use of candle-power curves and illumination charts in their application to lighting problems is playing a more important part than formerly, and it is only a matter of time when those who wish to study illumination must be capable of interpreting such diagrams. Now, it is true that a common difficulty encountered by those who are not familiar with the study of curves is due to what might be termed psychological opposition. At first glance the characteristics appear complicated and technical and are not immediately intelligible, and that usually settles it. In reality they are very simple and not difficult to analyze, and if you will free your mind from this adverse feeling you can readily interpret the following diagrams.

The subject of relative operating costs is greatly influenced by local conditions and forms a distinct commercial problem apart from the lighting power of the units. Such analysis will not be attempted in this paper.

Lamps

The lamps under comparison are as follows:

9.6 ampere carbon open arc, 50 volts, consuming in practice from 450 to 500 watts; commercially rated at 480 watts; equipped with clear globe and no reflector. Electrode life 16 to 20 hours. This lamp is normally designated as 2000 c-p. This rating, however, is regarded merely as a trade name and is not an indication of the illuminating value.

6.6 ampere carbon enclosed arc, 70 to 75 volts, consuming in practice from 450 to 500 watts; commercially rated at 480 watts. Equipped with light opal inner globe, clear outer globe and street reflector. Electrode life 100 to 150 hours.

4 ampere luminous arc, 75 to 80 volts, consuming in practice 300 to 320 watts; commercially rated at 310 watts. Equipped with clear outer globe, internal concentric diffuser, and magnetite electrode. Electrode life 150 to 200 hours.

6.6 ampere luminous arc, 75 to 80 volts, consuming in practice from 495 to 530 watts; commercially rated at 510 watts. Equipped with clear globe, internal concentric diffuser and magnetite electrode. Electrode life 75 to 125 hours. (Large unit.)

6.6 ampere Boston flame arc, 75 to 80 volts, consuming in practice from 495 to 530 watts; commercially rated at 510 watts. Equipped with 26 in. concentric diffuser and light opal outer globe. Electrode life 20 to 25 hours. (Large unit.)

Lamps	Amps.	Volts	Watts	Hs. C.P.	Watts per Hs. C.P.	S.C.P.	Watts per S.C.P.	Total Lumens	Downward Lumens
Open arc	9.6	50	480	813	.59	540	.89	6800	5100
Enclosed arc	6.6	70–75	480	505	.95	310	1.55	3900	3180
Luminous arc	4	75–80	310	523	.59	276	1.12	3500	3300
Luminous arc	6.6	75–80	510	1328	.38	718	.71	9000	8300
Flame arc	6.6	75–80	510	2964	.17	1821	.28	23000	18600

The 9.6 ampere open arc is familiar to all, and in order that the relative candle-power and illumination values of the other lamps can be readily appreciated this unit is herein used as the common basis of comparison. Additional general detail can be obtained from the above tabulation.

Polar Curves

Fig. 1 is commonly known as a polar curve sheet and illustrates the characteristics of distribution, showing the intensity of light given in different directions.

The light thrown in a horizontal direction is indicated where the curves intercept the line running horizontally through the center of the chart. By following this line from the center out you can read directly the candle-power of the respective lamps. The candle-power projected vertically is indicated on the vertical lines.

* A paper read before the National Electric Light Association at St. Louis, Mo.

The candle-power at any desired angle can be read by noting where the curves intercept the spherical lines; for example, the curve representing the old open arc touches the horizontal line at about 300 c-p.; at 45° it is at a maximum registering 1250 c-p. It approaches the vertical line at 100 c-p. We can therefore readily see that there is not much light thrown in the vicinity of the horizontal and consequently a relatively large amount of light would not be projected to a great distance from the lamp. The strong light at 45° indicates a bright band of illumination on the street not far from the pole, while the weak vertical illumination indicates a shadow below the lamp.

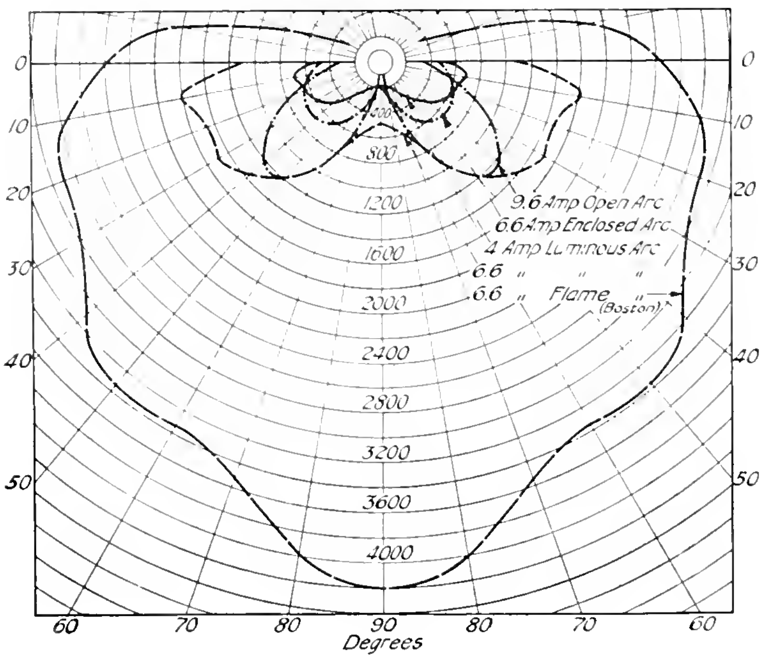


Fig. 1
Candle-Power Curves

Now, it will be observed that the enclosed arc gives more light than the open arc between the horizontal and 10° below, where it must go a greater distance; relatively less light at 45° or thereabouts; and a stronger illumination in the vicinity of the vertical. This indicates more light going to the distant points, not so strong a band near the lamp, and better illumination in the immediate vicinity of the pole. These conclusions are borne out in practice and are largely responsible for the fact that this lamp has superseded the open arc, notwithstanding that the latter gives a greater total luminous flux.

We next observe the four ampere luminous arc, with a strong peak at about 10° below the horizontal and a more gradual reduction of light from this point to the vertical, showing another advance in the art on the basis of distribution favorable to street illumination.

The 6.6 ampere luminous arc has the same excellent characteristic as the smaller unit of the same type, but is vastly higher in efficiency and not only gives stronger light in the vicinity of the horizontal, but at 45° an illumination equal to the old open arc.

The Boston flame arc has a somewhat different characteristic, but gives vastly increased candle-power at all angles over the other units in comparison. While this is an index of what the lamp is doing in the present stage of development, the characteristic and efficiency may undergo certain changes, either for the purpose of increasing the life of the electrodes or improving the distribution, and should not be regarded as final.

I would like also to explain that while the polar curve is useful in studying the relative directions in which the light is thrown, it is liable to mislead the interpreter in comparing the total volume of light delivered; not only because the lamps are of different wattages, but because the area enclosed by the curve is not a correct measure of the flux of light. In other words, it would appear by looking at this chart that the flame arc was giving four or five times as much light as the 6.6 ampere luminous, when in reality it is giving only about twice as much. If we wish, however, to study the total amount of flux, or light sent out by the lamp, we must resort to the spherical or hemispherical chart.

Spherical and Hemispherical Chart

The average candle-power given by a lamp in all directions, or in the lower hemisphere, is not a true index of its value as a street illuminant; nevertheless, comparisons on this basis are useful as an indication of the flux available. This comparison is given in Fig. 2.

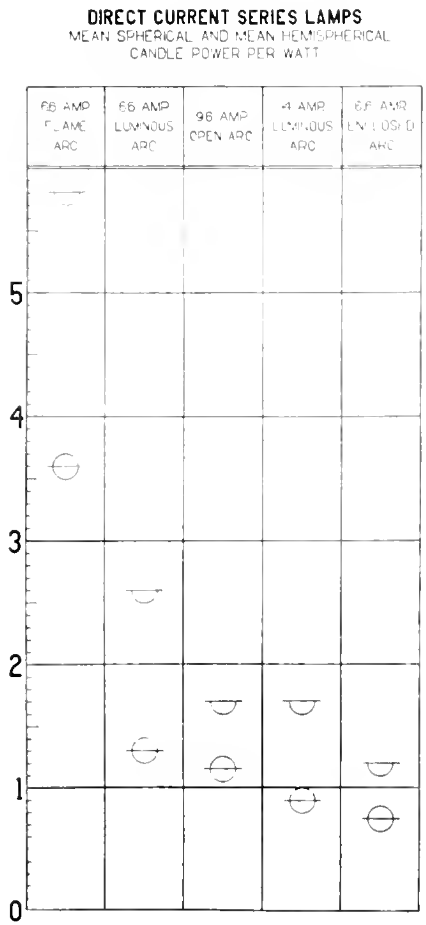


Fig. 2

Without going into detail as to how spherical candle-power is measured, it is sufficient to know that if we surround a lamp by an imaginary sphere and average the candle-powers of the light source projected to every point of the sphere, we will have the spherical candle-power, and this divided by the watts consumed by the lamp will give the spherical candle-power per watt.

$$\frac{\text{s.c-p.}}{\text{watts}} = \text{s.c-p. per watt.}$$

Likewise if we should average the light in the lower hemisphere, that is, below the horizontal, we would have the lower hemispherical candle-power (commonly known as hemispherical candle-power), and by dividing this by the watts we obtain the hemispherical candle-power per watt.

$$\frac{\text{hs.c-p.}}{\text{watts}} = \text{hs.c-p. per watt.}$$

In the chart the spherical candle-powers are given for lamps without reflectors, and the hemispherical candle-powers for lamps with street reflectors as ordinarily employed. You will observe that the spherical candle-power of the open arc, for example, is represented by a circular disc and the hemispherical candle-power by a semicircular disc, and that the candle-power per watt values can be read directly from the column on the left. It is interesting to note that the open arc gives 1.2 s.c-p. per watt as compared with 3.6 for the Boston flame arc; and 1.7 hs. c-p. per watt as compared with 5.8; showing in both cases approximately three times the flux per watt for the Boston flame arc.

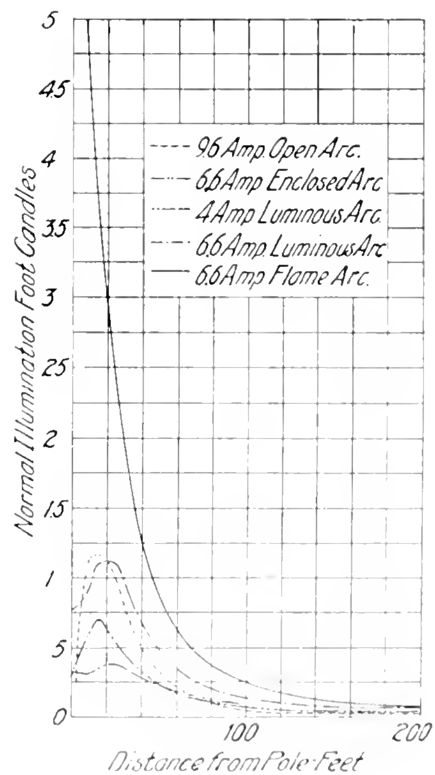


Fig. 3

Foot Candle Curves

Having studied the characteristics of distribution and the relative spherical and hemispherical efficiencies, we may now devote our attention to the illumination obtained on the street. This is illustrated in Fig. 3. These curves are calculated from the polar curves

The enclosed carbon arc lamp shows less illumination at 20 feet and crosses the open carbon arc at about 80 feet. From this point on it gives relatively more light.

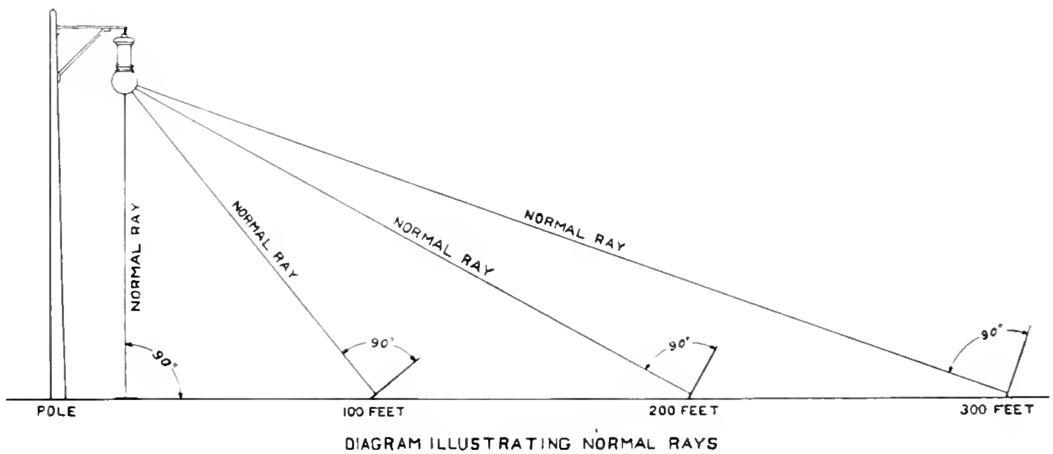


Fig. 4

(Fig. 1), and represent the intensity falling upon surfaces normal to the rays of light to distances up to 200 feet from the pole. The normal ray is the light striking the surface at right angles to its plane, as illustrated. This was taken, after careful consideration, for street comparisons in preference to light falling on the horizontal surface, since it is the more useful light in illuminating objects, obstructions or irregularities in the street (see Fig. 4).

A foot-candle is the intensity of illumination that would be obtained from a light having the strength of one candle falling on a surface perpendicular to the ray one foot from the source.

The distances from the pole are recorded at the foot of the chart, while the foot-candles for the different distances can be read from the intensity figures on the left. These results are based on arcs suspended 25 feet above the street, the measurements being made about 5 feet from the ground.

At a glance you will observe that the open arc gives a strong light about 20 feet from the pole. This falls off rapidly at a distance of 100 feet.

The 4 ampere luminous is more subdued in the vicinity of the pole and stronger beyond 80 feet.

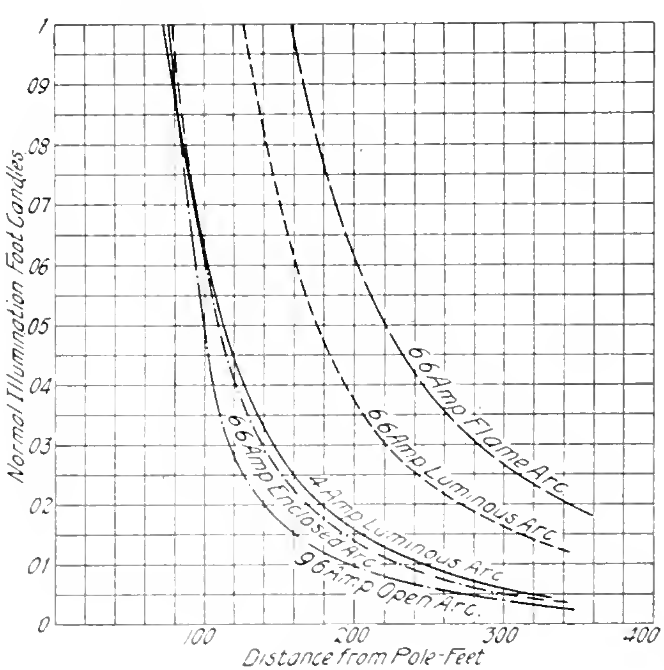


Fig. 5

The 6.6 ampere luminous gives about the same illumination near the pole as the open arc, but relatively increased light at all points beyond. The Boston flame runs to 6.7 foot candles near the pole and throws stronger illumination to distances where it is most needed.

While Fig. 3 is clearly readable up to 100 feet, the relative intensities for distances beyond can not readily be interpreted on account of the smallness of the scale, which is unavoidable owing to the wide difference of intensities from the pole to 400 feet. The 100 to 400 foot interval is in reality the fundamental basis of our comparison, and a large scale of this section is shown in Fig. 5.

I call your attention to the merging of the lines of the open arc, enclosed arc, and 4 amp. luminous arc lamps, at 80 feet or thereabouts. From this point on the open arc falls off rapidly, showing the diminishing

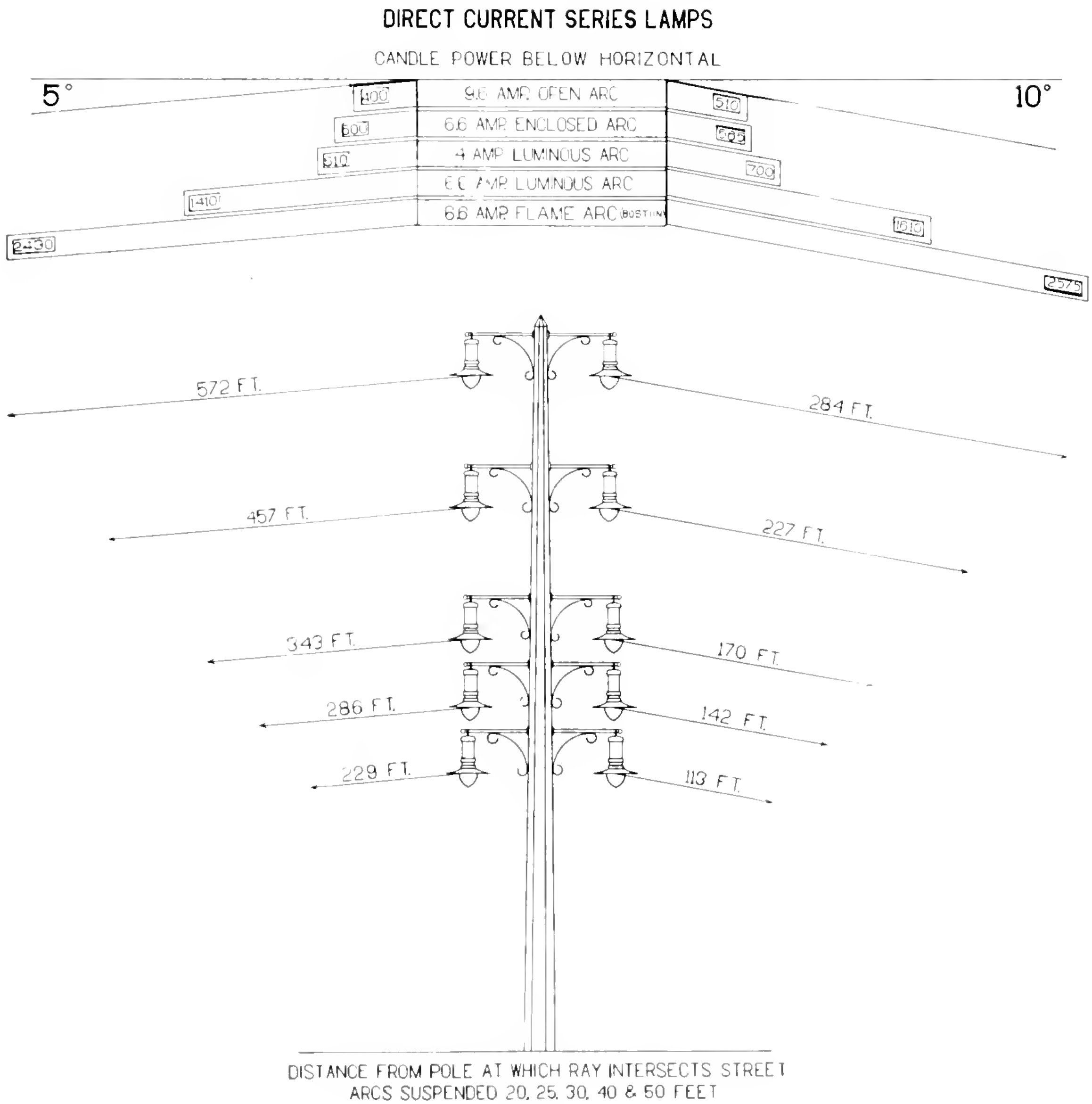


Fig. 6

intensity as contrasted with the light from the other lamps. At 250 feet the relative foot-candles are as follows:

Open carbon arc = 0.006
Enclosed carbon arc = 0.008
4 ampere luminous = 0.010
6.6 ampere luminous = 0.023
6.6 Boston flame = 0.039

Height of Lamp

It is common practice in America to place lamps anywhere from 18 to 20 feet above the street, the limitation being determined largely by trees and other light intercepting objects. Where it is possible, the average height should be increased to 25 or 30 feet for intermediate units, such as the open and

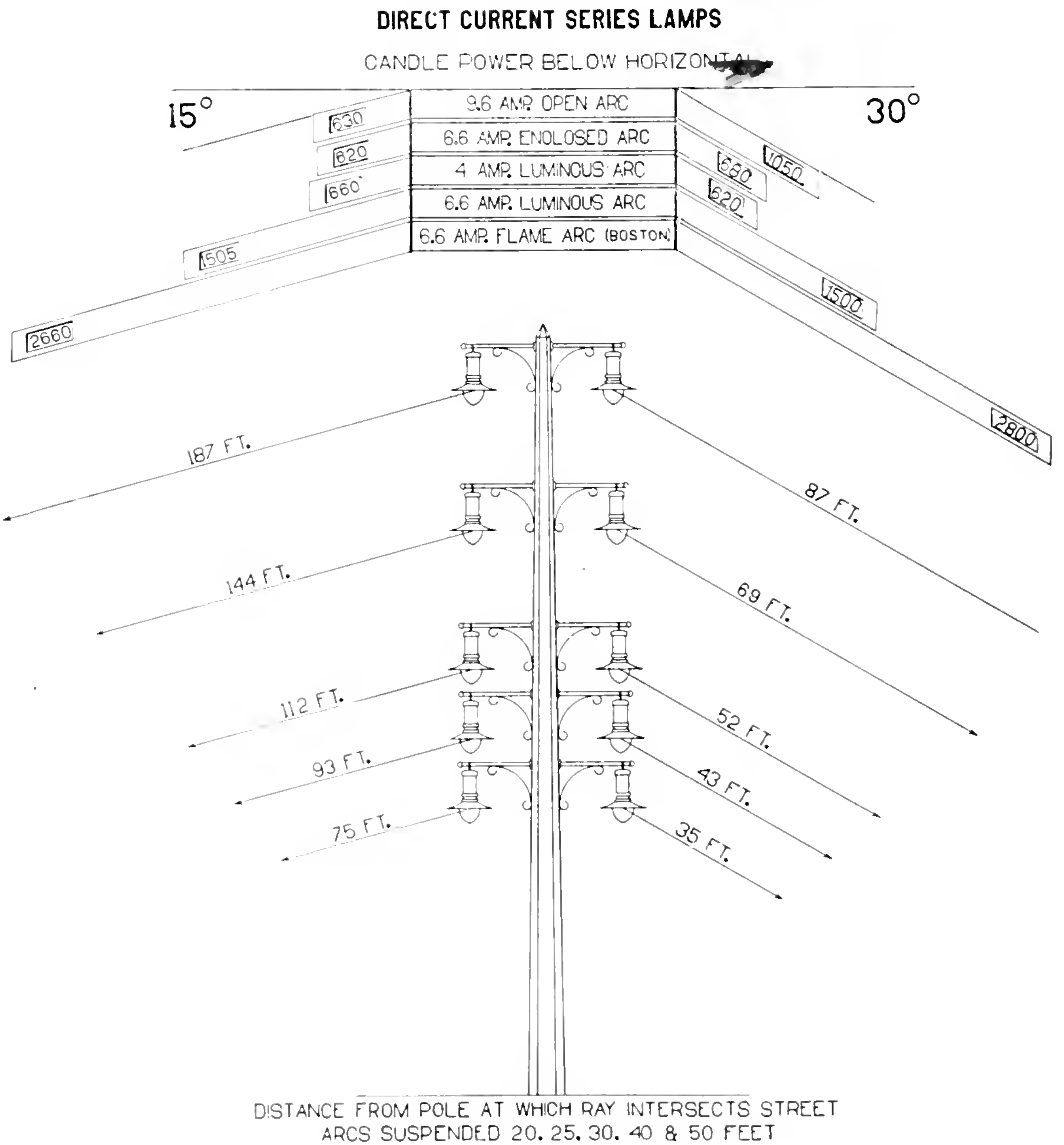


Fig. 7

enclosed carbon arcs and the low current luminous lamps; and 30 or 50 feet for large units, such as the 6.6 ampere luminous and the Boston flame arc. This not only removes the light further from the direct line of vision but reduces the intensity near the pole and projects the useful light to a greater distance.

A ready means of comparing the relative candle-powers and resulting intensities for different spacings and heights of lamps is furnished in the elevation candle-power chart, Fig. 6. As an illustration: assuming we have open arc lamps spaced at 300 foot intervals and 25 feet high, and wish to know how much we would increase the illumination half way between the lamps by substituting Boston flame arcs: we refer to the chart and find that at this height the 10° ray of light would strike the ground at 142 feet, this being approximately one-half way between the lamps mentioned. The open arc projects 510 c-p., while the Boston flame arc projects 2575 c-p., or approximately five times the light. Inasmuch as the distance is fixed, the intensity at the point midway between the lamps would be directly proportional to the candle-power; that is, we would have five times the illumination. The comparisons for the other lamps are obtained in the same manner.

Now, if the lamps are spaced 600 feet apart we use the left of the chart and find that the ray in order to strike the ground approximately 300 feet from the lamp would be projected 5° below the horizontal, and in this comparison we find that the Boston flame arc is giving approximately six times as much light at the intermediate point, and so on.

For making comparisons of lamps spaced at shorter intervals, refer to Fig. 7, which is similar to the foregoing chart and gives the light falling at 15° and 30° below the horizontal.

Area Lighted for Equal Minimum Illumination

While it is true that street arcs are employed largely for linear lighting; that is, up and down the street, there are many cases where open squares, parks, or other places must be illuminated, and a comparison of the area over which the various lamps will project a given minimum light is interesting and valuable.

Area diagram, Fig. 8, illustrates that an open arc at 250 feet radius will throw a certain minimum illumination covering a circular area that may be taken as unity. Now, compare with this the area over which the other lamps project the same minimum illumination. We find that the Boston flame will light a circle having a radius of 625 feet, or approximately six times the area of the other lamps falling within these limits.

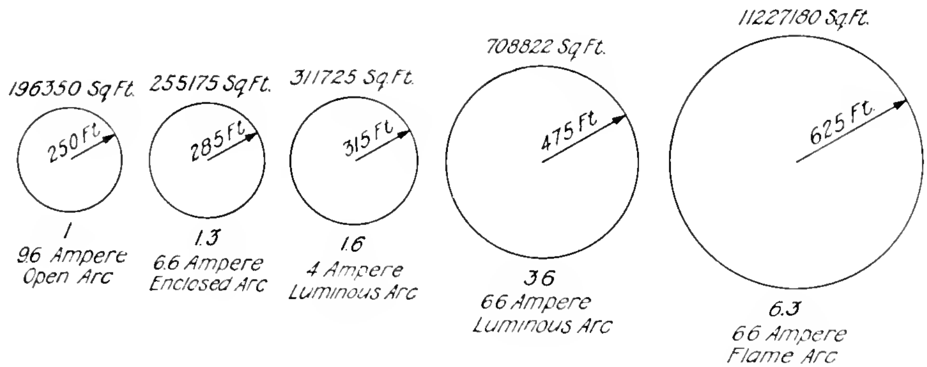
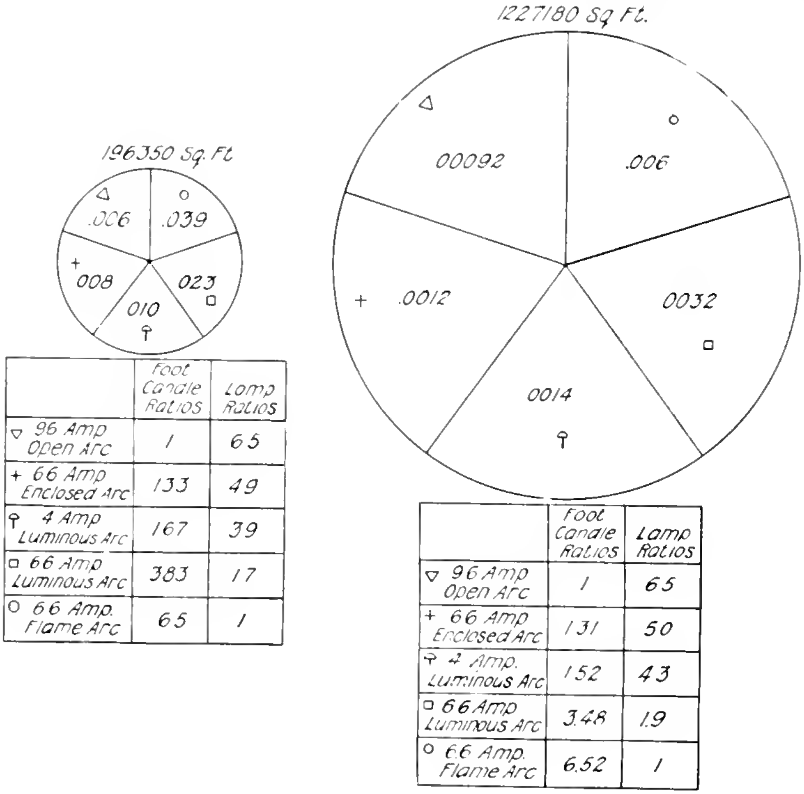


Fig. 8. Areas Lighted for Equal Minimum Illumination. Basis: Open Arc at 250 ft.

It is not an uncommon condition to find lamps spaced 500 feet apart, as represented by the smallest disc, and in many cases 1000 to 1200 feet apart as represented broadly by the largest disc. This shows that the public has been more or less satisfied with making one lamp light anywhere from 5 to 28 acres; at least the lamp would be doing this if placed in an open space.

In the lighting of European cities the wattage used per linear foot of street will be commonly found to exceed our practice anywhere from two to three times, and the light, owing to the nature and size of the units employed, is in excess of this.

While there is a strong tendency in all directions to improve our street illumination, the improvement must be very great before we can approach anything like extravagant lighting, particularly in residential or suburban districts, where we have hardly advanced beyond what might be called "path-finding" illumination.



	Foot Candle Ratios	Lamp Ratios
▽ 96 Amp Open Arc	1	65
+ 66 Amp Enclosed Arc	133	49
⚲ 4 Amp Luminous Arc	167	39
□ 66 Amp Luminous Arc	383	17
○ 66 Amp. Flame Arc	65	1

	Foot Candle Ratios	Lamp Ratios
▽ 96 Amp Open Arc	1	65
+ 66 Amp Enclosed Arc	131	50
⚲ 4 Amp. Luminous Arc	152	43
□ 66 Amp Luminous Arc	3.48	1.9
○ 66 Amp. Flame Arc	6.52	1

Fig. 9
Normal Illumination in Foot Candles at 250 and 625 ft. from Pole. Arc 25 ft. High

Foot-Candle Values for Equal Distances

In Fig. 9 the sector disc on the left shows that the open arc at a radius of 250 feet (500 foot spacing) gives a peripheral illumination of 0.006 foot-candles, while the Boston flame lamp gives 0.039 foot-candles—an illumination of $6\frac{1}{2}$ to 1.

The sector disc on the right shows the open arc at 625 foot radius (1250 foot spacing) as giving 0.0009 foot-candles, or an illumination equivalent to one candle at 33 feet, and the Boston flame as giving six and one-half times this illumination. While this intensity is absurdly low, it indicates, as previously stated, the requirements that we frequently place upon the lamps.

The relative illuminating power of the various units for distances of 250 feet and beyond is given broadly in the lamp ratio figures, indicating the number of lamps required of each type, if massed at one point, to equal one Boston flame arc, as follows:

6.6 ampere Boston flame arc . . .	1 lamp
6.6 ampere luminous arc	2 lamps
4 ampere luminous arc	4 lamps
6.6 ampere enclosed carbon arc . .	5 lamps
9.6 ampere open carbon arc . . .	7 lamps

It should be understood that these comparisons represent the relationship of the lamps under laboratory conditions and do not take into account the inherent variations incident to commercial practice. Furthermore, by referring to Fig. 1 it will be observed that a slight change in the number of degrees in the vicinity of the horizontal in some of the lamps makes a big difference in the candle-power. In other words, we are working in what might be called critical angles. At the best these distance comparisons should be regarded as only roughly approximate and should not be used as a basis upon which to draw contracts.

X Values

At the 1907 meeting of this Association, specifications for street lighting were established to supersede the specifications of 1894. In order to determine the relative values of different arc lamps in service, extensive tests were made on a large number of lamps in various cities. The measurements were taken at a distance of 250 feet from the pole and are naturally more accurate than the estimated values calculated from photometric curves and differ from them, being generally lower.

Briefly, the X value indicates the relative strength of the light as compared with a standard 16 c-p. incandescent lamp at a fraction of the distance. An arc lamp, for example, having an X value of 4, gives the same light as a 16 c-p. incandescent lamp at one-fourth the distance, and a lamp having an X value of 5 gives the same illumination as the 16 c-p. incandescent lamp at one-fifth the distance; the measurements, of course, being made in accordance with definite given specifications.

By referring to the X value chart, Fig. 10, you will observe the vertical column giving an X value of 4 for the open arc. The highest lamp measured in the test is indicated by the upper triangle directly above the column; the lowest lamp by the triangle on the face of the column. The top of the column represents the average finally selected and this, as you will note, is considerably less than the average of the highest and the lowest lamp.

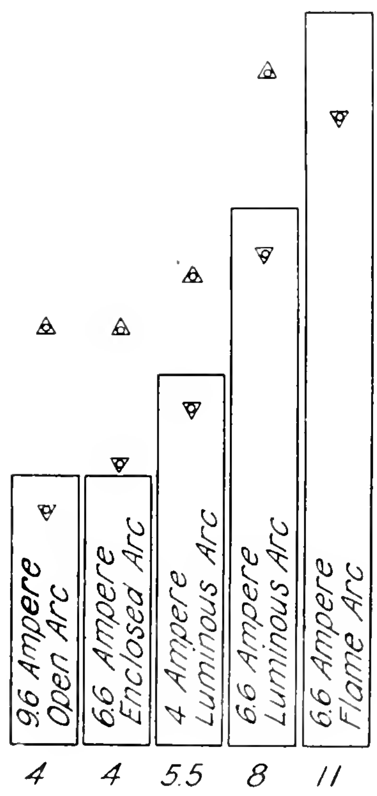


Fig. 10
Comparison "X" Values

The 6.6 ampere enclosed carbon arc taking the same energy as the 9.6 ampere open carbon arc, which it has practically superseded, shows the same maximum as the open arc, but a higher minimum and consequently a higher average. In order, however, to mini-

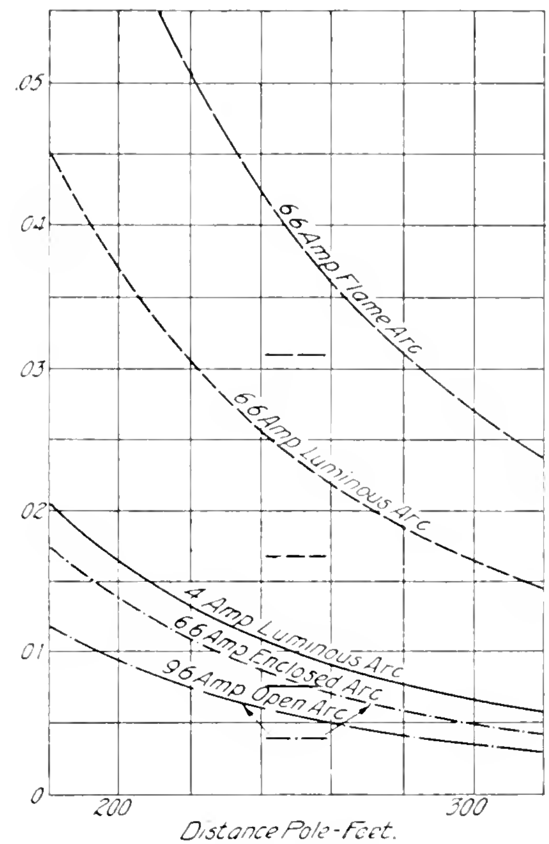


Fig. 11
Foot Candle Values

mize the number of standards it was given the same X value as the open arc, namely 4.

The 4 ampere luminous lamp has an X value of $5\frac{1}{2}$. This was the largest unit in use at the time the specifications were made.

If we should treat the 6.6 ampere luminous on the same basis, it should be credited with an X value of 8, and while it is rather early to determine the value of the Boston flame lamp we have given it a temporary value of 11. In the course of development this may vary one way or the other. It is not intended to suggest that these readings be included at the present time, but they are interesting by way of comparison on the X value basis.

Fig. 11 is a comparison of the street illumination tests and X values with the laboratory candle-power results. It serves to show the variation in units. The X values, represented by the short horizontal lines, generally fall below the foot-candle values calculated from laboratory tests.

This should be expected, inasmuch as not only are lamps but incandescent, gas and all other artificial lights undergo inherent and operating depreciations and changes which have varying ratios between the initial and the average amount of light delivered throughout their useful life.

buildings is quite as important in giving the city the appearance of being well illuminated as the amount of light projected directly on the street surface.

Large units should be placed 30 to 50 feet high and intermediate size units 25 to 30 feet high when possible. Where it is the practice (in the suburbs particularly) to space arcs at very long intervals, it is impossible to obtain good results. In such cases it would be much more satisfactory to use small units, such as

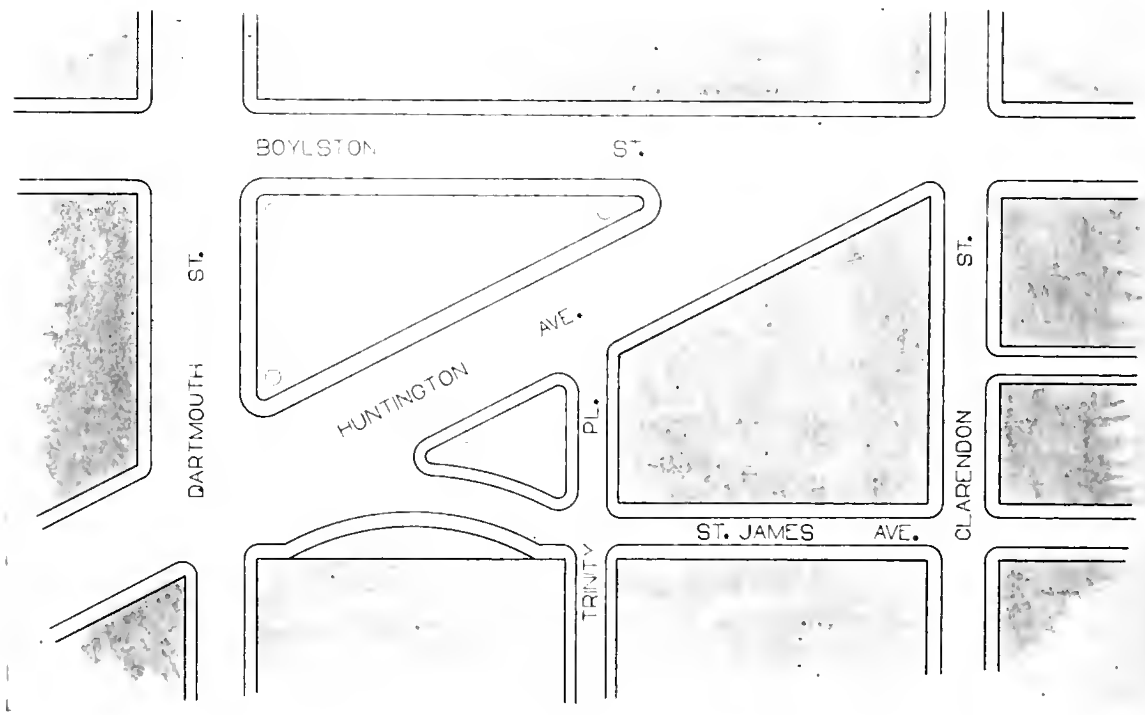


Fig. 12. Copley Square, Boston

Fig. 11 is a diagram of Copley Square in Boston and shows the lighting of approximately five acres by four Boston flame lamps on 50 foot poles. This represents first class practice for the illumination of an open square.

Conclusion

The question of the relative merits of large and small units resolves itself largely into a problem of local requirements and conditions. In general, it is good practice to use large units to light the principal streets of a city. We should not lose sight of the fact that a large volume of light reflected from the

Mazda lamps, at shorter intervals. This is especially true where the buildings are considerably removed from the sidewalk line and do not assist in the general effect by reflection; that is to say, in cases where the direct projection of the light from the source must do all the work.

The knowledge gained from a study of the illuminating strengths of the different lamps is generally useful and can be applied in a measure in determining the size of unit best suited to meet practical requirements. In the majority of cases the location of lamps is fairly well fixed by established practice or otherwise. Lamps are commonly located on street corners and in certain sections possibly one or two in the intervening space.

With present pole spacing a great improvement in the lighting is possible by the substitution of the 4 ampere luminous arc for the open carbon arc and the enclosed carbon arc. In cases where, for aesthetic or other reasons, it is not desirable to further obstruct the street by increasing the number of lamps or poles per mile a still higher standard of illumination can be obtained by substituting the large units herein referred to. While these large units are more expensive to operate and should therefore demand a higher rate per lamp, the increased expense to the city would be relatively low in proportion to the improvement in the lighting.

In conclusion, one of the strongest features of the present condition of the art is that we now have available three high efficiency units which can be operated in series on the same circuit, namely:

The 6.6 ampere luminous arc for lighting the principal streets.

The 6.6 ampere Boston flame arc for lighting parks, squares and other open places.

The 6.6 ampere Mazda units for residential and incidental lighting.

This should encourage and materially assist in a marked advancement and general improvement of our street illumination.

TRANSFORMER OPERATION AND ECONOMY*

By J. L. Buchanan

The importance of low core loss and copper loss, together with good regulation for distributing transformers, has been so frequently brought to the attention of the central stations by the various manufacturers that a discussion of these features would hardly be an interesting topic at the present time.

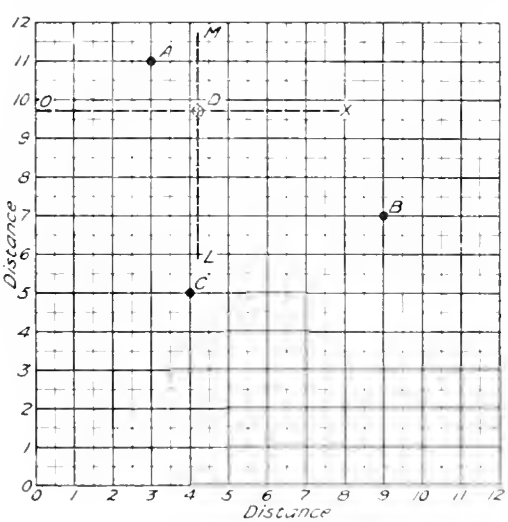


Fig. 1

On the other hand, points concerning location of transformers, selection of capacities and re-location as the system enlarges, have as great a bearing on the economical operation of a system as the characteristics of the individual transformers.

Obviously, the ideal location of a transformer is at the center of its distributing system, this location being determined by the connected load at each point of the system. Practical conditions will always vary this somewhat, as such a point might be on private property; this apart from the fact that the connected load at any one point is not always an indication of the proportion of power used.

A determination of the theoretical center of distribution should be an aid, however, in reaching a decision as to the proper location for a transformer. This can be very easily worked out by the following method:

A diagram should be made referring all receivers to two rectangular axes. Multiply the current to be delivered to each receiver by the distance of the receiving point from one of the axes, and then divide the algebraic sum of these products by the sum of the currents. Next draw a line parallel to the axis used and at a distance from it equal to the above quotient. The center of distribution will lie on this line. A similar computation referred to the other axis will determine a second line which will intersect the first. The point of intersection represents the center of distribution. For example, take the case outlined in Fig. 1.

* Paper read before Kansas Gas, Water, Electric Light and Street Railway Association.

200 amperes at A
50 amperes at B
25 amperes at C

$$\begin{array}{rrl} 200\times 11 & = & 2200 \\ 25\times 5 & = & 125 \\ 50\times 7 & = & 350 \\ 275 & & 2675 \end{array}$$

$$\frac{2675}{275}=9.7 \text{ (thus determining line } OX)$$

$$\begin{array}{rrl} 200\times 3 & = & 600 \\ 25\times 4 & = & 100 \\ 50\times 9 & = & 450 \\ 275 & & 1150 \end{array}$$

$$\frac{1150}{275}=4.2 \text{ (thus determining line } ML)$$

The intersection of the lines OX and ML determine the position of the point "D," which is the center of distribution.

One of the most perplexing problems involving the installation of a transformer is the selection of an economical capacity. If a transformer supplies but one consumer, there must be capacity to carry the total connected load, as the demand may be equal to this several times during a year's service, although under ordinary conditions the transformer may operate at less than one-fourth of its normal output and therefore under a very poor load factor.

A 7.5 kw. transformer will often replace ten 1 kw. transformers when a number of consumers can be conveniently taken care of from one distributing point. Such a change represents a saving of approximately 65 per cent. in investment and also adds much to the efficiency of the system. The combined core loss of the ten 1 kw. transformers would be about 200 watts compared with 62 watts for the 7.5 kw. size. The larger transformer operating at a higher load factor also helps to improve the power factor of the system.

As new customers are added to the lines the center of distribution necessarily changes and a periodical checking of load conditions will often result in the withdrawal of several transformers.

With transformers properly located the question of power factor should be of little concern as regards the transformers themselves. A 5 kw. transformer having a core loss of 15 watts and an exciting current of 5 per cent. would have a power factor of approximately 20 per cent. at no load. A load of two 50 watt lamps, or 1/50th of its capacity would increase the power factor to over 50 per cent. These values would be relatively higher in practice, as the value assumed for exciting current is high; so that a transformer with any load at all will operate at a high power factor.

Considerable savings in transformer capacity can often be effected by the use of compensators, these being applicable in transformations where the differences in the voltages is slight, or where there is no objection to having a metallic connection between the high and low tension circuits.

When used in a two to one transformation, an ordinary transformer operated as an auto-transformer will have its output doubled. The division of currents and the method of determining the capacity of an auto-transformer is shown by the diagram of Fig. 2.

Assuming the losses to be negligible with 10 amperes flowing in at 220 volts, the current in BC must be the current in the 220 volt circuit. This current in BC causes a current of like value to flow in AB and in the direction indicated by the arrow. The currents in AB and BC unite at B, sending 20 amperes into the 110 volt side, which divides at A again. To determine the actual transformer capacity, BC may be considered as the primary and AB the secondary. The voltage across BC multiplied by the current flowing will give the volt-ampere capacity of the primary, which is the actual transformer capacity of the device. In the above combination the transformer

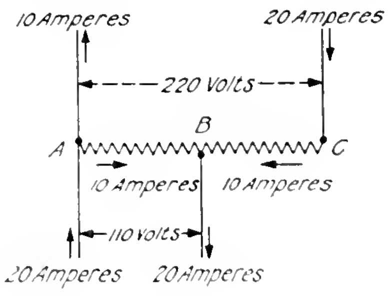


Fig. 2

capacity is 1.1 kw., although 2.2 kw. is being changed from 220 to 110 volts or vice versa.

This use of the compensator is also applicable to the 3-phase 2-phase Steinmetz connection and the saving in capacity by such a combination is very great. This arrangement often has practical value for use in tying 3-phase and 2-phase systems together.

The use of taps to compensate for line drop on distributing systems where transformers remain on the lines continually is not good practice. When the transformer is fully loaded (a condition which may occur only for a few hours in 24) the line drop may be such that the use of a tap gives proper voltage for normal operation. During the periods of partial load, however, the voltage rises, the core loss and exciting current of the transformer are very materially increased and any customers wishing to use current at such times will subject their lamps to excessive voltage. The economical remedy for line drop on a distributing system is to use larger conductors and to add more feeders.

The method of connecting transformers is an important factor in successful operation, especially on three-phase systems. If three single-phase transformers are wired with a Y connection on the primaries and no delta on the secondaries, a triple harmonic voltage will be induced in each. This triple harmonic tends to produce an unstable neutral and causes an increase in voltage which results in a heavy strain on the transformers. A closed delta in a three-phase bank of transformers allows the triple harmonics to dissipate themselves in the delta and the above conditions do not occur. If the customer must operate with a Y connection on the secondary side, the primary neutral of the transformers should be connected to the neutral of the generator. This produces the same effect as the delta connection on the secondaries.

In operating three-phase four-wire systems, however, the neutral of the primary of the transformers must not be connected to the generator if the secondaries are in delta, as any unbalancing of voltages between outside lines and neutral will tend to set up circulating currents in the delta. A slight unbalancing of voltage will cause very heavy currents to circulate and these added to the load current of the transformer are liable to result in a burn-out. If, however, the customer is operating with a four-wire Y connection on the secondary, the neutral of the primary should be connected to the generator neutral.

In other words, the following connections will give successful operation: -

Primary Y—secondary delta—no neutral connection.

Primary Y—secondary Y—neutral of primary connected to generator.

The following connections should not be used:—

Primary Y—secondary Y—no neutral connection.

Primary Y—secondary delta—neutral connection.

Open delta operation of transformers is permissible on voltages below 10,000. Transformers when connected in this way operate at a disadvantage on account of the fact that approximately 15 per cent. idle current flows in the windings, resulting in a higher copper loss and poorer regulation for a given kilowatt capacity. On systems above 10,000 volts, very serious disturbances may result when switching or from arcing grounds. *

In connecting up two banks of transformers for parallel operation on a three-phase system, ten phase combinations are possible, six of which will operate successfully as follows:

Designating the banks as A and B,

	LOW VOLTAGE SIDE		HIGH VOLTAGE SIDE	
	A	B	A	B
1.	△	△	△	△
2.	Y	Y	Y	Y
3.	△	Y	△	Y
4.	Y	△	Y	△
5.	△	△	Y	Y
6.	△	Y	Y	△

The remaining four will not parallel successfully:

7.	△	△	△	Y
8.	△	△	Y	△
9.	Y	Y	△	Y
10.	Y	Y	Y	△

Years of study and experimenting, together with experience in manufacture, have enabled the designer to effect unlooked for improvements and economies in transformer products; yet a proper realization of these efforts to attain a high standard of efficiency and durability will always depend upon the operator.

* While this is the generally accepted opinion, open delta has notwithstanding been used in high tension systems with entire success. Ed.

THE ENGINEER SALESMAN *

By Fred M. Kimball

Manager Small Motor Department, General Electric Company

In treating of the qualities of a salesman and commenting on how, when and where he should perform his duties, I must of necessity go over old ground and reiterate a great many truisms which have been spoken and written by the multitude who have been dealing with this important subject for centuries. One can say little about the subject that is original, and all that I can hope to do on this occasion, is to co-ordinate and bring forward many old ideas—possibly in a "new dress," and I hope in an attractive form. In the small motor department, as well as in some other departments of the General Electric Company, we have a school for salesmen, and to every one pursuing his novitiate we present a written statement in respect to the qualities, the aims and the duties of a salesman, which is as follows:

"A salesman in our business must first of all be a man who possesses good health, correct habits, and a determination to succeed. He must not be afraid of hard work, should have a good technical education, considerable general knowledge, must be thoroughly honest and energetic, and preferably should have had some experience in construction and shop work.

"Preferably, no man should seek to become a salesman in our line who takes up the occupation simply and entirely as a means of subsistence, for in all likelihood he will achieve but mediocre success if he does not fail altogether. Again, the monetary returns during the first few years will, alone, rarely induce a man to put that concentration and labor into the preparation necessary to become a high grade salesman, or subsequently support him in that enthusiasm, activity and persistent effort required to secure the largest achievements and rewards. A prerequisite to conspicuous success in this field is a real liking for and pleasure in the work, and a hearty interest in the occupation for itself.

"The standing and compensation of a salesman are not so much dependent on the gross volume of his sales 'per se,' as on the volume of his profitable sales. In judging the value of a salesman, therefore, we consider the volume of profitable business which he secures; the discriminating economy which he uses in incurring traveling and other expenses; the completeness of his knowledge of the merits, in detail, of the products made by his employer, with their value in comparison with the products made by competitors and his ability to use this knowledge effectively in inducing customers to choose his employer's products, and in maintaining such prices as may be determined by his principals.

"A salesman will also be judged by the promptness, persistence, reliability, tact and generalship he displays in handling business and negotiations entrusted to his care; by his success in holding old and securing new customers, and making valuable affiliations; by his honesty, his loyalty and his exercise of painstaking care to insure completeness and accuracy in all his orders, contracts and correspondence; and finally—and most important as to results—by the new business he actually digs out of the ground. Manufacturers are almost wholly dependent on their salesmen for seeking out and securing new customers and introducing and exploiting new products; but their office forces and clerks can, in large measure, care for the current needs of existing customers and the distribution of well-known and widely used items of their regular manufacture, the merits of which have already been thoroughly demonstrated.

"Salesmen should always bear in mind that the obvious way is the easy way, and almost any man can travel that path. The employer stands most in need of salesmen who are ever alert, who can exercise initiative, discover those possibilities for business which are not immediately obvious, and, when discovered, follow them actively, persistently and intelligently to a successful culmination.

"A salesman should be systematic in laying out and carrying on his work. He should use his time honestly and economically, in the highest grade of work of which he is capable; and to that end, exercise his best judgment in discriminating between that work which requires and justifies the expenditure of much of his own time and that which can be referred to the office force or dismissed with minor attention. He should not allow himself to be overwhelmed with routine, but cultivate the faculty of turning

* "A Talk on Salesmanship" to the Student Salesmen of the General Electric Company at the Harrison Lamp Works, May 27th 1911, by Fred M. Kimball.

the unimportant details of his operations over to the office force with such concise directions as will secure accuracy and promptness in dealing with them. He should aim high in all things and never permit himself to act perfunctorily or get into a rut.

"Every salesman should aim to secure at least one new permanent customer each week, and should make it a point to visit all his customers regularly, and endeavor to present at least one new and definite suggestion leading to increased activities on the occasion of each visit.

"Finally, let the salesman always remember that, other things being equal, the employer is most interested in the man who digs up new and profitable customers and business, who thinks actively, broadly, and to a purpose, and who, thus thinking, initiates, follows up and achieves."

This talk being a very intimate and informal one, I wish to touch on the subject of personal habits. I assume that all the gentlemen before me know how to conduct themselves under any circumstances in which they may be placed; but there are certain points in a salesman's bearing and conduct that merit particular emphasis.

When a salesman visits a customer, he is, for the time being, the embodiment of his employer; and in your cases, your appearance, your conduct and your character, as reflected by your conversation, will be, to the customer, the appearance, the conduct and the character of the General Electric Company. Your action, your speech, and your expressed attitude on all matters of business or ethics, will, in the customer's estimation, reflect the similar characteristics of the General Electric Company, so that it is imperative for you to insure that the reflection be a truthful one. To this end you should be dignified without being unapproachable, cheerful without being volatile, friendly without being familiar, helpful without being officious, polite without being servile, and frank without being indiscrete.

Your first object must be to secure and hold the confidence of your customers, and an exhibition of the qualities referred to above will go far to enable you to achieve this end.

Be brief in your visits, without an exhibition of haste. Emphasize on your customer's mind that your time is valuable, and respect the value of his time as you do the value of your own.

Beware of too much story telling. There is no objection to an occasional story which aptly illustrates a point or carries a moral, but avoid telling any stories that you would not tell to your wife or mother. There is a decided objection to acquiring the habit of telling questionable stories; not only is this habit apt to grow on one, but the man who habitually tells stories of this class must necessarily lower his own moral tone, as well as suffer in the estimation of his best customers.

Be very careful how you entertain. Under no circumstances try to buy a man's confidence or business with dinners, drinks or cigars. When properly used, entertaining is an excellent means of securing closer relations with a customer and cementing friendships, but it should never be offered in a "crass" fashion. I remember that some years ago, when I was Manager of the New England Supply Department of the General Electric Company, one of the concerns from whom we made large purchases sent a new man into the territory. The head of the firm sent me an advance copy of a letter of introduction which had been given to this new salesman, with the request that I give him as much attention and encouragement as possible, on his first trip. Having in mind my own earlier experiences as a salesman, I was glad to make the young man's visit as pleasant and profitable as possible. I therefore asked my Stock Clerk to make up a good order for standard material which we could hand to the young man on the occasion of his visit. We did this with some little hesitation, because it happened that our stock of the merchandise which the young man sold was very complete at that time. In due course the man called, and sent in his card. I sent word that I would see him at once. As he came in at my door, I arose to give him a cordial welcome. In crossing the room, as he extended his right hand in salutation, with his left he drew a large cigar from his pocket and offered it to me, even before he was seated, and notwithstanding the fact that he was not smoking and neither was I. This exceedingly raw attempt at promoting the "entente cordiale" resulted in my cutting the man's visit short, withholding the order, and putting him down, mentally, as a "boor" and a man with whom I did not care to do business. I could not but put the mental question: "Do I look as if I could be bought with a cigar?"

Of all varieties of entertaining, perhaps the most innocuous is the invitation to lunch or dinner. For myself, I rarely, if ever, offer any entertainment to a customer unless there is a most obvious reason for so doing, until our negotiations are substantially completed, or until they are at least pretty well advanced. I adopt this course because I do not wish to cause my prospect any embarrassment, nor give him any cause to feel that I am trying to put him under special obligation, which might possibly lead to a lack of straightforwardness on his part.

If you are to meet a customer for the first time and feel that a little suitable entertainment may serve to "break the ice," select the proper hour for seeing your man, tell him your time is limited and your engagements pressing; you wish to spend as much time with him as possible, and as you both must lunch or dine, you will be pleased to have the pleasure of his company in order to utilize both his time and your own to the best advantage. If a prospect accepts an invitation of this nature, be modest in your expenditures; do not embarrass him by offering too lavish nor too long an entertainment, and devote your conversation to matters of general interest until the meal is approaching its end. To offer a very elaborate menu or expensive wines, or to plunge immediately into business is exceedingly bad form on such an occasion.

A salesman should always be considerate of the best interest of a customer, because in the long run, the interest of the customer is the interest of your company and of yourself.

Never sell a customer an article that you have good reason for believing will be unsuited to his use, until you have cautiously called his attention to your doubts, and your reason therefor. Avoid urging a customer to overstock.

Never misrepresent any article you sell, but always remember that the best way to serve the interest of your employer is by acting fairly, squarely and honestly toward the customer.

In respect to bearing and dress, remember that appearance really counts for a great deal. Stand erect, walk smartly, do not loll in your chair, be alert. It is not necessary to be a fop, but it is essential that you be neatly dressed, and that your clothing and your linen be clean and whole. A salesman bedecked in spotted clothing, dirty linen, uncleaned shoes and disarranged necktie, cannot impress a prospective customer very favorably, no matter how pleasant his conversation or how valuable his offerings may be. Try to keep yourself, as they say in the army, "well set up." Be well dressed, but not over-dressed.

Avoid anything conspicuous in your action, your speech or your clothing. If you were selling horses, you might well wear clothing so loud in design that your coming would be known before you were seen; but quiet, neat and unostentatious dress should characterize salesmen who represent a company possessing the standing and dignity of the General Electric Company.

Never take liberties with your customer or presume to be too familiar with him. Do not assume to know him so well that you can enter his office while smoking, or begin smoking without asking permission. Do not help yourself to a seat without an invitation, unless your friendship is of long standing; do not handle his books and papers, monopolize his desk and chairs; do not gossip with his stenographers, or otherwise indulge in similar familiarities.

Be very careful that you never put yourself under obligation to your customer, for once under obligation, you are always at a disadvantage in dealing with him, both in your individual capacity, and as a representative of your employer.

Be candid; and while you should under no circumstances permit an injustice to be done to the reputation, the product, or the finances of your employer, you should not quibble with customers about trivialities, and under no circumstances attempt to justify a self-evident defect in service or material. An attempt to excuse a fault in order to avoid the trouble necessary to remedy it and set the customer right, is to indulge in a very dangerous policy. Your employer wishes honestly to give every customer a full dollar's worth of service or material for every dollar which is received therefor; and to haggle about the cost of making good a self-evident defect, or to protract a settlement unduly, will frequently be the cause of alienating a customer, if many times repeated.

In similar manner, a salesman should never permit himself to be stampeded by unsupported claims in respect to poor service or defective goods. He should never take concessions until he has carefully investigated the cause for complaint, and satisfied himself that it is legitimate and has occurred through no fault of the customer.

In commenting further on the methods to be adopted by a salesman, I will quote a few excerpts from an address to a body of motor salesmen, which I made not long since, and the gist of which is equally applicable to lamp salesmen.

"A salesman should never approach a prospective customer until he has first made a careful survey of the undertaking to be accomplished for his prospect. It is well to make an inspection of any premises where an installation is to be made, before you interview the proprietor. The possibilities of the situation can be much better sized up during a leisurely preliminary inspection than when in company with the prospective customer, who must necessarily receive the principal share of the salesman's attention on such an occasion.

Again, valuable pointers may frequently be obtained from the workmen or other employees, if the proprietor is not present, and the salesman is in no great haste. All this requires time. It is advantageous always to be courteous to subordinates, for frequently they are able to assist a salesman materially with information, indirectly or directly, or even to influence their employer's decision.

The salesman should sketch out a number of alternative plans for making each installation, compare them carefully, criticise each from the standpoint of the purchaser, and finally determine which plan will best meet the imposed requirements at the least initial cost, insure the largest advantages, and be capable of operating at the least expense. He should then marshal the arguments in support of his proposition in due order, and fix them thoroughly in his mind, so that he may be able to answer all the questions which the prospective customer will probably ask, and promptly meet objections by sound and definite statements in support of his recommendations. By so doing the salesman will be able to approach the customer with what we may call a dominant mind. In other words, he will know more about the whole subject than the customer does, and, therefore, be on the defensive as well as the offensive, and at a distinct advantage in discussing the proposition.

To prepare for such a campaign requires careful study and patient investigation, and a man can neither do his employer nor himself justice if his mind is distracted by the pressure of other and entirely dissimilar duties.

A salesman should never deal in 'glittering generalities.' He should have his subject so well in hand that he can make definite recommendations and give definite facts, which alone are convincing.

A salesman should never call on a customer when he is not in good bodily health and perfect mental poise. A man with a bad cold or laboring under acute nervous strain, is rarely in the best condition to exercise a dominant influence over the person to whom he is presenting his proposition. There is everything to be gained by making the first attack properly, and a salesman should not only be in perfect condition himself when approaching the customer, but he should be tactful enough to choose an opportune time for introducing his business.

If during a visit a prospective customer shows an indisposition to discuss the matter at issue, the subject should not be pressed to a point where he becomes, in any way, annoyed. A salesman should never allow a customer to say "No!" The moment he thinks that the customer is about to do so, he should immediately change the subject or take his departure. This leaves an opening for returning at another time. Many men, if they once decide against a proposition, will not reopen it, particularly if it does not appeal to them; but if they are never pressed to the point of refusal, the salesman may come back again and again.

One should always acquire his customer's confidence, if possible, before bringing up the main subject of the interview, and it may require several visits to do this. There is always some channel of conversation through which a prospect may be successfully approached. If he will not talk your business at once, then lead up through another subject. Nearly every man has some hobby in which he is interested, and if one can but find out what this hobby is, he may in a reasonably short time pave the way for a better reception of his proposition than if he broaches it immediately. One can usually determine what particularly interests a prospective customer by observing his surroundings. If one sees a bag of golf clubs in a corner, he may be pretty sure that a little talk on golf will be well received. If there is a fishing-rod or a rifle in evidence, an off-hand remark about fishing or hunting may make a good opening. If a roll of films is on his desk, photography may furnish a channel through which the man's attention may be secured. The subject should never be 'thrown' at a prospect with nervous haste or without previous preparation. To do so is frequently to invite a rebuff and a refusal to consider, which may delay further progress for weeks or months.

If the customer has radical ideas of his own in regard to what equipment he needs, he should not be immediately opposed, but be accorded careful attention until he has exhausted his ideas; after which the salesman may gradually and carefully suggest changes and modifications. If the salesman's reasons for proposed changes are sound and well-supported by facts, there is little difficulty in leading the customer to adopt them, for no man will knowingly purchase that which is inadequate for his needs or unduly expensive to install or operate. The shrewd salesman will never assume an arbitrary attitude, nor urge a prospective customer to purchase more or larger equipment than is really necessary; but will rather coax his prospect along by suggestion and gentle persuasion, and induce him to make only such investments or contracts as will be for his real advantage.

It is very necessary that a salesman be acquainted with the largest number of uses to which current may be applied; otherwise he will not appreciate the possibilities which are continually being presented to enlarge his sales along new lines.

A good collection of photographs showing typical installations is of great value in interesting a prospective customer, as well as keeping constantly in the salesman's mind the wide range of uses for electricity. He should also keep copious and systematic notes of his work and recommendations. These, with a scrap book, in which may be preserved clippings describing and illustrating novel uses of electric service, may serve a very useful purpose.

When a salesman is walking about through a city or town he should always be alert to note any latent opportunity for developing a new customer; and with that end in view, should make a mental analysis of the possibilities for the sale of electrical apparatus in connection with the business carried on in every building that he passes. From such a mental analysis he may frequently deduce a latent possibility of introducing electric service, which, if followed up, will yield a customer.

When the initial installation has been made, the work is but just begun. The customer should frequently be visited and a real interest manifested in the success of his undertaking and the satisfactory operation of the equipment installed. Such visits are not only of great value in building up confidence in the salesman and his principals; but they make for better acquaintance, and offer the best possible opportunities of introducing other uses of current or suggestions for extensions of the class of service already being rendered.

As a general rule, it is inadvisable for a salesman to spend too much time in elaborating the technical side of the propositions which he presents to customers. It is better to make the principal argument along the lines of general results to be secured and the ultimate advantages to be gained. As a rule, prospective customers are not so much interested in a technical description of the apparatus with which it is proposed to furnish them, as they are in receiving information as to its fitness for proposed use, cost of operation, or economies to be secured. A vacillating customer may frequently be led to close a contract through a visit to an existing installation similar to the one which he is contemplating. Salesmen, therefore, should keep themselves thoroughly informed as to the success which attends every installation which they make, and the attitude which the owner may be expected to assume when advising a visitor in regard to the satisfaction that he has obtained from electrical service.

When starting a new salesman on his work, I think no better directions can be given him than these:

Be honest in your representations and advice. Make your employer's business your own, and remember that the unreserved approval of satisfied customers is the best asset that both an employer and a salesman can enjoy.

Be observant of every possibility and opportunity for the use of electricity.

Be receptive for every new and valuable idea, every hint and every suggestion for obtaining new business or new customers.

Be enthusiastic: for enthusiasm, tempered with good judgment and joined with accurate knowledge, will surely bring success.

Be aggressive in following up every prospect, and in endeavoring to find legitimate purposes for which every customer may use more electricity.

Be determined that you will achieve the reputation of being the best salesman in the business."

A salesman must not only use his physical eye in looking for business, but must cultivate the use of his mental eye as well. As an illustration of what I mean, I will cite the following instance. A few years since, I visited a large city where the General Electric Company had a selling agency, that considered itself to be very active. The Company felt that the city was not yielding all the business that it should, however, and having occasion to be in that vicinity, I called on this agent. After a very pleasant reception, he volunteered to show me the evidences of his activity in selling motors. As we started down the principal street, he remarked that he was turning by electricity every wheel that could possibly be thus turned, at that time.

We came to a large brick building, four stories in height, with fireproof shutters securely closed. There seemed to be no signs of life in the building, but as we came opposite the first of two doors, I noticed on the sidewalk something which caused me to stop, while my companion, not noticing my halt for a moment, walked on. He soon turned, came back and asked me what I was looking at. I pointed to the sidewalk and suggested that there was evidence of a possibility of using motors in that building. "No," he said, "that building is a store house. There is no machinery in there, and it is used but very little." I pointed out a number of thin parallel ridges of flour on the sidewalk, which showed that barrels had been rolled between the door and the curb. "Now," said I to him, "there is probably flour in that building, and very likely there is a good deal of it. If there is a good deal of it, the upper as well as the lower floors must be utilized for storing it. As a barrel of flour is heavy, there must be some means of hoisting it from floor to floor. If there are hoists, then there is a probable use for motors." As I thus commented, we had walked along until we were opposite the second door which was open; and glancing in, we could see four burly stevedores pulling on the down haul of an old-fashioned rope hoist, with which they were hoisting flour. Further investigation showed that there were several of these rope hoists in the building (which was a wholesale grocery and provision warehouse, well filled) and that manual labor for hoisting was employed altogether. Furthermore, lanterns were used in the darkened rooms. Here was an opportunity for the application of both light and power that my friend had not noticed, although he had been walking by this building every day for several years. His mental eye had not been alert to this particular situation. Having had the opportunity called to his attention, he was able to take active measures for the immediate installation of both light and power.

Having now touched on what I consider to be some of the most important points in the salesman's qualifications and methods of work, I wish to emphasize the importance of ensuring that your capital, which is your knowledge, experience, and particularly your favorable and wide acquaintance, yield the largest and most constant returns; and while I do not minimize the importance of securing new customers, I feel that too little emphasis is usually laid on the necessity for retaining the old ones, and systematically making attempt to enlarge their purchases or secure information from them which will lead to new business elsewhere.

Notwithstanding the expense which we incur to discover new customers, and the activity and labor which supplement it when a new prospect is discovered, it is quite certain that in the absorption of developing new business with new customers a very large and profitable field, and one which is directly at the salesman's hand, is frequently overlooked, or at least unexploited to anything like the extent to which it is capable. I refer to the additional business which may be secured from those who are already one's customers. In the case of these people no advertising and no introduction is necessary. The preliminary visits, the diplomatic phrases and guarded advances frequently employed at a first interview, are not required. We were obliged to gain the confidence of these old customers to a greater or less extent on the occasion of our first dealings; and if our business with them has been properly conducted their initial confidence has probably been strengthened and confirmed, so that we need spend no time in preliminaries but can address ourselves to the matter in hand almost at once without reservation and without diffidence. Furthermore, the old customer will talk with us more freely, allow us more latitude in seeking to develop possibilities where just cause may be shown for urging further purchases, and altogether be more mellow and responsive than the brand-new customer. Too often a salesman, having effected a sale and believing that the customer will afford no more business in the immediate future, not only fails to express an interest in the results which have attended the first business undertaking, but entirely fails to follow up the customer properly thereafter, and thus does not take advantage of what may be a great latent opportunity. If full advantage were taken of all the latent possibilities which exist in connection with or through our present line of customers, we should most of us, I feel sure, be enjoying a very considerably greater volume of business than at present.

If the customer has been induced to light his store or factory, the salesman who closed the contract should make a point of dropping in frequently, not only to felicitate his patron on the improved appearance of his store in general, but an effort should be made each time to pick out and emphasize some special benefit which has resulted from his enterprise, or to draw sharp contrasts with less efficient means of illumination employed elsewhere. A real live interest should also be manifested in ascertaining that all the apparatus furnished is in proper adjustment and operating with the best results. After a time an effort should be made to enlist the customer's interest in other uses of electricity, including any specialties which will contribute to the success of the business in any way. If the inertia of a householder has been overcome to an extent that he adopts electric lighting, the salesman who made the sale should, before his personality is forgotten, or before he loses touch with the customer, approach him again in an effort to develop his interest in electric heating, cooking, the use of sewing machine motors, electrically operated ice cream freezers, washing machines, irons and all other devices which find place in domestic use. It would not be desirable to urge the adoption of all these electrical services at once, but they should be taken up one at a time and as soon as each has been adopted another should be pressed without undue delay. Calls on the women of the household, if properly timed and made by a salesman of easy address, who can enlarge on the value of electrical applications in the household in an interesting way, and who really knows enough of domestic needs to meet the women on common ground, are frequently productive of good results.

I am very confident that the majority of salesmen, especially the younger ones, having sold an equipment of lighting or power apparatus, fail to follow it up in the fullest possible manner, and assure themselves that it is operating to the customer's satisfaction. After such an installation has been made and the customer has paid his bill, not only is it a source of particular gratification to him if the man who sold it is interested enough to come in, once in a while, to ascertain if he is satisfied, and the apparatus or service is continuing to give good results; but, as well, such visits betoken the agent's confidence in the service and apparatus which he sells and beget new confidence on the part of the customer. The display of such interest goes very far to cement friendship and strengthen that "entente cordiale" which must constitute a large part of the salesman's stock in trade. A man who does this can obtain a hearing in presenting a new proposition when a stranger, although provided with the strongest letters of introduction or coming under the most favorable circumstances, would not be heard. Furthermore, a customer thus looked after can, and frequently will, voluntarily give the salesman remarkably good points concerning the wants of others with whom he may be acquainted, or will even divulge a latent interest in some nebulous plan of his own, which he would not dream of disclosing to a comparative stranger, and which still may be crystallized into an order by a resourceful salesman. He will allow the salesman in whom he has confidence to go over his factory or his store and make the most intimate investigations into the additional possibilities for utilizing other electrical devices, and otherwise afford him facilities and opportunities quite out of reach of the new salesman. I think that every solicitor should make it a definite part of his routine work to visit all his customers frequently enough to preserve their close acquaintance and full confidence; and when business is somewhat quiet and routine work diminished in consequence, then is an auspicious time to work over the old ground and take out whatever values have been overlooked or passed by in the rush of past activities.

In closing these remarks, let me reiterate that a man who wishes to become a successful salesman must love his work; be indefatigible in acquiring knowledge of his business in general, and the products he sells in particular; cultivate a conservatively optimistic and cheerful disposition; take a broad view of life; aim high; be strictly honest and ever industrious.

The vicissitudes and trials, the achievements and conquests of one who aims to be a true salesman and therefore a true man, are well summed up in one of Kipling's latest poems, "If":

If you can keep your head when all about you
Are losing theirs and blaming it on you;
If you can trust yourself when all men doubt you
But make allowance for their doubting, too;
If you can wait and not be tired by waiting,
Or being lied about, don't deal in lies,
Or being hated, don't give way to hating,
And yet don't look too good, nor talk too wise;

If you can dream—and not make dreams your master;
If you can think—and not make thoughts your aim,
If you can meet with Triumph and Disaster
And treat these two impostors just the same;
If you can bear to hear the truth you've spoken
Twisted by knaves to make a trap for fools,
Or watch the things you gave your life to, broken,
And stoop and build 'em up with worn-out tools;

If you can make one heap of all your winnings
And risk it on one turn of pitch-and-toss,
And lose, and start again at your beginnings,
And never breathe a word about your loss;
If you can force your heart and nerve and sinew
To serve your turn long after they are gone,
And so hold on when there is nothing in you
Except the Will which says to them: "Hold on!"

If you can talk with crowds and keep your virtue,
Or walk with Kings—nor lose the common touch;
If neither foes nor loving friends can hurt you,
If all men count with you, but none too much;
If you can fill the unforgiving minute
With sixty seconds' worth of distance run,
Yours is the Earth and everything that's in it,
And—which is more—you'll be a man, my son.

USE OF ELECTRIC AUTOMOBILES BY GAS COMPANIES

By J. E. Kearns

A general discussion of this subject naturally divides itself under two distinct headings, principally because of the commercial situation. The first division covers the use of electrically propelled vehicles by corporations whose entire interest is confined to the manufacture of gas, and when used by such companies the motive is primarily business economy, it being found that the power-operated vehicle is less expensive than wagons drawn by horses.

Fig. 1. Electrically Propelled Vehicle, Containing a Motor Driven Centrifugal Pump

The second division deals with the increasing tendency of companies marketing both gas and electricity to use storage battery vehicles for reasons other than purely operating economy; that is, to present to the public a working demonstration of the practicability of electric wagons and thereby stimulate the local use of such wagons. This results in another source of revenue in the sale of electric current for battery charging.

In this article no attempt will be made to set forth any facts on the comparative economy of the commercial electric power wagon versus the horse-drawn vehicle, because almost every case must be studied separately. A few general statements derived from reliable sources after an experience of ten years are nevertheless interesting, the most important of which are:

First: Any vehicle user who can so arrange his work as to keep a motor wagon busy 60 per cent. of the time will find it cheaper than to do the same work with horses.

Second: Motor transportation economies do not necessitate the use of a large number of machines, as many concerns using but one motor wagon find it profitable.

Third: One electric vehicle will, in general, do the work of two horse-drawn wagons, reducing the time of labor on trucking and delivery from 35 per cent. to 50 per cent.

Fourth: Counting every item entering into the cost of operation, results show that the electric commercial vehicle, used instead of horses, will save its cost during the third year of its use and sometimes during the second year.

Fig. 2. Another View of the Electric Pumping Vehicle Shown in Fig. 1

Fifth: The accepted life of an electric vehicle is from 8 to 10 years, based upon the excellent condition of hundreds that have been operating from 6 to 8 years.

The practicability of the modern electric truck for all general trucking, delivery and labor purposes required by the business of a gas company, is best evidenced by the fact that the United Gas Improvement Company of Philadelphia employs regularly at its Philadelphia Gas Works six wagons of 2000 pounds capacity and one of two tons capacity, while the Central Union Gas Company of New York has two 3-ton machines in its service. The New England Gas and Coke Company employs three 3½ ton trucks, while the combined service companies of Oklahoma City, Okla., Lynn, Mass., New Bedford, Mass., Denver, Colo., and others, have long used them with success and economy, for delivering meters, gas ranges, water heaters and cooking appliances. The vehicles owned by the above mentioned companies were all manufactured by the General Vehicle Company of Long Island City, who have kindly furnished us with the cuts appearing in this article and the condensed specifications of their different sized vehicles given below.

Figs. 1, 2 and 3 show an original and novel electric vehicle which this company recently built for the Edison Electric Illuminating Company of Boston. They present very clearly the interesting uses to which similar outfits could be put by other companies. As seen, the wagon carries a motor-driven direct-connected centrifugal pump, which is used for pumping out manholes and flooded conduits. Electric light and telephone companies are using other types of electric wagons, equipped for their various needs with hoists, winches and windlasses suitable for drawing cable through conduits, erecting poles, stretching wires, etc. It seems very probable that before long gas companies will make use of labor and construction

Capacity	1000 LB.	2000 LB.	2 TONS Express Truck		3½ TONS Freight Truck		5 TONS Slow Freighter	
Type of vehicle	Delivery Wagon	Express Wagon	High Seat	Low Seat	High Seat	Low Seat	Beer Truck	Standard Truck
Speed in miles per hour	12	10	9	9	8	8	7	7
Mileage travel on one charge	45	45	45	45	40	40	35	35
Wheel-base	83½"	102"	111½"	111½"	125"	125"	129"	138"
Gauge	55"	60"	61"	61"	65"	65"	66½"	66½"
Overall length	126"	150½"	181½"	166½"	199"	184"	203"	215"
Overall width	67"	72"	74½"	74½"	79"	79"	79"	79"
Clear loading space: width	41"	48"	56"	56"	60"	60"	65"	72"
Clear loading space: length	72"	96"	137"	120"	154"	137"	160"	180"
Clear loading space: height	60"	66"	72"	72"	72"	72"	72"	72"
Height of platform loaded	32"	35½"	42"	42"	40½"	40½"	41½"	41½

wagons electrically operated, equipped with motor driven tools for pumping out street main drips, tapping mains, threading pipes, and performing many similar operations, the necessary power being taken from the storage battery equipment. It may be found necessary, however, when tapping mains, to use a flexible driving shaft in order to keep the motor away from escaping gas.

For general commercial work within its working radius, that is, within the mileage capacity of the modern storage battery, the electric vehicle is found to be far more economical and reliable than the gasolene machine, while its greater safety from fire risks, smooth and quiet operation, freedom from disagreeable odor and dirt, simplicity and greater durability, represent additional advantages of great value.

In considering the second subdivision, that is, the use of electric vehicles by combined gas and electric companies, we shall not consider the large number of companies who are at the present time using electric vehicles for such work as general trucking and motor wagons, repair trucks, construction wagons, wagons for overhead repair and arc light trimming, as they have already found the investment highly profitable by comparison with horse haulage costs. We shall refer particularly to the excellent work being done by electric central stations and combined gas and electric plants, in showing the local merchants the many advantages and economies of motor trucking and delivery.

The prevailing opinion among the merchants is that the cost of battery charging and operation is high. It therefore seems quite evident, in view of the fact that nearly all central stations maintain during certain hours of the day a large unused load, that they could stimulate a local interest by offering a reduced rate to the public for storage

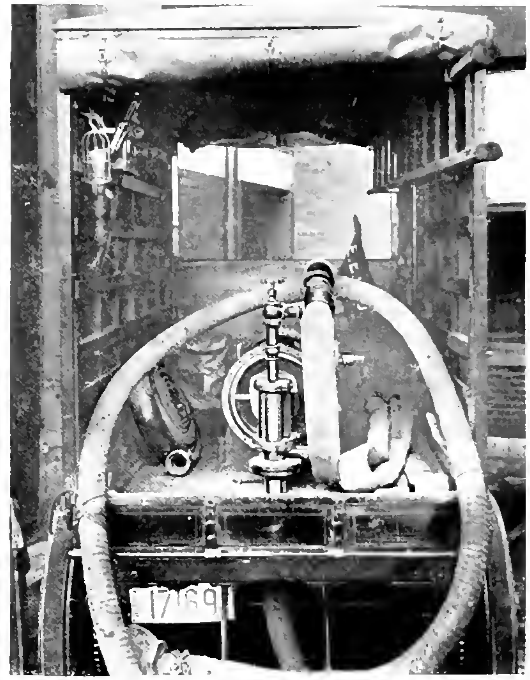
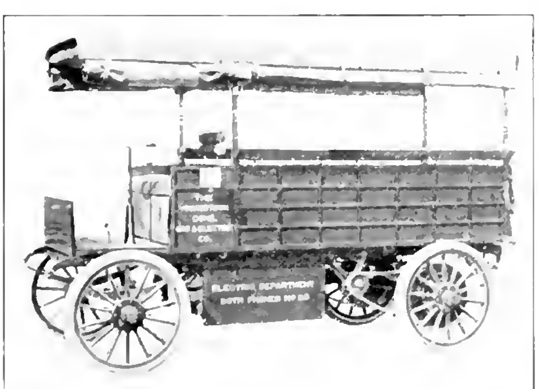
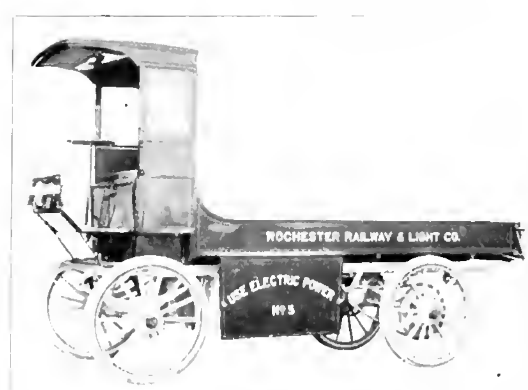


Fig. 3. Near View of Pump and Motor Installed in Vehicle of Fig. 1

battery charging, since they can arrange to charge the batteries at such times as their load is low. This additional revenue would entail practically no expense, as the current, labor and other details are available, and





Figs. 4 and 5. 2000 Lb. Electrically Propelled Trucks every central station could make use of them without an additional investment and practically no increase in operating expense.

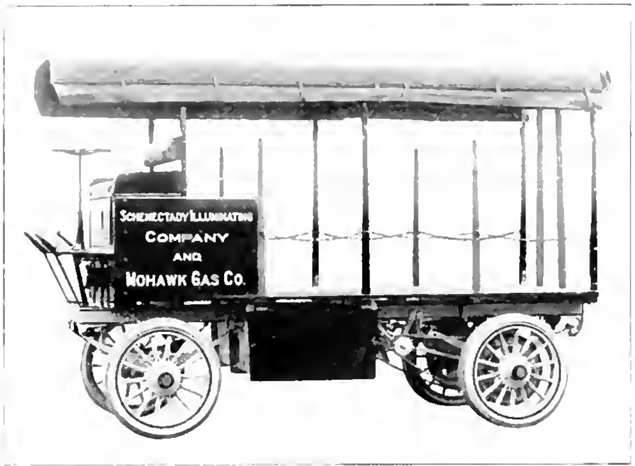


Fig. 6. General Utility Truck, Electrically Propelled

A few statements as to how this may be brought about might be presented. In the first place it should be carefully understood that the average automobile agent trained in the selling of pleasure cars only, is of practically no service in the selling of power wagons. The arguments and methods used in the sale of pleasure cars carry little weight in selling power vehicles and the successful agent must be capable of grasping to the fullest extent the working capacity of the vehicle he offers. The agent must select for the customer the correct size, that is, determine whether it is to be of 1000 pounds, one, two, three and one-half, or five tons capacity, and how many machines of each size will do the work efficiently. In addition to this he must be familiar with the various routes, number of trips, handling of loads, etc., in order to give his customer the advantage of all the savings possible in the use of the electric vehicle. This, one can readily see, is a very different problem from selling an ordinary pleasure car.

In the present state of the vehicle industry the manufacturers can canvass thoroughly only the largest industrial centers and cannot expect to reach every central station, even through the medium of advertising. Therefore it seems that if the central station would take advantage of this additional field of revenue, they will necessarily have to push it on their own initiative, just as they have pushed electric cooking, lighting, motors, etc., and in the case of combined gas and electric companies, the sale of gas and gas ranges. This may necessitate the building of a garage and the organizing of a vehicle department, with inspectors and salesmen of ability; in which case the local agency for some first class vehicle should be secured, and profit derived not only from the sale of power for charging batteries but also from the sale of the vehicle. In this way the interests of the local business men can be furthered by offering them inducements to use electric vehicles that the ordinary local agent would not be in a position to offer.

In conclusion, it only remains to add that in order to obtain the best results it is necessary to have a hearty co-operation on the part of the electric vehicle manufacturer, central station management, the user and the consumer.

Fig. 7. 2000 Lb. Electrically Propelled Truck

SERIES LIGHTING TRANSFORMERS

By J. J. Frank

Within the past two or three years there has been a marked increase in the demand for series incandescent lamps in locations where the only available source of power was a series arc lighting circuit. For the operation of such incandescent lamps in places where the potential of a series circuit is objectionable, there has been developed a new line of lighting transformers designed for series operation. The primary winding is connected in series with the arc circuit, and under all conditions of load on the secondary carries the full current of the series circuit. The secondary circuit supplies constant current to the group of series incandescent lamps. The connections are shown diagrammatically in Fig. 1.

For satisfactory operation of the incandescent lamps it is desirable to obtain as nearly constant current as possible in the secondary circuit. The design of the transformers is such as to secure a regulation of the secondary current within 2 per cent. above or below normal from no-load to full-load. In such a transformer it is also desirable that the secondary voltage shall not rise excessively if the secondary circuit is opened while the full current in the primary winding continues to flow. A drooping characteristic in the secondary voltage has been secured by so designing the core of the transformer that

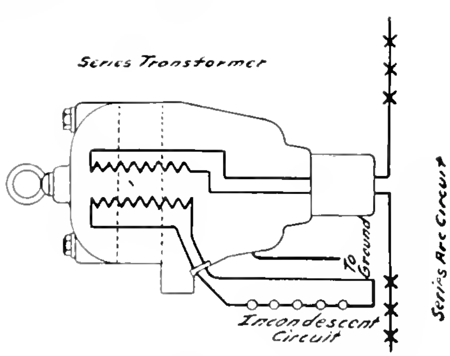


Fig. 1. Diagram of Connections of Series Lighting Transformer

the section of the magnetic circuit is contracted at several points. This permits of saturation of the iron with no current in the secondary winding and limits the open circuit secondary voltage to approximately 150 per cent. of its normal full-load value. A characteristic regulation curve, from a 0.5 kv-a., 5.5 ampere, 1:1 ratio transformer, is shown in Fig. 2.

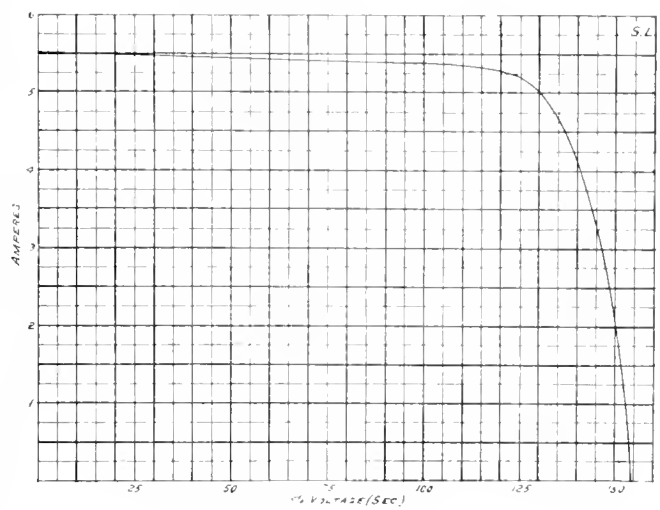


Fig. 2. Characteristic Regulation Curve, obtained from ½ kv-a. 5.5 Ampere Series Lighting Transformer

The general construction of such a transformer is illustrated in Fig. 3. The containing box or case consists of a funnel shaped casting, at the back of which is a shelf or bracket with slots for bolting the transformer to the cross arm of a pole or other support. In the lower end of the box is a large porcelain bushing through which pass the primary or high tension leads in a double conductor rubber insulated cable. The secondary or low tension cable is brought through the back of the case beneath the overhanging bracket.

The coils are form wound, and after being insulated are assembled together with the secondary placed on the inside of the primary. The primary winding is insulated from both secondary and core to withstand a test of 20,000 volts. The core forms the central outside surface of the transformer and is surmounted by the cover, in the top of which is an eye bolt for convenience in lifting. After the case, transformer, and cover have been assembled and tightly bolted together, the interior is filled with hot insulating compound, poured in through the hole in the top of the cover. The windings are thus encased in a solid mass of insulating compound, which assists in conducting the heat to the outside surface.

Fig. 3 illustrates the standard outdoor construction. The transformer may be converted into the so-called "subway" type by changing the construction of the primary and secondary bushings. Fig. 4 illustrates a 40 watt subway transformer, showing the metal bushing by which connection is made to the lead armor of a subway cable. The secondary cable is brought out through a small iron pipe, the lead joint being made to a copper pipe which is joined to the iron pipe by a standard iron coupling.

Fig. 3. Standard Outdoor Construction of Series Lighting Transformer

Although of recent development these transformers are finding a ready market. The 40-watt transformer, Fig. 5, was developed particularly for the Rochester Railway & Light Company, Rochester, N. Y., who have already acquired some 250 of them for use in connection with their system of lighting fire-alarm boxes by means of 40-watt, 3.5 ampere tungsten lamps. An interesting description of the scheme is given in an article entitled "Lighted Fire-Alarm Boxes in Rochester, N. Y.," *Electrical World*, December 29, 1910.

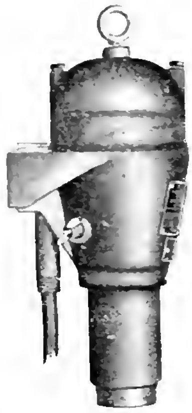


Fig. 5. 40 Watt Transformer for Lighting 3.5 Ampere Mazda Lamps

Wherever these transformers have been installed they have proved satisfactory in operation. Their extension to series arc lighting, where the high potential of the series circuit is objectionable, has widened their application to many problems of rural and interior lighting. Their light weight and self contained construction, with none of the attendant troubles of oil filled transformers, make them desirable wherever such transformers are required.

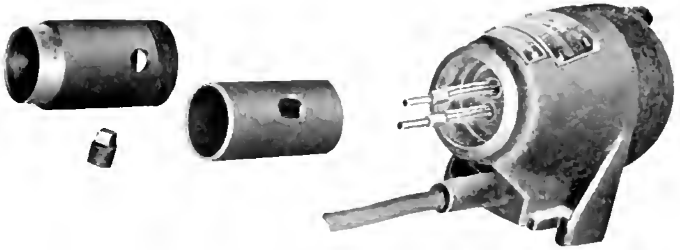


Fig. 4. 40 Watt Subway Transformer showing Metal Bushings for Connecting to Lead Armor of Subway Cable

NOTES

NATIONAL ELECTRIC LIGHT ASSOCIATION

The 1910-1911 session of the Schenectady section of the National Electric Light Association was brought to a close on the 25th April when a meeting was held at which Mr. Willcox, assistant manager of the General Electric Company's lamp works, Harrison, N. J., read a paper on the relation of the metal filament lamp to the illuminating industry. Mr. Willcox, who has recently returned from an extensive tour in Europe and South America, drew many interesting comparisons between the position of the industry in this and in foreign countries. He showed that the development of the metal filament lamp had been of the greatest benefit to every branch of the illuminating industry, and further expressed the belief that it was destined for marked development and extended application in the future.

Dr. W. R. Whitney, Mr. A. A. Anderson and Mr. Arthur Baldwin were among the contributors to the discussion which followed the reading of the paper.

The success of the Schenectady section during the past session has been an index of the general activity of the National Electric Light Association throughout the country. The membership has continued to show a marked increase from month to month, and signs of health and activity are everywhere in evidence; so that the results of the session of 1911-1912, which commences on October 1st, may be looked forward to with the utmost confidence.

The National Convention of the Association will be held at New York during the week ending Saturday, June 3d. The business program includes 16 sessions, at which 24 papers and nearly 40 committee reports will be presented, and the program is in all respects a most impressive one.

During convention week the Schenectady section will be in possession of a suite of offices located in the Engineering Building on 39th Street, and stenographic assistance will also be placed at its disposal. The members of the Section will therefore be fully posted as to the proceedings of the convention, and will be placed in possession of information other than may be obtained through the medium of the technical press.

Very considerable interest will center in the transactions of the commercial section of the Association at the National Convention. Although of recent birth, this section can show a membership of some 700 and it is hoped that by convention week this will have reached the thousand mark; there should be little difficulty in attaining this figure if the advantages of membership are fully realized by all sections of the electrical community. Copious reports illustrated with plans, blue prints and photographs will be presented at the meetings of the various committees. The subjects dealt with include power applications, ornamental street lighting, sign illuminating, residence business and application of electricity in rural districts; and these reports and publications, continued, as they probably will be, from year to year will constitute a compendium of information upon commercial electrical matters of inestimable value to all members of the commercial section.

PRESENTATION OF EDISON MEDAL TO F. J. SPRAGUE

The annual meeting of the American Institute of Electrical Engineers was held on Tuesday evening, May 16, 1911, on which occasion the Edison Medal was presented to Mr. F. J. Sprague for meritorious achievements in the development of electric traction and other branches of electrical engineering.

The program included the presentation of the medal and certificate of award by Professor D. C. Jackson, President of the Institute, followed by several addresses relating especially to those lines of electrical work, the development of which has been largely due to Mr. Sprague's genius.

Mr. W. S. Andrews, consulting engineer with the General Electric Company, was invited to attend the above function as guest of honor, as a graceful compliment in consideration of his early association with Mr. Frank Sprague in central station work.

THE FIRST ALTERNATOR BUILT IN AMERICA

On May 4th, the fourth annual dinner of the Pittsfield section of the A.I.E.E. was held to commemorate the twenty-fifth anniversary of the first commercial application in this country of the transformer and the alternating current generator. Mr. William Stanley, the pioneer of alternating current transmission work in America, delivered the principal speech of the evening, upon the subject, "Our First Alternating Current Plant and How it Started." The keynote of the whole function was naturally one of reminiscence and a number of interesting incidents and experiences were related by the other speakers of the evening—men who in the 'eighties were assisting in the uphill pioneer work, and whose names are now household words throughout the industry.

The souvenir menu issued on this occasion contains a copy of an article written by Mr. Stanley for the *Electrical Review* in February, 1902, in which the author describes his original generator imported from England and his transformers designed for stepping up from 500 to 3000 volts and down again from 3000 to 500. He also tells of the research and experiments upon which he based the design of the first Westinghouse alternator installed at Buffalo in the fall of 1886. This machine normally operated at 490 volts, and had the wonderfully good regulation of less than 5 per cent. when the load was increased from one lamp to full load.

The whole subject was but imperfectly understood and designing was largely a matter of guesswork, but in the early 'nineties transformers were operating up to 10,000 volts. In 1902 Mr. Stanley mentioned that a system was in operation at 60,000 volts and prophesied that, reckoning from that time, the next 20 years would probably witness as remarkable a development as the two preceding decades. Half of this time has not yet elapsed, and it would seem that these prophesies are destined to be fully borne out.

COMING CHICAGO CONVENTION OF THE A. I. E. E.

We have received an advance notice of the forthcoming annual convention of the A. I. E. E. to be held in the Hotel Sherman, Chicago, on June 26th to 30th inclusive. The list of papers to be presented at the convention is not yet complete, but a glance at the partial list is sufficient to indicate that practically every phase of electrical activity will receive expert treatment.

It is many years since the convention has been held in Chicago, although the electrical attractions of the city and its vicinity are exceptional in interest and variety. Due advantage will be taken of the opportunity afforded in this direction, and the program will include a number of visits to these points of interest; various social functions will also be held, and it is confidently expected that the 1911 convention of the Institute will be one of the most successful in its history.

IOWA ELECTRICAL ASSOCIATION

The eleventh annual convention of the Iowa Electrical Association was held in Davenport, Iowa, April 19th and 20th. The opening address of President Crawford was followed by the reports of the various committees. That of the committee on grounded secondaries is particularly interesting and comprises some results of tests made on various grounding devices, including plates of iron, copper and aluminium, as well as piping of various bores, in earth and in charcoal. The general conclusion arrived at would seem to be that galvanized iron pipe is capable of providing the best ground, and also that plates buried in charcoal provide a less efficient ground than when buried in plain Iowa soil.

A number of interesting papers were also presented dealing with such subjects as recording charts for transmission systems, refrigerating considered both as actual central station ice making and also as a central station load, underground distribution, systems of rating, electric automobiles, ornamental curb illumination, industrial heating loads, etc. We have no space here to report these papers in full, but the foregoing will give some idea of the scope included by these contributions.

Particular mention should be made, however, of the report of the committee on facts and factors, as this constitutes a very complete record of Iowa central station activity. The report includes a table showing returns from thirty-one central stations, which should be of the greatest service to all interested in central station economy, as authentic data of this kind is usually hard to come by. The returns are divided up into sections, according to the population of the district served by each individual station. Results for 1909 and for 1911 are given and the tabulated figures include population of districts served, customers per hundred of population, station rating, ratio of station rating to connected load, average load, annual load factor, with further statistics as to investment, gross income and expenditure. Averages for each group are given, as well as the grand averages for all groups. A comparison of the results of 1909 and 1911 show that the station rating per capita has increased very considerably, and Mr. Austin Burt, compiler of the report, draws from this fact the conclusion that the advent of the tungsten lamp has favorably influenced the demand for electric service.

The table referred to is excellently arranged and is reproduced in full by the *Electrical World*, April 27th.

GENERAL ELECTRIC REVIEW

VOL. XIV, No. 7 JULY, 1911

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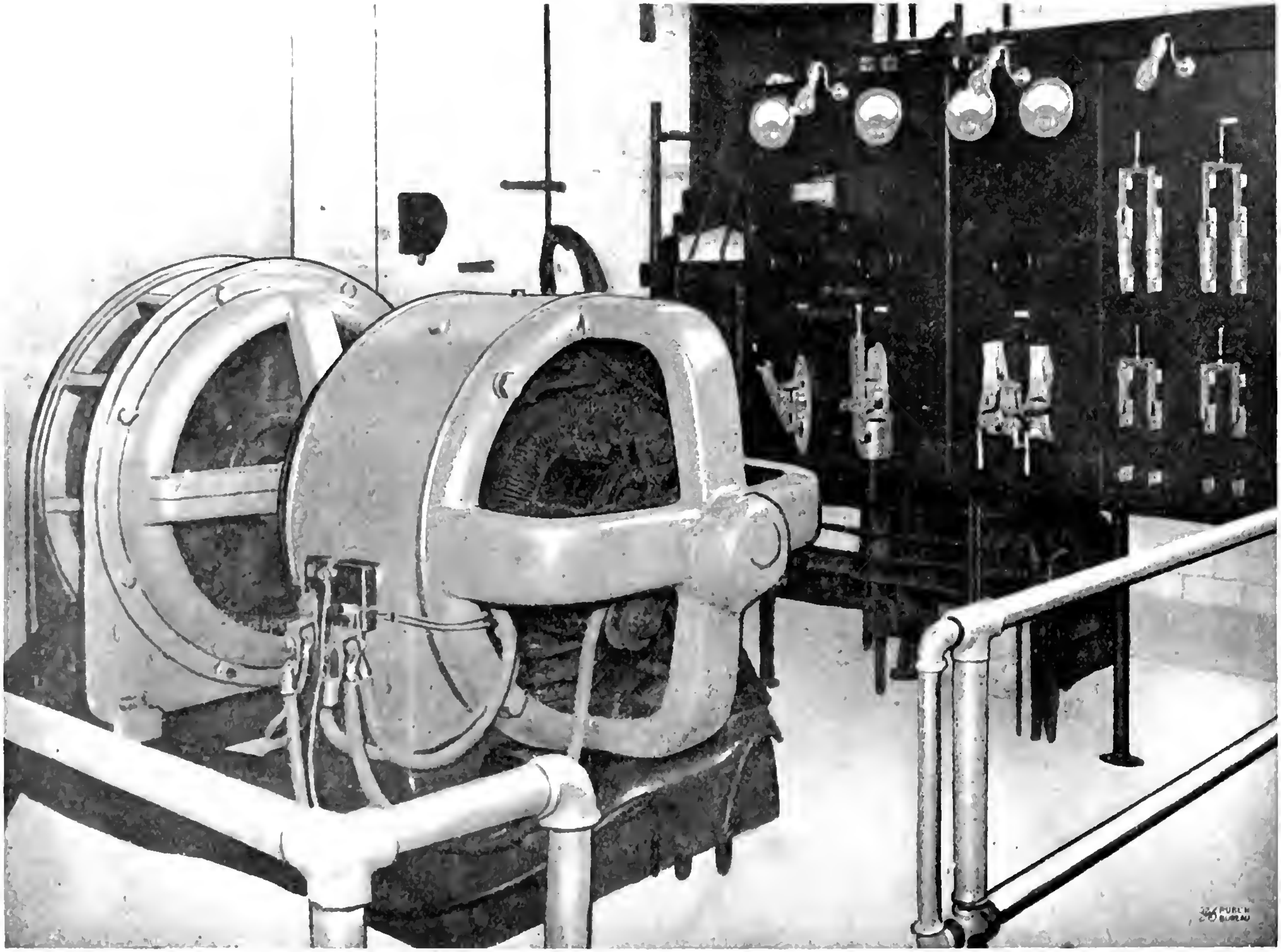

170 Kv-a. Synchronous Condenser Generator Set
(See page 340)

GENERAL ELECTRIC REVIEW

THE CENTRIFUGAL COMPRESSOR FOR CUPOLA USE

Modern processes for the production of all grades of steel have been brought to such a state of perfection that this metal has to a large extent superseded cast iron in many engineering structures and machines. In the opinion of many engineers this tendency has perhaps been carried too far, with the result that steel and wrought iron are often employed for duties which could be performed by cast iron with equally satisfactory results. The problem upon which the iron founder is at present engaged is to obtain a cast iron of a sufficiently high grade as to uniformity, tenacity, hardness and density, to enable it to regain its old position in the eyes of mechanical engineers for certain classes of work—a position which has been usurped by steel or wrought iron, phosphor bronze or other more costly alloy.

Conservatism, or the tendency to cling to traditional practice, has in the past hampered the iron founder's art and retarded its progress; but of recent years greater enterprise has been evidenced, and close attention is now being paid to ways and means of perfecting all the details of the craft which go towards improving the nature of the finished product.

The chemistry of the subject alone requires, and is receiving, the attention of men specially trained for the purpose, and research is carried out to determine the mixture of pig irons which will produce the best results, and the correct percentage of all the various elements in the mixture, carbon, silicon, phosphorus, manganese and sulphur. At the other end of the scale the question of molding constitutes in itself a study for the specialist, and presents a large field for the introduction of labor-saving machines; and although the personal element in this department will always be conspicuous, machine molding is obtaining a wide popularity for a variety of work. The intermediate stage concerns the design and operation of the cupola itself, and any advantage which may be obtained from other refinements may be negatived through neglect of the importance of this stage.

In the operation of the cupola one of the most important points to be considered is the source of power that supplies the air to the fuel; and this brings us to the question of the requirements which must be fulfilled by the fan or compressor, or whatever device is employed for furnishing the driving power of the air supply.

From a chemical standpoint, pressure itself is not required for assisting combustion of the fuel in the cupola, but simply to furnish an ample supply of oxygen; it therefore serves as a motive power for carrying, or rather driving, the oxygen to the carbon in the fuel. From a mechanical standpoint, however, pressure is required, as it serves, to a certain extent, actually to support the charge in the cupola. In order that the operation of the cupola may be steady and regular, it is essential that the charge descend in a regular and uniform manner, and it is therefore important that the air pressure be even and steady. Of all machines that have been devised for supplying the air pressure there is none which is capable of providing this steady action to the extent achieved by the centrifugal compressor. The introduction of this type of machine is of recent date, but it seems certain that the success with which it has already met will ensure its extended application for foundry use in the future. Regarded, too, from the standpoint of efficiency, the centrifugal compressor is a desirable machine. Upon the basis of the ratio between the energy used in the compressor and the quantity of iron melted in the cupola in a given time, this type of machine shows a greater economy than any other known type.

We are publishing on page 309 of this issue a paper by Mr. R. H. Rice, in which will be found a full description of the operation of the centrifugal compressor, and a more detailed explanation of the advantages which are obtained with this type of machine for cupola use. A further point which the author brings out in this paper is that the mistake of over-estimating the quantity of air required is frequently made. The point which is usually lost sight of in such conditions is that all air forced into the cupola undergoes an increase in temperature before it can enter into combustion; and if a greater quantity enters the cupola than can be utilized in combustion, the surplus will simply absorb useful heat and thus tend to retard the melting, besides causing an unnecessary destruction of the cupola's lining.

THE MANUFACTURER AND THE CONVENTION

The thirty-fourth annual convention of the National Electric Light Association was held in New York from May 30th to June 3rd. The growth of the Association was impressively illustrated by the record attendance; but more than this, the presentation of seventy papers and reports, and their unusually thorough discussion, proved beyond question that the serious business of the convention was successfully accomplished; and a mighty impetus was given to the industry through the united efforts of nearly one half of the most responsible central station men of the country, as well as the representatives of the leading manufacturing organizations.

Valuable reports of these proceedings are to be found in the columns of the weekly press and elsewhere, and to attempt further reproduction would require many issues of the General Electric Review. Perhaps we may be excused, however, for adverting to the share which the manufacturer takes in this forward movement. Valuable as are the recitals of practical experience by the operating engineer concerning the behavior of electrical apparatus under service conditions, an equal value attaches to the work of the manufacturer in the design of the apparatus and in the research upon which such design is based; and perhaps the most vitally important feature of a meeting such as the recent New York convention, is the mingling together on common ground of the two parties most intimately concerned in the advancement of the industry, where full opportunity is provided for unrestrained discussion of the problems which have to be faced, and the methods best calculated to solve them.

It is difficult to overstate the importance of such interchange of opinion, and the manufacturer, taking this view point, regards such conventions, in a sense, as the culminating point of the manufacturing year. One of the main planks in the general policy platform of the General Electric Company is co-operation with the central station. Where it has been able to render assistance to the power companies, such assistance, we venture to believe, has been found forthcoming, not only in its contributions to educational data regarding economical operation, but in its policy of doing its share in assisting the central stations to meet competition. In the knowledge that it is able to render material assistance in these directions, the General Electric Company welcomes the conventions where closer relations with the operating engineer may be cultivated, and where it may take stock, as it were, of the electrical situation as it exists at the present time. Further opportunities will be afforded in these directions at the annual convention of the American Institute of Electrical Engineers, which will be held in Chicago June 26th to 30th inclusive, and a preliminary notice of which appeared in our June issue.

The keynote of such a convention is that it represents the latest of everything, and the observer cannot fail to be struck by the fact that here is a record of all that has been accomplished up to the present, with a pointer as to the direction in which energy should be applied in the future. Mr. Hewlett, for instance, in the discussion on Electrical Apparatus, at the third technical session, described the results of experiments which had been carried out at the General Electric Company's Works, on fusible cut-outs for potential transformers on high voltage circuits; these results being obtained within the last few weeks, and thus giving a report of progress made practically up to the time of the very meeting itself. Similarly upon the power transmission question, industrial lighting, transformer design, and in fact upon nearly every phase of the purely technical side of the program, data were provided by the manufacturing engineers embodying the latest results from the laboratory and the test room, such data being indispensable to a comprehensive treatment of each individual question.

We are fortunate in being able to publish in this issue, an article from the pen of Mr. Charles F. Scott, in which he amplifies the view that the manufacturing companies have constituted one of the principal sources supplying the scientific and engineering knowledge, which have formed the basis for the present practice of electrical engineering.

CENTRAL STATION COMMERCIAL ENGINEERING*

By Egbert Douglass

Sale of Electric Service

In recent years the managers of electric light and power companies have come to realize that electric service can be successfully sold only by the same means that industrial establishments employ to market their products. Modern commercial methods are necessary, and no central station today is complete without a well organized force of salesmen.

The gradual lowering of prices for electric service for light and power purposes has opened up new fields for the use of electricity, and as prices are further reduced the field for the application of electric service will rapidly widen.

The development by manufacturing electrical engineers of special lines of apparatus for industrial application, has called into requisition the services of engineers who possess a more or less intimate knowledge of the processes of machine operation for which each particular device is intended; and in order to present to the prospective customer in the most attractive manner the advantages of special electrical machinery for some new process, a type of engineer has been developed known as the engineer salesman. In addition to his technical knowledge, this functionary is required to possess some of the attributes of the successful salesman.

Similarly, in the sale of central station electric service, new problems and special applications are encountered from time to time. The solution of each requires technical knowledge, and the effective presentation of the subject to a prospective customer requires salesmanship. This has led to the development of a new profession known as central station commercial engineering, which includes within its scope illuminating engineering and industrial engineering.

Illuminating Engineering

The ordinary layman is inclined to judge the value of light source by its intrinsic brilliancy, i.e., the effect produced on the eye by looking directly at the lamp, but it must be understood that this is a misleading measure of the value of the light source.

The principal units of measure encountered in illuminating engineering practice are comparatively few, and easily comprehended.

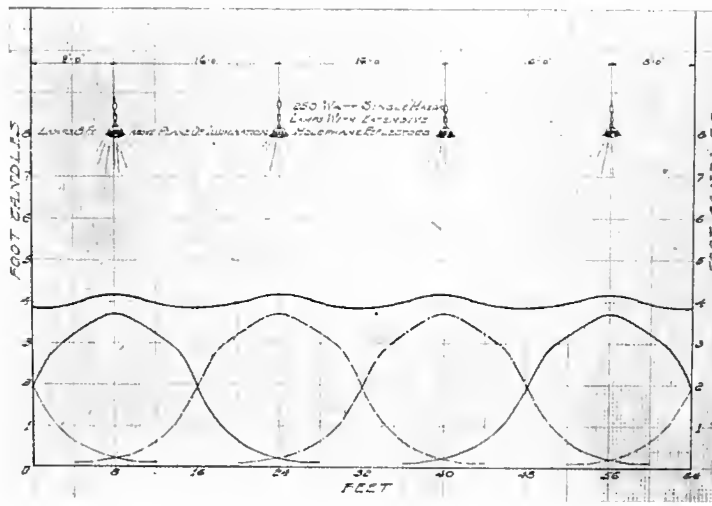

Fig. 1. Distribution of Illumination in Space Lighting. Side of Square, 16 ft. Intensity of Plane of Illumination, 41 foot candles. Watts per square foot, 0.976. Dark Wall and Ceiling

Foot candle is the intensity of light on a point on a plane one foot distant from a light source of one candle-power.

Illumination intensity is measured and calculated on the *plane of illumination*, this being the plane on which merchandise is displayed and sold, or work executed. The plane of illumination varies in different classes of business, e.g., in a drygoods store, the plane would be the top of the counters; in a shoe store, the floor; in an office, the desk tops. In a department store various sets of conditions would be met with in the several sections such as departments for wall papers, rugs, etc. Here the plane of illumination would vary, and the material would require to be illuminated at many angles.

Intensity of illumination on the plane varies materially with the use to which the light is put. A dim light that would be sufficient and satisfactory for a church, would be wholly inadequate for a store or unsuitable for a ball-room, although the tendency to

* Paper read before Salesmen of Milwaukee Electric Railway & Light Company.

exceed the limits of effective illumination and produce a glare should be avoided as carefully as too little intensity.

Intensity may be largely governed by the class of material displayed, color of walls and ceiling, and in the following table will be found intensities which are recommended for various classes of service.

Distribution deals with the arrangement of the various light sources and the determination of candle-power, the object in view being to obtain uniform brilliancy on the working plane or within a given space, rather than the intrinsic brilliancy of the light source. A room uniformly lighted, even though comparatively dim, gives the effect of much better illumination than a room where there is a great brilliancy at some parts and comparatively little at others. Such a condition is undesirable, and unpleasing to the eye.

The curve in Fig. 1 shows the resultant intensity secured in a typical case of space lighting where due attention has been paid to location and height of units and type of reflector used.

Developments with regard to light sources have been very rapid recently from a standpoint of efficiency and color value. This is especially true of the vacuum bulb lamps. The latest refinement in this direction is the tungsten filament lamp, with an efficiency of 1.1 to 1.3 watts per mean horizontal candle-power, and producing about eight lumens per watt (clear bulb). However, this cannot be termed effective lumens on the working plane, as a large percentage of the light is given off on a plane parallel to the lamp filament and must be properly redirected in order to illuminate the working plane.

A large number of types of shades have been designed and placed on the market. Typical curves of the distribution of light in a vertical plane, for three types of holophane glass reflectors, are shown in accompanying curve sheet, Fig. 2, the nominal candle-power of the lamp without shade being 200.

Class of Building	Foot Candles	WATTS PER SQ. FT. TUNGSTEN LAMP HOLOPHANE REFLECTOR	
		Light Walls and Ceilings	Dark Walls and Ceilings
Drafting room	5	1.00	1.25
Factory, general illumination only, where additional special illumination of each machine or bench is provided	2	.40	.60
Factory, complete illumination	5	1.00	1.25
Hotel, halls	1	.20	.30
Hotel, guest's room	2	.50	.70
Hotel, parlors	1.25	.40	.50
Office, waiting or consulting room	1.25	.40	.50
Office, private office or board room (No individual desk lighting)	3	.60	.75
Office, general office or book-keeping (No individual desk lighting)	4.5	.90	1.20
Office, private or general (general illumination only where individual desk lighting will be used in addition)	1.5	.30	.45
Residence, halls	1	.20	.30
Residence, sleeping rooms	1.5	.30	.45
Residence, living rooms	2	.50	.75
Saloons, depending on effects desired	2	.50	.75
Store, book, furniture	3.5	.75	1.00
Store, light-colored fabrics, china, drug, shoe, hardware, etc.	4.5	.90	1.20
Store, dark-colored fabrics, clothing	6	1.20	1.50
Train sheds	1.5	.30	.50
Window lighting	25	5.0	6.0

When the intensity has been determined, the next step in the design of a lighting installation is the question of size and spacing. This is largely governed by room dimensions, height of ceiling and architectural restrictions.

With regard to the size of lamps to be installed, large size units are preferable to small, both in first cost and maintenance, without sacrificing the primary functions of good illumination, while single units are preferable to clusters of equal watt value on the same grounds, and also on the score of simplicity. The cluster method can provide no better distribution or higher intensity than the single unit system, although the latter possesses the disadvantage that failure of a single unit may cause greater derangement of the whole scheme than in the case of the cluster method. Accessibility of lighting units would have considerable bearing in determining which system was the more suitable for a specific case.

For general space lighting such as large stores, etc., it is found that the 250 watt unit equipped with proper reflector gives great satisfaction provided the ceiling is of such a height that even distribution can be obtained. The height above the plane should be at least one-half of the width of the area to be lighted, the limit of which can be approximately 275 sq. ft.

Industrial Engineering

Central Station Industrial Engineering at the present time covers the two broad fields of

(a) Applications of Electric Motors; and
(b) Applications of Electric Heating Devices.

Motor Applications

The application of electric motors to industrial plants has become so universal that to-day there are few fields of industry into

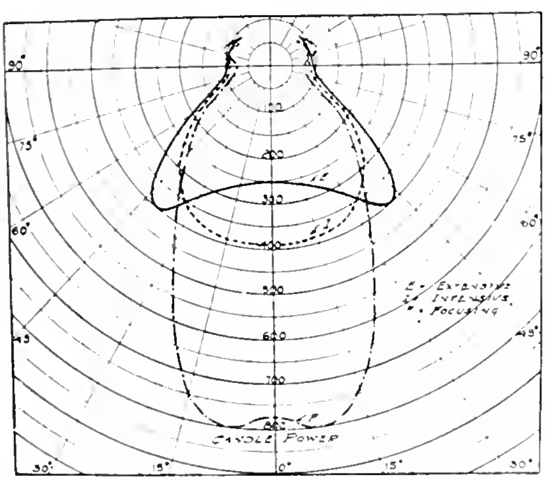

Fig. 2. Characteristic Curves Frosted Bowl 250 Watt Mazda Lamp, with Holophane Reflector

which the electric drive has not penetrated. The expiration of practically all broad patent claims on the design of electric motors has thrown the manufacturing field open to almost endless competition, nd the evolution of the motor has now reached the stage beyond which further refinements are largely a question of detail. These conditions have brought the cost of motors down to the point where their use for factory driving is well within the required limits of first cost successfully to compete with the mechanical drive, which is therefore rapidly becoming obsolete.

At a glance this would seem greatly to simplify the task of the power user in making selection and purchase of the proper factory equipment; but the situation sometimes becomes more complicated for the reason that to the inexperienced user of motors there is a strong inclination to use too many motors and sub-divide the power too far. In this manner the first cost of equipment is readily increased beyond the point of profitable investment. There are industries, however, where individual motor applications are very desirable apart from the questions of saving in power or increase in production. The linotype and monotype printing machines are examples of this, the uniformity of speed necessary for successful operation justifying the use of the individual drive.

Other conditions are met where individual motors are desirable solely on the score of cleanliness. The individual drive, for instance, in a laundry or printing shop makes possible the elimination of overhead shafting and belts, and is thus the means of removing much undesirable dirt.

There are certain applications where the nature of the service would indicate the group method as being preferable, on account of rapidly fluctuating load conditions, but where the nature of the finished product renders it impossible to take advantage of this drive. The ribbon loom is a case in point. This machine takes little power and gives rather an erratic load, and as far as load is concerned, grouping is desirable. The nature of the product, however, is such that belts are undesirable as the frictional electricity from them tends to distort the silk threads and make the fabric crooked. On account of high cost of material, few second grades can be tolerated, with the result that individual motors are here very desirable.

The amount of power is sometimes overestimated, and in the absence of accurate information on average commercial load conditions, plants are often over-motored, and with the desire to play safe, motors are usually too large rather than too small. This is often due to a neglect of the load factor of machines or groups of machines, while in some cases insufficient attention is given to the nature of the plant and character of material used. For example, a 36 in. lathe in a manufacturing plant, used for roughing shafting of low carbon steel and taking two cuts at a speed of 150 ft., will require say 25 h.p. The same lathe in another plant used for finishing or repair work, might only require 3 to 5 h.p.

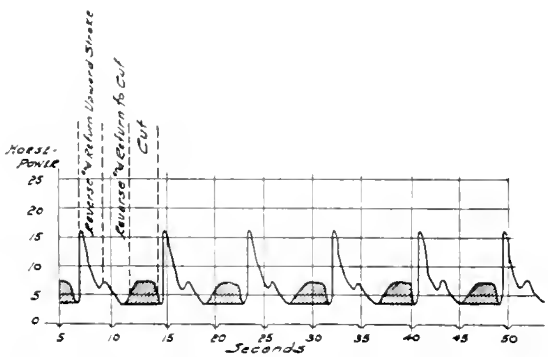

Fig. 3. Graphical Record of 48″ Vertical Newton Slotter taking one cut ⅞″ by 1/16″ feed on Cast Iron, cutting 21.4 ft. per minute. Diagram is made from two curves superimposed. Maximum Power equals 16 h.p. Average Power equals 6.7 h.p. Shaded Portion shows useful work done in removing metal

In large factories where competition is keen, the tools are, as a rule, worked much harder than in repair shops and small plants. It will be realized therefore that the motor requirements are radically different for the same tools in different industries.

The cycle of operation of machines where the duty is intermittent, should also be given careful consideration in selecting the motor to secure proper size and resultant heating.

Let us suppose an application requiring 50 h.p. for 5 minutes and 10 h.p. for 10 minutes; the operation to be repeated every 15 minutes. The average load of the motor is:

50 h.p. × 5 minutes = 250 h.p. minutes
10 h.p. × 10 minutes = 100 h.p. minutes
Total, 350 h.p. minutes
350/15 = 23.3 h.p. average.

This average load will not produce the same heating that the cycle will, for the reason that the copper losses in the motor vary as the square of the current. The root mean square or equivalent heating will be produced by the following:

$50^2 \times$ 5 minutes = 12,500 h.p. square minutes
$10^2 \times$ 10 minutes = 1,000 h.p. square minutes
Total, 13,500 h.p. square minutes

Dividing this by 15 minutes we get the average square of 900, the square[root of which is 30 h.p. This root mean square load value represents the equivalent load which the motor would carry continuously, to give the same heating as the cycle of operations specified above.

In machine tool applications where the cutting is intermittent, such as planers, shapers, slotters, etc., the maximum load almost invariably comes when the reverse is made from the cutting stroke. This is due to accelerating the work or tool carriage.

The central station commercial engineer finds it difficult, with inexperienced motor users, to prevent them in such cases from purchasing motors rated equal to the maximum load.

Again, we find applications when the load is on a motor for, say, an hour to an hour and a half once a day, as for instance a small grey iron foundry cupola. In such a case where the load is taken on by a cold motor, a 20 per cent. or 25 per cent. overload on the motor would be conservative, as the motor would hardly reach its rated temperature by the time the work was finished.

Heating Applications

The general subject of the application of electric heat is divided into two classes, viz.,

(a) Domestic Applications
(b) Industrial Applications

Both these classes of applications of electric heat are now receiving well merited attention from central station commercial engineers, since the former has an important bearing on the financial results of distributing electric energy in a residence district, while the latter sometimes influences the use of central station service in place of privately produced power.

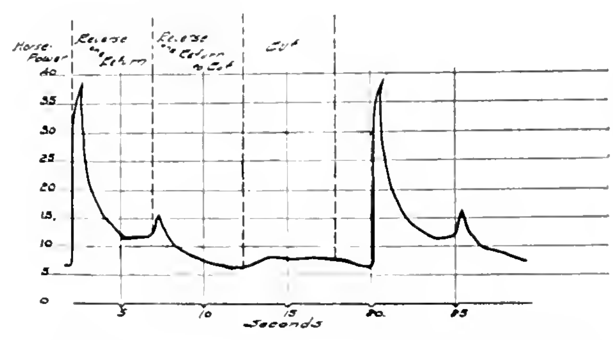

Fig. 4 Graphical Record of Detrick & Harvey Open Side Planer taking cne cut 1/16″ by 36″ with 1/32″ feed on Steel, cutting speed 35 ft. per minute. Maximum Power = 39 h.p. Average Power = 10.9 h.p. Mean Power = 12.4 h.p.

(a) Domestic Applications

The price at which electric service can be profitably sold is dependent largely on the density of the business and the load factor which such business produces. In a city with the residence lighting business only moderately developed, it is probable that the business is being carried out with only a very small return on the investment devoted to such business. This is due to the relatively low density of business, i.e., sale of energy per mile of line, and to the low load factor developed by this class of business. Any use of electricity that will tend to increase the density and load factor of the residence lighting business, is looked upon with favor by Central stations.

The first application of electric heat that found a large application for use in residences was the electric iron. Following closely upon the development of this device, came other heating devices such as chafing dishes, coffee percolators, water-heaters, heating pads and toasters, the most weighty argument for the use of these devices being that of their convenience.

The electric stove or cooker is now assuming a prominent place in the mind of central station operators. Much has been done in the development of the design of such stoves, including considerable research upon a type of stove that would use electric energy at a low rate through a large number of hours each day, store the heat so produced in a heat absorbing medium, such as cast iron or zinc, and give off heat at such a rate as was necessary to perform the cooking process. This method has so far only been applied to that part of the stove in which roasting or baking is done, i.e., the oven.

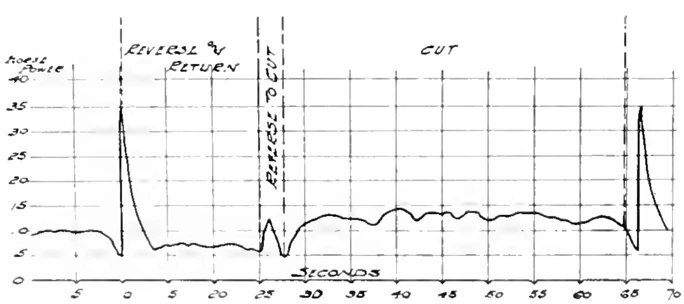

Fig. 5. Graphical Record of Bement Niles 120″ Planer taking two cuts ½″ by 151″ with ⅛″ feed on Cast Iron, cutting speed 22 ft. per minute. Maximum Power. =35 h.p. Average Power = 11.4 h.p Mean Power =12.3 h.p.

Along this line, there has been developed in England the Therol System of heat storage and in connection therewith a few devices for making use of the heat so stored. In these devices the heating elements are embedded in a block of cast iron or zinc which forms the heat storage medium. In the case of the water-heater, the iron or zinc is cast around a coil of pipe into which passes the water to be heated. The insulating medium consists of magnesia, and outside the magnesia a water jacket, etc.

(b) Industrial Applications

Aside from the interest in industrial heating appliances arising out of the extension of the field of central station electric service by their use, central stations are further interested in such appliances, as they in many cases afford a means of assistance in handling the isolated steam plant problem. One of the difficulties often confronting those of us engaged in putting into practice the gospel of central station electric service, is the requirement of a small amount of live steam for heating in some part of the industrial process. In many such cases, electric heat can be economically applied and result in increased output or saving in time, with better factory working conditions.

The field for the introduction of electrical heat for industrial purposes is a wide one and covers an enormous variety of applications in which steam and direct combustion methods are now used The adoption of electric heat presents many of the advantages over the older methods that the electric drive does over the mechanical system of transmitting power. Safety, cleanliness and flexibility are as apparent as in the motor applications. Increased production, improved product and decreased manufacturing costs are also included in the testimony given upon the results obtained by its use.

New industries have been created by the aid of electric heat through processes only possible by this method. Some of the industries which present opportunities for its use are printing and publishing houses, for embossing and matrix drying; paper box industries and furniture factories for heating glue; while in the leather trade it finds a ready application for heating the large variety of tools required in finishing and ornamentation. In laundry work it has been found preferable for ironing even in the natural gas belt; the celluloid industry, the clothing industry and textile trades, are places where its use has been found desirable; while the bakery and confectionery trades are likely fields for its further development.

As an example of the advantages it has over live steam, the newspaper industry for matrix drying may be cited. In this work temperatures as high as 450 degrees fahr. may be safely used, and since time is a vital factor in getting out extra editions, this high temperature is very desirable as it greatly reduces the time required to dry a matrix. To secure this high temperature requires such high steam pressure that the use of electric heat has proved its superiority. The temperature increase with various steam pressures is as follows:

Steam Pressure Pounds per Square Inch	Temperature Degrees Fahr.
125	352
140	361
195	385
235	400
435	456

It is readily seen from the above that prohibitive steam pressures are reached long before the desirable temperatures are approached.

The initial temperature of the matrix drying apparatus can in many cases be secured at times when other power is not being used; which arrangement, under modern rates, secures the energy for the heating at relatively low rates, on account of the fact that the maximum service demand is not increased.

The field is in fact so broad that it is impossible here to treat the matter in more than a very general way; the central station commercial engineer, however, realizes that the solution of the power problem is often to be found in the furnishing of electric heating devices for industrial purposes.

Units of Measurement

While units of measurement are quite generally understood, the application of these terms is sometimes so varied that classification becomes necessary.

Horse power is perhaps the best known generally, and the one that is most used; likewise, the most abused (so far as power costs are concerned). Steam engines are usually sold on the basis of indicated horse power and gas engines are sold on the basis of brake horse power. Motors are sold on the brake horse power ratings and the power and energy to run them are sold on the kilowatt and kilowatt hour basis respectively, which results in the application of the term "horse power input."

Commercially, the terms kilowatt and kilowatt hour have often been used synonymously.

Kilowatt is the unit of measure of power, and kilowatt hour is the unit measure of energy.

Power is the time rate at which energy is exerted, and energy is the exertion of force through distance.

In the commercial application of electric service, equitable and uniform rates are necessary, the adjusting of such rates introducing two factors for fixing the cost of service, one for the amount of power and one for the energy consumption.

These factors bring into use other terms, as follows:

Maximum Demand, Maximum Service, Individual Demand, and Average Demand.

Maximum Demand is the maximum load of a consumer's premises as made up of all the individual or group demands simultaneously.

Maximum Service Demand is the resultant demand of the several individual applications under commercial conditions, and is usually referred to as Maximum Demand.

Individual Demand is the demand of a single motor, whether it be driving a group of machines or a single machine.

Average Demand is the average load in a consumer's plant. It could be ascertained by dividing the consumption of the plant in kilowatt hours by the number of hours the plant was operated during any given period.

Power Costs

The costs of producing power can be divided generally into two groups, viz.,

(A) *Fixed Costs*, which for a given size of plant do not vary with the load thereon or the number of hours during the year that such load is carried. These costs include the following items: Return on Investment, Depreciation, Taxes, and Fire, Boiler and Flywheel Insurance.

(B) So-called *Variable Costs*, which vary more or less with the magnitude of the load and the number of hours during the year that such load is carried. In reality, these costs do not vary directly with either the magnitude of the load or the number of hours such load is carried, but tend to increase at a less rapid rate than output; i.e., the cost per unit of energy output tends to decrease with increasing output. These so-called variable costs may be further subdivided into:

(1) *Fixed Operating Costs*, such as salaries of engineers, a large part of the expense of other labor around plant, fixed fuel consumption of plant including fuel losses through grates, radiation losses from boilers and piping, fixed steam consumption of prime mover, steam consumption of auxiliaries, and maintenance of apparatus.

(2) *Variable Operating Costs*, such as fuel to supply the variable steam consumption of prime movers and lubricating oil.

As a matter of fact, the variable operating costs in a moderate sized factory do not form a very large proportion of the total so-called variable costs. The combination of the "Fixed Costs (A)" and "Fixed Operating Costs (B) (1)" results in a sum comprising a very large part of the total costs of power production. Were it possible properly to distribute the various items of expense between the three items "Fixed Costs (A)," "Fixed Operating Costs (B) (1)" and "Variable Operating Costs (B) (2)," and divide the first two items by the kilowatts demand and the third item by the kilowatt hours of energy produced, it would be found that the demand charge was large and the energy charge small.

Return on Investment

In figuring on the relative cost of operating individual or group drive, steam or gas engines, or purchasing or manufacturing one's power supply, we are inclined to place the rate of interest at 5 or 6 per cent. In the average industrial establishment, money is invested with the expectation of a higher rate or return than the ordinary rate of interest. New industries are not regarded in flourishing condition if they earn less than eight or ten per cent. on the money invested in the plant. In computing therefore the relative economies we should look at our problems from the view point of the stockholder who invests his money and expects a reasonable return thereon. If a reasonable return be eight or ten per cent. we should in comparing economies, figure return on investment at not less than eight per cent. One device might prove the more economical if interest were figured at five per cent. and more costly if returns on investment were figured at eight per cent.

CONTRIBUTIONS OF MANUFACTURING COMPANIES TO THE SCIENCE OF ELECTRICAL ENGINEERING

By Chas. F. Scott

In the opening address at the Pittsfield-Schenectady mid-year convention of the American Institute of Electrical Engineers, I directed attention to the important part which large electric manufacturing companies have taken in the electrical engineering advancement of the country along scientific as well as commercial lines. While these companies are primarily manufacturing companies whose purpose is to produce machinery and electrical appliances and sell them at a commercial profit, they have in addition devoted large amounts of money and effort to scientific research, to painstaking development which converts novel ideas into practical forms; and these companies have been one of the principal sources from which have come the scientific and engineering knowledge which have formed the basis for the present practice of electrical engineering.

For example, the papers which were presented at the mid-year convention were very largely devoted to investigations of various phenomena dealing with the advanced problems of transmission and the protection of apparatus and the like. These are problems requiring the highest skill as well as ability and money for their solution, and all these facilities have been furnished by the manufacturer. The contributions made to the pages of the Institute proceedings by the papers from the General Electric Company at this convention add very materially to the value of these proceedings and to the advancement of engineering knowledge. This is a particular instance; and a review of the Transactions of the Institute will show that a very important part of its valuable papers have been contributed by engineers connected with manufacturing companies.

The rapid development of the electrical industry has made necessary this research, experimental and development work on the part of the companies themselves. It would be impossible to depend upon independent scientific research and invention. Such work is likely to be misdirected and does not meet the immediate pressing and practical problems which the manufacturer is called upon to solve. He must furnish all that is necessary for a complete system—dynamos and transformers alone are insufficient—they may be inoperative without switches and lightning protection. Hence, the problems of the oil switch and the lightning arrester have forced themselves forward and made imperative the research, experimental work, observation and manufacturing development which will produce the practical apparatus which is essential to successful operation. Obviously, the most efficient place to deal with the problems of interrelated apparatus is the commercial factory, where the problems arise, and where there are groups of men who can deal, not only with the individual questions, but with the interrelated problems which pertain to the various elements which must work together in the successful operation of a large system.

The result of these conditions is that the scientific research and the experimental development which have been carried on by the manufacturing companies, have been the basis for the advance in electrical machinery and appliances for the generation, transmission and application of electrical power which has brought electrical operation to its present state of efficiency.

Nearly every step in the progressive advance during the past twenty-five years, from the small dynamos and the elementary lighting service of those days up to the present time, has been made through the efforts of the manufacturing companies. The growth of electric generators, through various types from the small bipolar, direct current dynamo to the modern turbo-generator; the development of the elementary transformer of a few kilowatts, wound for a thousand volts, to the modern transmission transformer of 10,000 kw. and 100,000 volts; the development of the railway motor, from the days when the pioneers labored to make a 5 or 10 h.p. run a car, to the monster locomotives of different types which are handling the railway traffic in the terminals of the metropolis are all examples of what has been accomplished almost entirely through the energies of companies whose normal purpose is usually considered to be manufacturing standard apparatus.

A large part of this new knowledge has not been held as secret, but has been widely published. The papers presented to scientific bodies by the engineers of manufacturing companies; the publications by the companies themselves covering the principles and operation of their apparatus; the opening given to young men in the works and laboratories of the companies, who have afterwards gone out into various fields such as consulting engineering, the operation and management of plants and as professors in technical schools, are all means by which these companies have contributed to the general knowledge and advancement of electrical engineering. While the technical school has been a great factor in furnishing trained men to the electrical industry, the industry has, on the other hand, contributed a great deal to the development of the technical school. It has not only supplied men of practical training to the schools, but there has been a general freedom of relation between them and its practising engineers, and by suggestion, advice and direct aid it has been instrumental in making the schools more effective in the training of young men.

The fact that the manufacturing company is a commercial company and that its prime purpose is to operate at a profit, raises a question in some minds as to the proper relation between an engineer of such a company and a professional society. In my view such an engineer is entitled to take a full and active part in society matters, and to deal with those subjects and those engineering questions in which he and his company are concerned. It is proper that he should, as an individual, put his own name and reputation back of the statements which he makes, and that he should make them clear and correct. It is proper that he should present the engineering features of commercial apparatus, and that he should deal with the technical side of apparatus and methods which are of commercial importance. He should be interested in the advancing of engineers in general and in the advancement of the art. He is dealing with questions upon which operating engineers and the public depend for the successful operation of electrical apparatus. It may be readily granted that proper limits may be overstepped and that commercialism may be unduly prominent. The true criterion is engineering merit, and it is as important to recognize merit where it is due as it is to resent and condemn the improper overstepping of the limits of propriety and good-taste.

THE CENTRIFUGAL COMPRESSOR FOR CUPOLA USE*

By Richard H. Rice

The problem of providing a proper supply of air for the operation of a foundry cupola is in many respects similar to the problem of providing a proper supply of air to a blast furnace. The blast furnace requires much larger volumes of air, and under more arduous conditions, since its operation is continuous for many months; whereas the foundry cupola is in operation only through a few hours each day. The latter, therefore, is not subject to the great variations in conditions of operation which occur in blast furnaces due to this long continuous operation, and, moreover, operates under improved conditions owing to the differences between the physical characteristics of the charge of pig iron, as compared with the physical characteristics of the ores which are charged in the blast furnace. We find, therefore, that the blast conditions in the cupola are much more uniform than they are in the blast furnace, and the requirements for properly operating a cupola under all conditions can be met by apparatus which produces practically a constant pressure; whereas, in the blast furnace apparatus, constant volume is the prime requisite, and apparatus must be provided capable of working under a considerable range of pressures in order to meet the fluctuating conditions encountered in the operation of the furnace.

Centrifugal compressors have been used for some five or six years in England and on the continent, consisting generally of one or more rotating impellers in series, taking air at atmospheric pressure and compressing it to pressures required for the service of the blast furnace, that is to say, 12 to 15 lbs. average pressure, and 25 to 30 lbs. maximum, with provision for passing air at a constant rate; but no machines of the type mentioned were put on a blast furnace in this country previous to March 1910, when the first was put in service at the Oxford Furnace of the Empire Steel & Iron Company Oxford Furnace, N. J. This apparatus has been found to be excellently adapted for the requirements of blast furnace blowing, and a number of machines of various capacities are under construction for similar situations as a result of the good performance of these first machines. Similarly with regard to cupola work in the iron foundry, it has been found that this type of apparatus is perfectly adapted for use in connection with a furnace for melting iron; and the same reasons which render it suitable for blast furnace service are also found to apply in the case of the cupola.

One of the important points in connection with this apparatus, which is of benefit in cupola work, is the extreme steadiness of the blast. You are, of course, aware that the steady melting of iron and the steady descent of the charge from the cupola are dependent on the maintenance of uniform conditions of air pressure, because the charge in the cupola is, to some extent, supported by the pressure of the blast; so that if this pressure varies, the charge is likely to descend in a more or less irregular manner, causing an irregular, unsatisfactory working of the cupola. The uniform, steady blast produced by the centrifugal compressor therefore produces more uniform, steady conditions of melting.

Another point which is of importance in this connection, is the high efficiency of the centrifugal compressor, and the maintained efficiency after long periods of service. This efficiency is due to improvements made in the design of the apparatus, as compared with the centrifugal fans which have often been used for this purpose, and which are, by comparison, very wasteful in power absorbed. In the case of the centrifugal compressor, the velocity impressed on the air by the movements of the impeller, is changed into pressure by the gradual slowing down of the air; and the fundamental principle which is responsible for this improvement in efficiency, and which has been observed, is that the slowing down of the air must be done in a perfectly definite manner and without the production of any eddies.

Having obtained this high efficiency, it is essential to maintain it. The apparatus in question is peculiarly suited for this, since there are no rubbing parts whatever inside the compressor, and the efficiency does not depend on the maintenance of such rubbing parts in their original condition. Since the impeller is the only moving part of the compressor, and since this impeller rotates with ample clearance on all sides, it always compresses air with the same efficiency. The parts which slow the air down, as above indicated, are stationary and are not subject

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to wear; so that no matter how long the machine may be in operation, assuming that this operation is unattended by accident, the efficiency will remain absolutely unchanged.

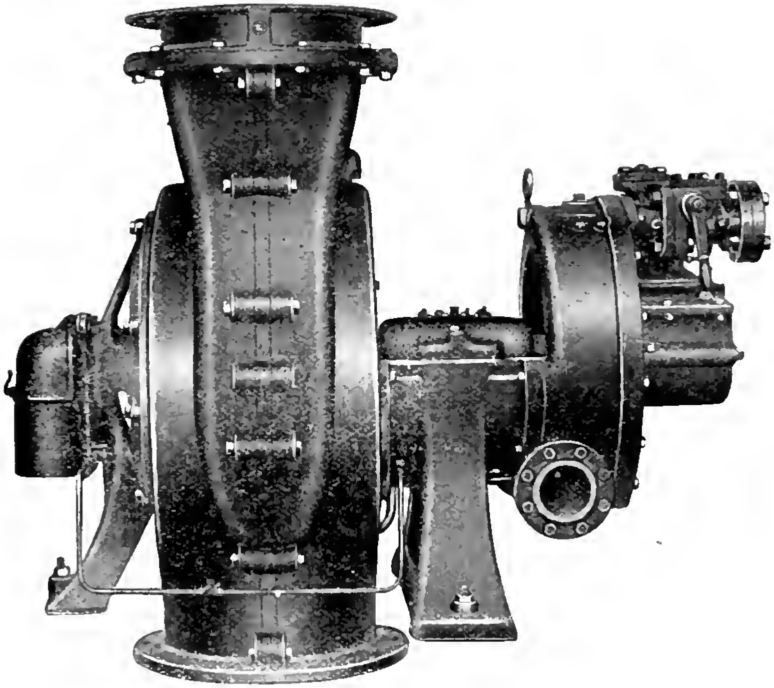


Fig. 1. Centrifugal Air Compressor Connected to 50 H.P. Curtis Turbine

Now, as regards the actual efficiencies obtained, the best way to discuss this question is to compare the centrifugal compressor with other forms of blowing apparatus for cupolas. I do not, however, propose here to enter into scientific discussions of the question of efficiency, because of the difficulty of making a strictly scientific comparison of the various types of apparatus used for blowing cupolas. This is owing to the fact that one of the principal means for blowing the cupola is the positive pressure blower, and this blower is very difficult to test for volume, as it discharges its air in the form of a pulsation or wave of air, which causes the pressure in the discharge pipe to vary to a considerable extent. The usual method of determining the volume discharged by a blower of this type is to calculate the displacement of the impellers per revolution, and from this, by determination of the speed, to estimate the quantity of air which is discharged. This quantity of air is called "displacement air;" and such experiments as we have been able to make indicate that the displacement air may be 15 or 20 per cent. in excess of the actual quantity delivered by the blower.

The means by which we are able to test the volume of air discharged by apparatus of this nature, do not give a true average if the quantities measured are fluctuating in amount, as they are when the air is discharged from a reciprocating compressor or a positive pressure blower; and therefore, the means of actually testing the air from such apparatus are not sufficiently accurate to give a thoroughly scientific test. Approximations can be made and these approximations are always in favor of the positive pressure or reciprocating machine since the quantities of air given by these methods are always too great. However, if precautions are taken to measure the pressure and volume at the end of a long pipe of large capacity so that the fluctuations in flow and pressure are smoothed down to a considerable extent, fairly accurate results can be obtained.

It is also legitimate to operate blowers of different types on a furnace under exactly the same conditions, in order to determine the power input of these blowers and the output of the furnace in tons of iron melted, and this method forms an excellent means of comparing such apparatus. Such comparisons have been made with the fan blower and with the positive pressure blower in competition with the centrifugal compressor blower which I am describing, and it has been found that the power input required to melt down the same quantity of iron is less with the centrifugal compressor than with any of the other forms. The positive pressure blower comes nearer to the compressor than the fan blower by a considerable extent, but there is still a reasonable margin of difference between the positive pressure blower and the centrifugal compressor blower in favor of the latter.

We have, therefore, the following points which are of importance as determining the superiority of the centrifugal compressor for blowing cupolas:

1. High efficiency.

2. Maintained efficiency.
3. Uniform, steady blast producing steady, uniform operation of the furnace

There are other disadvantages of somewhat less importance attendant upon the use of the positive pressure blower and the fan blower. Positive pressure blowers occupy much greater floor space, and with their greater weight require stronger floors to support them or stronger foundations, as the case may be. A larger number of bearings are required, while the maintenance costs are heavy, due to the wear of the parts and necessity of making good such wear. The centrifugal compressor on the other hand has two bearings, automatically lubricated, which do not ever come in metallic contact and therefore do not wear; and the absence of any necessity of repairs in the compressor end of the machine requires but a small amount of attention and nominal cost for maintenance.

Figs. 1 and 2 will give an idea of the general appearance of the centrifugal compressor, which consists of a shaft supported in two bearings, carrying on one end an impeller of the most rugged and substantial construction, and on the other, between the two bearings, the rotor of an electric motor, or turbine wheel of a steam turbine. In the case of motor drive, the motor may be actuated by alternating current or direct current. The design of the high speed motors is the result of extended experience, and the machines are reliable and satisfactory. In the case of a steam turbine, the steam may be at any pressure from 100 lbs. upward, and may be discharged into the atmosphere, or be run condensing. The turbines are of great simplicity and of high efficiency, and since compressor and turbine are of best efficiency when running at high speed, the combination of the two is efficient and desirable.

The principal difficulty which has been met with in the installation of such compressors in connection with iron foundry practice, has been that the requirements for air have been over-estimated by the purchaser, and in many cases the apparatus which was installed was found to be too large. Owing to the fact that all the data which have been compiled on the requirements of air on the cupola have been based on figures of displacement made in the manner above indicated, there is a tendency to overestimate the quantity of air required. Tests have been made under my direction on a cupola in actual service melting iron in an efficient fashion, and it has been found that the quantity of air required for melting iron in the cupola was considerably less than

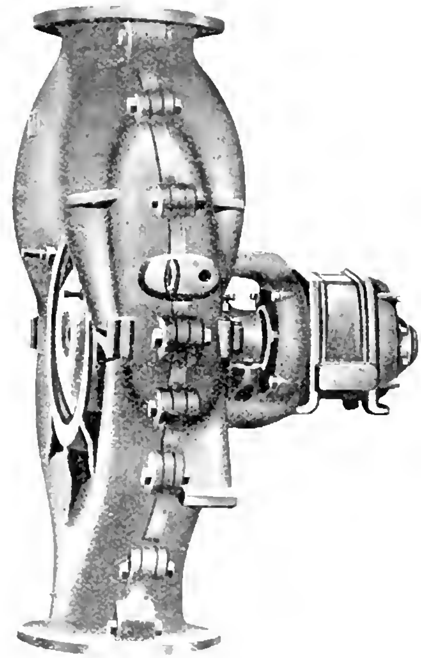


Fig. 2. Centrifugal Air Compressor Connected to 5½ H.P. Induction Motor

that usually supposed. For instance, the well established rule for the selection of positive pressure blowers for iron foundry cupolas is based on allowance of 30,000 cu. ft. displacement for one ton of iron. This rule has been reinforced by computations of the number of cubic feet of air required for burning one pound of carbon to CO_2 and the further fact which has been established experimentally, that one pound of coke is sufficient to melt ten pounds of iron. The computation which is the basis of the statement that 150 cu. ft. of air are required to one pound of carbon burned to CO_2, assumes that coke is pure carbon, which is not the case. Coke contains only about 90 per cent. carbon and is not all burned to CO_2; a great deal is burned to CO, so that the quantity of air required is only about 90 per cent of the quantity which would be required if all the coke were burned to CO_2. The result of these qualifications is that only 80 per cent. of the theoretical amount of air above computed is actually needed. This 80 per cent. efficiency of the air necessary is also about the ratio between the actual air discharged by a positive pressure blower and the computed, or displacement air. The rule is therefore correct for positive pressure blowers and is not correct for computations of the actual quantity of air needed. The tests above mentioned confirm these figures. They showed that one pound of coke would melt from 10 to 12 pounds of iron, the variation apparently being due to the difference in temperature of the iron tapped off. The conclusion is that the ratio of one to ten commonly used is reasonably correct.

The tests involved accurate measurements of the quantity of air passing into the cupola, by means of pitot tubes and by the most accurate methods of measuring quantity; and these tests showed that 24,000 cu. ft. of air was sufficient to melt a ton of iron, or in other words that 400 cu. ft. of air per min. would be required for each ton per hour. We know that this figure agrees exactly with the 30,000 cu. ft. of displacement air usually assumed in positive pressure blower work and a volumetric efficiency of 80 per cent. Enough tests have been made on the foundry cupolas to warrant the statement that these figures are correct and should be used in proportioning blowers for cupolas which are to be made on the centrifugal compressor design.

Tests made by the above method on apparatus delivering a steady blast without pulsations, i.e., on fan blowers or centrifugal compressors, are extremely accurate; and the accuracy of such tests and quantities may be determined with a possible error of not even one to two per cent.

Tests have also been made by piping up a positive pressure blower and centrifugal compressor to the same furnace, in such wise that either one of these machines could be operated at will; and it has been found that the quantity of iron, produced with the same input of current, is greater in the case of the centrifugal compressor than in the case of the positive pressure blower.

HIGH TENSION SUBSTATION

By C. M. Hackett

Simplicity in design, and the absence of special features, are the most desirable characteristics that a high tension substation may possess. Consideration of these points should not be confined to the station itself but also extended to the immediate surroundings, and a sufficient study made of site and position of building on same to insure a direct and uncomplicated approach for transmission lines and the avoidance of crosses in either lines or phases.

The type of line anchorage and entrances, being to a considerable degree involved with the design of building and its location, should be taken into consideration along with other features of the general layout. If ground space is available an anchorage tower 12 ft. or more in height, located close to the building in such a position as to give short direct runs of cables to line entrances, possesses the advantages of giving a substantial anchorage, as well as providing for horn gaps with their operating mechanism in a location where they will be convenient for operation and can be readily observed. This arrangement permits of the use of either roof or wall entrances for lines without involving structural features of the building to as great a degree as other types of anchorage and horn gap supports.

In case it is found advisable to place the line anchorage and horn gap supports on the roof of the building, this portion of the work should be planned in conjunction with the arrangement of apparatus inside the station, as not only will the placing of arrester tanks and the operation of them be affected, but the bringing of lines into the building and the arranging of operating mechanism for horns can be done in a way to permit interior portions of the equipment to be placed to the best advantage.

Horn gap supporting towers, if combined with line anchorage, will of necessity be rigid, and this condition should obtain also if an independent structure is used, especially where the voltage is very high. A supporting structure which is so light as to vibrate easily from wind or the operation of the horns, is likely to cause breakage of the insulators, which will necessarily be somewhat large and heavy for very high potentials. Connections to these insulators from lines should be made so as to avoid putting lateral strain on them, or rendering it possible for any effects of line whipping to reach them. The method which naturally suggests itself, is a dead end anchorage of lines, with a short flexible tap to horns from lines. The taps from horns to entrance bushings should also be short and arranged so as to avoid strains on the insulators.

In view of the fact that the operation of horn gaps is to some extent involved with the control of the balance of the arrester equipment the operating shafts and levers should be so arranged that the station attendant can be certain of moving the proper levers and by no chance become confused and either fail properly to charge the arresters or cause a short-circuit on the system.

If the horns are mounted on a tower alongside of station, the entire arrester control can be either inside the building or in the open air, as desired, while if the horns are mounted on the roof of the station the arrester control will normally be inside the building. Open air installation of the whole arrester equipment possesses several advantages, the chief among which are: reduction in number of line entrance bushings, smaller building, concentration of the entire equipment for any line where its operation can be observed, and the reduction in fire risk. The advantages of inside installation are: closer attention and greater degree of care from the operator, security from outside interference, protection from weather, greater efficiency and longer life, and ability to make emergency repairs or changes at any time.

Climatic conditions are frequently the determining feature in locating arrester equipment in a building or in the open. In regions where zero F. temperature is common with severe storms, it will be found economical to place arrester tanks in the station. In very warm climates the tanks should be shaded and this can often be done most economically by placing them in the building. In sections located between the two temperature extremes, each installation should be considered individually, and decided in accordance with local conditions.

Line entrances for high voltages are at present largely in an experimental stage and there are about as many methods for bringing lines into stations as there are high voltage developments supplying power. The test of time, which is the only satisfactory one for this piece of equipment, has not been continued for a sufficient period to make it possible to say that any of the methods in use, either in its present or modified form, will be the one finally adopted for this particular service. This paper will therefore consider only the general features of entrances which affect the building.

Roof entrances for lines are the simplest to install and in most cases cause the least modification in the structure to accommodate them, and generally make it possible to bring the lines in at the points which give maximum saving in space and direct wiring. This type of entrance is, however, exposed to all weather conditions and is more likely to be accidentally injured. The protected entrance is the one most generally used, and is usually sheltered by a projection of the roof if horizontal or set at an angle, or mounted in a hood if vertical. The latter method gives the best protection and makes it possible to arrange for convenient inspection and cleaning.

If the substation is an intermediate one the transmission lines should have a short direct route in their passage through the building, and the entrance conditions should be duplicated on both sides of the structure. The building necessary to house high tension switch and bus equipment will be of small size if the power is supplied by a single line and an oil switch is provided merely to cut the transformers from line. If, however, power is supplied by duplicate lines with oil switches on both the incoming and outgoing sides of the station in addition to those on the transformer banks, and with disconnecting switches arranged to cut all of the oil switches from lines and buses, the space required for the high tension part of station will be large, for voltages around 100,000.

The space needed for the low tension portion of the apparatus will usually be small, as stations of this type are seldom placed in such a way that the large number of low tension feeders required for a diversified service can be economically run from them direct.

All high tension conductors in the station should preferably be of tubing with sleeves both inside and outside at joints, carefully fitted, pinned and soldered. The tubing should be supported by either post or suspension insulators placed not more than 10 ft. centers on straight runs, while for curved or offset runs, the supports should be so placed as to insure that the tubing cannot either by straightening or twisting under short circuits, bring the different phases into an unsafe proximity to each other, or to ground. The phase centers should be 6 ft. or over, with 33 in. to 36 in. to ground for 100,000 volts.

Open wiring is preferable for high tension connections and should be kept as far above the main floor as possible. This can be done without difficulty by proper spacing of the vertical and horizontal supports for insulators so as to give ample passage for conductors. The elimination of corona can usually be accomplished by the use of shields formed to suit the special conditions of each case.

The static charge on the steel framework of the building may at times become heavy enough to be dangerous unless arrangements are made for its discharge. Thorough grounding of columns, supplemented by bonding to them of that portion of the steel framing which is adjacent to the high tension conductors, will usually meet the case, but this should be supplemented by a careful examination and test after operation is begun, and such additions and modifications made as are necessary to take care of any special trouble which may develop

It will generally be found that owing to the considerable width of the building there will be economy if a flat roof is used, and the interior columns needed for its support can be arranged to carry, in conjunction with the walls, all the horizontal and vertical framing necessary for the mounting of insulators to support choke coils, disconnecting switches, relays, buses and connections to them.

The portion of substation containing high tension apparatus will as a general proposition have a ground floor only, on which will be placed transformers and oil switch and lightning arrester tanks. The oil and water piping required for satisfactory and efficient operation of a station should be run in such a manner that little, if any, of it need be removed when transformers or switches require to be shifted. A basement conveniently located under part of the building will accommodate oil storage tanks, pumps, heating plant and conveniences for operators.

The radius of crane operation can be confined to a space sufficient for assembling transformers, and the use of a transfer car will take care of any shifting that may be required. The tracks on which the transformers are placed should be elevated a sufficient amount above the transfer car track to permit a car of simple and economical design to be used. Doorways of ample size to permit convenient removal of large pieces of apparatus should be so placed that they can be quickly and easily reached without interfering seriously with other apparatus or the operating of the station.

The lighting of a high tension station will not differ materially from that of one of low voltage. It should if anything be more liberal, as the spaces to be lighted are larger, and inspection must, to a considerable extent, be made at a considerable distance from many parts of the equipment. Natural lighting should be from the side, and windows should be as plentiful and large as good building design will permit. Artificial lighting will normally be from service transformers, and, if a battery is required for switching or other service in the station, it should be of size sufficient to permit of its use on an emergency lighting circuit.

In addition to the grounding of all steel columns in the building a well distributed system of ground points should be provided for all arrester, switch, and transformer tanks, as well as the usual grounding for low tension apparatus. A convenient method of doing this work is to run a copper band around the entire building, fastened to the outside of the foundation wall about a foot below grade. This band should be brought inside the building to a connection board at one or more points and arranged to permit of the condition of the ground being tested. All ground connections from apparatus will be connected to this copper band with as direct runs as possible. The grounding points proper may be of iron pipe or rod from six to eight feet in length, driven their full length into the ground a few feet from the wall of building, and solidly connected to ground bus with copper ribbon or wire; all joints being well soldered.

The number of grounding points may with reason vary with the capacity of station and condition of earth. There should, however, seldom if ever be less than twenty, and unless the connections from apparatus to ground bus are grouped, they may be equally spaced around the building. This type of grounding is highly efficient when properly installed and is quickly and cheaply renewed or enlarged if occasion requires.

ESSAYS ON SYNCHRONOUS MACHINERY

PART VI

BY V. KARAPETOFF

VI. OVERLOAD CAPACITY OF SYNCHRONOUS MOTOR

(First Method)

It is sometimes required to find the maximum load at which a synchronous motor falls out of step. In some cases a certain overload capacity must be guaranteed at the rated voltage, in other cases the operating engineer wishes to know the maximum load that the motor can pull through when the line voltage is say 10 or 20 per cent. below normal. The purpose of this article is to show how the overload capacity of a given synchronous motor can be predetermined by means of the general diagram (Fig. 6 June REVIEW, 1911, page 262). A modification of this method is given in the next article. One or the other method is the more convenient in numerical applications, according to the circumstances of the case. When using either method the reader must remember that the overload is assumed to be applied gradually, so that the revolving part has time to assume a new stable position with respect to the armature magnetomotive force. With a sudden overload, the inertia of the field structure swings it back past the stable position, and as a result, the motor falls out of step at a load which it could pull through if it were applied more gradually.

The true power input into the motor, per phase, is ei_1 (Fig. 6). The part of this input which is transmitted through the electromagnetic torque into the secondary is equal to $Ei \cos \phi'$, because E is the total counter-electromotive force of the motor and $i \cos \phi'$ is the component of the current in phase with it. Resolving the voltage E into its components E_1 and E_2, and the current into the corresponding components c_1 and c_2, the preceding expression for the power becomes $E_1c_1 + E_2c_2$.

The expression E_1c_1 can be deduced as follows: The torque between the armature and the revolving structure is proportional to (armature current in phase with flux)×(number of armature turns)×(flux). The output is proportional to the above expression times the speed, or is proportional to (armature current in phase with flux)×(number of armature turns)×(flux)×(speed). But the product of the three last factors is proportional to the e.m.f., E_1, induced by the flux. Consequently, the output is proportional to the current in phase with the net flux times the induced e.m.f., or is proportional to c_1E_1. By using the proper units and coefficients in this proof one can readily show that the output is not only proportional but is equal to c_1E_1. A similar proof holds for E_2c_2.

The problem is to find a maximum of the input into the field, or

$$P = E_1c_1 + E_2c_2 = \max. \tag{30}$$

for a given value of the field current. The latter condition must not be lost sight of, for the overload capacity depends essentially upon the field flux and hence upon the exciting current. In all contracts in which the overload capacity of a synchronous motor is guaranteed, the value of the field current must be definitely stated. For instance, "the machine must stand momentarily a 100 per cent. overload at 85 per cent. line voltage. When performing this test the field current will be adjusted to a value which corresponds to 90 per cent. leading power-factor at full rated load and voltage."

In formula (30) both E's and both c's are unknown; the problem is solved by expressing them through the given quantities e, r, x, and by introducing the demagnetizing and the cross-magnetizing ampere-turns given by formulæ (5) and (7) (see REVIEW, February, 1911).

Let the direction of E_1 be the axis of reference, and let the projections of the terminal voltage e upon E_1 and upon E_2 be e_1 and e_2 respectively. Projecting the figure $OABDO$ upon the direction of E_1 we have:

$$E \cos(E, E_1) = e \cos(e, E_1) + ir \cos(i, E_1) + ix \sin(i, E_1), \tag{31}$$

or

$$E_1 = e_1 - c_1r + c_2x. \tag{32}$$

Projecting the same figure upon the direction E_2 we get

$$E_2 = e_2 - c_2r - c_1x. \tag{33}$$

In this expression E_2 can be replaced by its value from equation (7), or

$$k_2 k\; k\; n\; T c_1 x = e_2 - c_2r - c_1x,$$

from which

$$e_2 = c_1(x + x_2) + c_2r, \tag{34}$$

where

$$x_2 = k_2 k\; k_f n\; T x. \tag{35}$$

Errata, June REVIEW, page 262: Equation (23) should read $\sin\beta =$ [illegible]. 2nd column, line 7 should read $=$ [illegible].

The quantity x_2 may be defined as the fictitious reactance which replaces the action of cross-magnetizing ampere-turns. In addition to the foregoing equations we have

$$c_1^2+c_2^2=c^2. \qquad (36)$$

The problem is thus reduced to the solution of the simultaneous equations (30), (32), (34) and (36). The number of equations is not sufficient, but an additional condition connecting the unknown quantities is that they must satisfy the given no-load saturation curve of the machine. The saturation curve cannot be very well represented by an equation, and, even if it could, the five equations thus obtained would be too complicated for a practical solution. Two methods can be used to obviate this difficulty:

(1) The equations are solved by trials, using different values of E_1 taken from the no-load saturation curve.

(2) The saturation curve within the working range, between no load and the maximum load, is replaced by a straight line.

The first method is explained in this article, while the second method is the subject of the next article of the series.

Let E_1 be an assumed value of the net counter-e.m.f., and let M_n be the net ampere-turns required to induce this voltage at no load. Since the field excitation M of the motor is fixed, the difference between the total and the net excitation is due to the armature reaction, and we have

$$M_1=M-M_n \qquad (37)$$

where M_1 is the direct armature reaction expressed by equation (5). Having assumed E_1 and found the corresponding value of M_n from the no-load saturation curve, the value M_1 of the armature reaction is calculated from equation (37). Knowing M_1, the internal reactive component c_2 of the current is calculated from equation (5).

Now, the equations (32), (34), and (36) contain only three unknown quantities, c, c_1, and c_2, and can be solved as simultaneous equations. The value of c_1 is needed for eq. (30), therefore we eliminate c_1 and c_2. Substituting the values of c_1 and c_2 from (32) and (34) into (36) and rearranging the terms we get the following quadratic equation for c_1:

$$c_1^2[(x+x_2)^2+r^2]+2\,c_1r(E_1+c_2x_2)-[c^2-(E_1-c_2x)^2-c_2^2r^2]=0. \qquad (38)$$

The positive root of this equation is

$$c_1=[\sqrt{z^2A^2+r^2B^2}-rB]/z^2 \qquad (39)$$

where

$$A^2=c^2-(E_1-c_2x)^2-c_2^2r^2, \qquad (40)$$

$$B=E_1+c_2x_2, \qquad (41)$$

$$z^2=(x+x_2)^2+r^2. \qquad (42)$$

The calculations are simplified in practice because the armature resistance r is small as compared to the reactance x. The square of r is negligible in comparison with $(x+x_2)^2$, so that approximately $z=x+x_2$. Besides, the term r^2B^2 can be neglected under the radical sign. Therefore, approximately

$$c_1=A/(x+x_2)-rB/(x+x_2)^2 \qquad (43)$$

where

$$A=\sqrt{c^2-(E_1-c_2x)^2} \qquad (44)$$

and B is expressed by equation (41). The second term in formula (43) is small as compared to the first so that the value of B needs to be calculated only approximately. For most ordinary cases, equations (43) and (44) are sufficiently accurate. There are instances, however, when r is exceptionally large, so that the correct expression (39) must be used. Such a case arises, for instance, when the motor is located at the end of a long transmission line of comparatively small cross-section. If the voltage is maintained constant at the generating end of the line, the resistance and the reactance of the line must be added to those of the motor armature, because the line drop may be considerable when the motor is heavily overloaded. In this instance r may be rather large, and it is safer to use the correct formula for c_1.

Having assumed E_1 and found the corresponding values of c_2 and c_1, as explained above, the value of E_2 is found by substituting the the value of c_2 from *eq.* (34) into (33). This gives

$$E_2=c_1x_2 \qquad (44a)$$

The values thus found, values are substituted into formula (30) and the output P is calculated. After this, another value of E_1 is assumed, a new value of c_1 is found, and the corresponding output calculated, etc. In this way, by successive trials the value of E_1 is found for which P is a maximum. The output P represents in reality the input into the revolving part, so that in order to find the useful power obtainable on the shaft, the iron loss, friction, and windage must be subtracted from P.

Numerical Illustration. It is required to determine the pull-out load of an 18 pole, 530 kv-a., 400 r.p.m., 6600 volt, three-phase Y-connected synchronous motor, at a field excitation $M=6300$ amp.-turns per pole. (*) The machine has 16 turns per pole per phase, the winding being distributed in 2 slots per pole per phase, with a winding pitch of 100

* The manufacturer's notation of the machine is ATB-18-530-400-6600 V.-C. The data are taken from G.E. Technical Report No. 7225. The excitation of 6300 amp. turns gives a slightly leading current at the rated load.

per cent. The equivalent armature resistance is 1.35 ohms per phase of delta, while the armature reactance x is estimated to be about 14 ohms, according to the rules given in the second article of the series. The demagnetizing ampere-turns, according to formula (5), are $M_1 = 0.75 \times 0.966 \times 3 \times 16\ c_2 = 34.8\ c_2$. The results of calculation are shown in the table below.

The value of x_2 used in these calculations is figured out according to formula (35); *viz.*, $x_2 = 0.23 \times 0.966 \times 3 \times 16 \times 1.35 = 14.2$ ohms. In this expression $v = 1.35$ is taken from the no-load saturation curve of the machine, and the coefficient of cross-magnetization k_2 is assumed to be equal to 0.23 (see REVIEW February, 1911, page 58). This is different from the value of $k_2 = 0.30$ used in the preceding illustrations of voltage regulation of alternators and phase characteristics of synchronous motors. The reason is that even at full non-inductive armature current the effect of cross-magnetization is comparatively small, and by assuming a somewhat large value for k_2, some secondary factors are thereby taken into consideration which are not accounted for in the theory. But near the pull-out point the current is several times larger than at the rated load, and the effect of the transversal reaction is quite considerable. Therefore, it is not permissible to take an exaggerated value of k_2. The value of $k_2 = 0.23$ has been found to give results consistent with the experimental data quoted in the next article.

The first two columns in the table give the assumed values of E_1 and the corresponding values of the net excitation M_n taken from the no-load saturation curve of the machine. The third column contains the values of the armature reaction calculated according to formula (37), in which $M = 6300$ amp. turns. Knowing M_1, the corresponding values of the reactive current c_2 are determined from the expression given above: $c_2 = M_1 / 34.8$ The values of A, B, and c_1 given in the next three columns are calculated according to formulæ (41), (41), and (43); the values of E_2 are computed from *eq.* (44a). The gross output P is found from equation (30) and the values are multiplied by $\sqrt{3}$ in order to get the output of the three phases. Subtracting iron loss and friction the net output is found as given in the last column. It will be seen that the output is a maximum for $E_1 = 4500$ volt, and is equal to 1920 kw. The overload ratio of the machine at an excitation of 6300 amp. turns per pole is $1920/530 = 3.6$ times the rated output of the machine.

OVERLOAD CHARACTERISTICS OF A SYNCHRONOUS MOTOR

Induced E.M.F. E_1 Volt.	Field Excitation M_n at no load, Amp. Turns	Armature Reaction M_1, Amp. Turns	Current Component c_2 Amp.	A Volt.	B Volt.	Current Component c_1 Amp.	Induced E.M.F. E_2 Volt	Gross Output P Kw.	Iron Loss and Friction Kw	Net Output Kw
6000	4850	1450	41.4	3745	6588	121	1720	1380	19.2	1360
5500	4300	2000	57.1	4635	6311	154	2190	1687	17.2	1670
5000	3800	2500	71.4	5250	6014	171	2430	1780	14.7	1765
4500	3350	2950	84.2	5705	5696	196	2780	1933	12.7	1920
4000	2950	3350	95.7	6040	5359	209	2970	1920	10.7	1910

It is sometimes desired to know the value of the current and the power-factor at which the motor falls out of step. These can be readily calculated from the values obtained above. We have, with reference to Fig. 6,

$$i = \sqrt{c_1^2 + c_2^2}. \qquad (44b)$$

The angle ϕ is a difference between the angles $H'OF$ and AOF, consequently

$$\cos\ \phi = \cos[(\phi' + \beta) - (\alpha + \beta)],$$

or

$$\cos\ \phi = \cos\ (\phi' + \beta)\cos(\alpha + \beta) + \sin(\phi' + \beta)\sin(\alpha + \beta).$$

This can be written in the form

$$\cos\ \phi = (c_1/i)(e_1/e) + (c_2/i)(e_2/e),$$

or

$$\cos\ \phi = (c_1 e_1 + c_2 e_2)/ie. \qquad (44c)$$

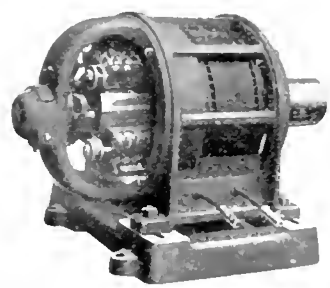
The values of c_1 and c_2 are taken from the table, the values of e_1 and e_2 are calculated from equations (32) and (34). Formula (44c) gives the value of the power-factor, but does not say whether the current is leading or lagging. It will be seen from Fig. 6 that when the current is leading the angle $H'OF$ is larger than AOF. But $\tan\ H'OF = c_2/c_1$ and $\tan\ AOF = e_2/e_1$. Consequently, the current leads the voltage when $c_2/c_1 > e_2/e_1$, and lags behind the voltage when $c_2/c_1 < e_2/e_1$.

THE REPULSION INDUCTION MOTOR

By C. H. Scott

Introductory

Many central stations and isolated plants find it both convenient and economical to combine their lighting and power loads on single-phase circuits. To successfully build up this dual field, a single-phase motor is required whose design and operating characteristics will allow favorable comparison with the starting torque, maximum overload capacity, efficiency, power-factor, mechanical simplicity and general reliability of the polyphase induction type.



General Electric Repulsion Induction Motor

The resistance-reactance type of motor is already so well known as to need but a moment's comment. This motor will continue to fill those service requirements for which it was specifically designed, that is, constant speed duty and the acceleration of loads requiring light or moderate starting torque up to 150 per cent. of normal.

For variable speed service and to accelerate loads whose static friction or inertia demands a reserve of torque in excess of the inherent limitations of the "split phase" or resistance-reactance motor, the repulsion type has been developed.

The succeeding paragraphs will be devoted to a consideration of the theory of design, and the electrical characteristics of the single-phase repulsion motor as manufactured by the General Electric Company.

Theory of Design

The leading characteristics of the direct current series wound motor operating through a wide range of speed and torque, are well known. This type has, however, no inherent speed regulation and its use is consequently confined either to fixed loads like fans or pressure blowers, or to varying loads where the motor controlling device is constantly under the operator's guidance. The speed, torque and load characteristics of the commutator series alternating current motor is distinctly analagous to that of its direct current prototype, and this design therefore fails to meet the requirements of constant speed service; this service demanding a motor that will maintain good regulation after having once been brought up to speed, with torque values increasing at satisfactory efficiency as speed decreases. In other words, the characteristics of a motor for constant speed service should approach those of the direct current compound motor having the usual proportion of series field winding.

The repulsion induction motor possesses this combination of series and shunt characteristics; namely, a limited speed, with increase of torque with decrease in speed. To secure the necessary starting torque in the straight repulsion motor, a direct current armature is placed in a magnetic field excited by an alternating current and short circuited through brushes set with a predetermined angular relation to the stator field. To further improve the operating characteristics of the plain repulsion motor, a second set of brushes, viz., the compensating brushes, is placed at 90 electrical degrees from the main short circuiting brushes, or energy brushes. The compensating field is auxiliary to the main field and impresses upon the armature an electromotive force in angular and time phase with the electromotive force generated by the main field. In addition to correcting phase relation between current and voltage, thus giving approximately unity power factor at full load and power-factors closely approaching unity over a wider range of load, the compensating field serves to restrict the maximum no-load speed; and also permits, where varying speed service is involved, slight increase over synchronous values. The compensated repulsion induction motor is capable of operating either above or below synchronous speed, and possesses heavy starting torque and high power-factor at all loads, as well as excellent efficiency constants. This motor has no tendency to spark or flash over, since the armature coils successively short circuited by the energy brushes are not inductively placed in the magnetic field and have consequently only to commutate their generated voltage.

Power-Factor

The importance of power-factor, i.e., the relation of true to apparent power, in an alternating current circuit and its effect upon both generator capacity and voltage regulation demand the most careful consideration in all cases where electrical apparatus of an inductive nature, such as are lamps, static transformers and induction motors, is to be employed. While the belief is current that a decrease in power-factor from unity value does not demand an increase of mechanical input, this is not strictly true, since generator and line losses become larger with decrease in power-factor and manifest themselves as heat; the waste energy to produce this heat being supplied by the prime mover. Apart from the poor voltage regulation of alternating current generators requiring abnormal field excitation to compensate for low power-factor, a part of the station's rated output is rendered unavailable and consequently produces no revenue. The poor steam economy of underloaded engines is also a serious source of fuel waste.

Careful investigations have shown that the power-factor of industrial plants using induction motors of various sizes, with changing load cycles, averages between 70 and 80 per cent. For plants supplying current to underloaded motors, a combined factor as low as 50 per cent. might be expected. Since standard generators are seldom designed to carry their rated load at less than 80 per cent. power-factor, the net available generator output is therefore considerably reduced.

With repulsion induction motors of mixed sizes, operating between $^3/_4$ and full load, the combined plant power-factor should equal or exceed 90 per cent. At half load, this combined value should not be less than 85 per cent.

Starting Current and Torque

To render efficient service, single-phase motors must be able to develop sufficient turning moment, or torque, to accelerate from standstill loads possessing large inertia or excessive static frictions, such for example as meat choppers and grinder, sugar or laundry centrifugals, heavy punch presses and group driven machines running from countershafts with possibly over-taut belting, poor condition of alignment and lubrication, etc., etc.

The starting torque demanded by the average type of industrial drive will be found to vary between 100 per cent. and 300 per cent. of normal. The repulsion induction motor, if started by directly closing the line switch, will develop from 250 per cent. to 300 per cent. full load torque, with current in like proportion.

From standstill these motors attain full speed under load in from two to five seconds, with normal frequency and voltage. The motors are ordinarily fused for 200 per cent. of normal full load current, exception being made for special service conditions where the percentage of starting to full load torque is excessive. As a general rule, starting boxes are not required up to and including the 2 h.p. sizes, while from 2 to 5 h.p. the use of a rheostat is optional, depending upon the degree of care to be exercised in maintaining voltage regulation. Starting boxes should preferably be used on the 7.5, 10 and 15 h.p. sizes, especially where light and power circuits are combined.

If motors of 2 h.p. and larger are installed on the same secondaries with arc or incandescent lamps, or where it is otherwise deemed essential to minimize current rush at starting, the use of a rheostat will secure full load torque with 225 per cent. full load current.

Owing to the exceedingly high power factor of the repulsion induction motor, current values, both at starting and full load, are markedly below those of other single-phase induction motors. If we compare, say a 3 h.p. repulsion motor with a 3 h.p. squirrel cage motor, each having a full load efficiency of 77 per cent., we shall find that the first motor, which we will designate as "A" motor, has a tested full load power-factor of 98 per cent., while the second motor, which we will call the "B" motor, has a tested full load power-factor of 80 per cent. Both motors are guaranteed to develop full load torque with $2^1/_4$ times full load current. On this basis motor A will require 31.5 amps. and motor B 36.5 amps. The example should clearly indicate that the proper method to determine the preferable motor should always consider true *ampere values* rather than *percentage* of starting current to full load. In the case at hand, motor A will develop the same torque with 87 per cent. of the current required by motor B.

Application

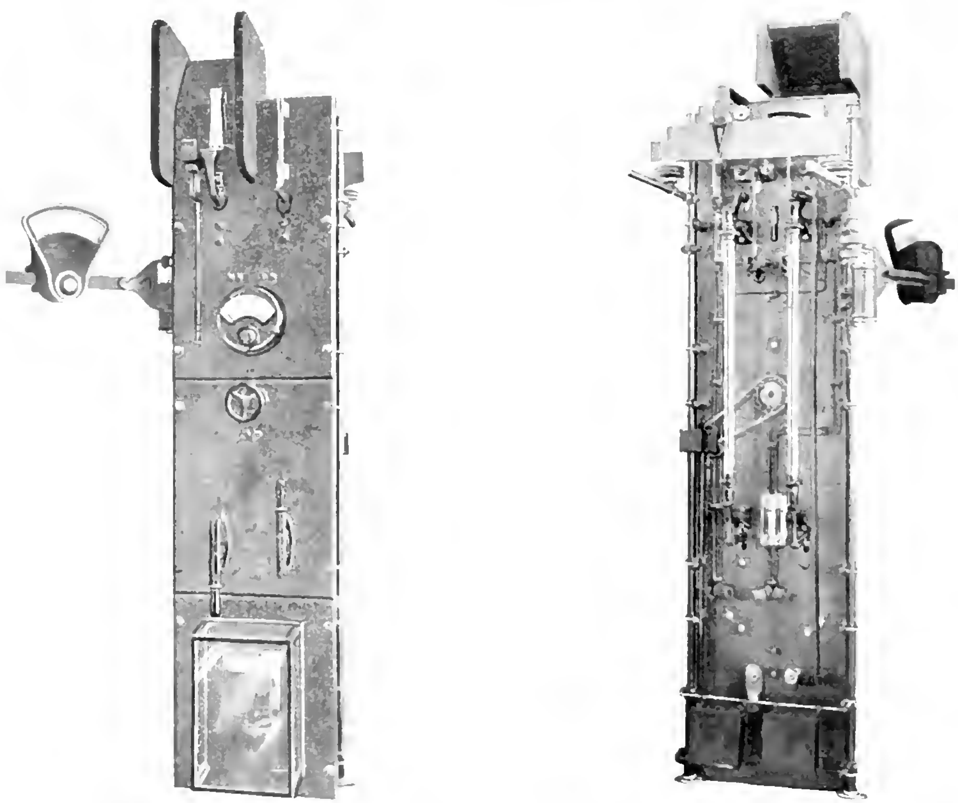
Repulsion induction motors are entirely automatic and may be thrown on the line without the use of rheostat, clutch coupling, or other external starting device. They are particularly suitable for operating refrigerating machines, air compressors, house pumps or other similar apparatus where a float switch or pressure regulator is used to close or open the supply circuit. Should the power service fail and the motor switch remain closed, these motors will not be injured in the slightest degree when the power on the line is resumed. Furthermore, no damage can result by opening or closing the line switch when the motor is at any point in its cycle of acceleration or deceleration.

Repulsion induction motors safely permit carrying very heavy overloads without sparking, down to or near standstill. This invaluable feature is not attainable with single-phase motors operating at full speed as induction motors, since upon excessive overload the motor will decelerate to the point where the automatic switch opens. A critical point may therefore exist where such a motor will hunt and become unstable, burning its switch contacts and otherwise causing trouble.

HIGH VOLTAGE D.C. RAILWAY SWITCHBOARDS

By S. W. Mauger

When the direct current 500 volt railway switchboard was developed up to the "panel" type of construction with standard generator and feeder panels, it was felt that the zenith of design had been reached. Although this was 16 or 17 years ago, there has been no sufficient reason for changing the idea of panel switchboards. As a matter of fact, there has been little change in the general design of these railway panels and their



Figs. 1 and 2. Front and Rear View of Panels for 1200 Volt Direct Current Railway Switchboard design has in the main been followed in making up other standard panels; office building switchboards being an exception to the rule. Even alternating current panel design follows the general scheme of the original railway panels, with modifications necessary on account of the use of oil switches.

The recent development of the 1200 volt railway system seemed to require a change from the design of the regular 500 volt panel, as with the higher voltage it became imperative that the possibility of accidental

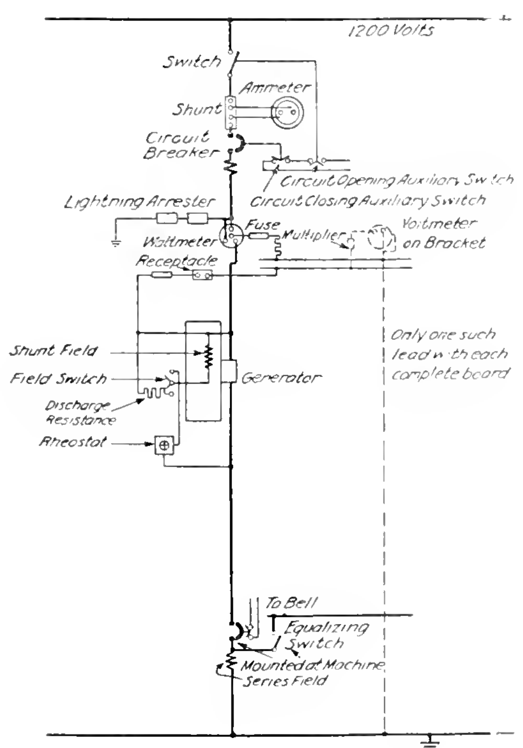


Fig. 3. Switchboard for 1200 Volt Railway Service, Generator Panel

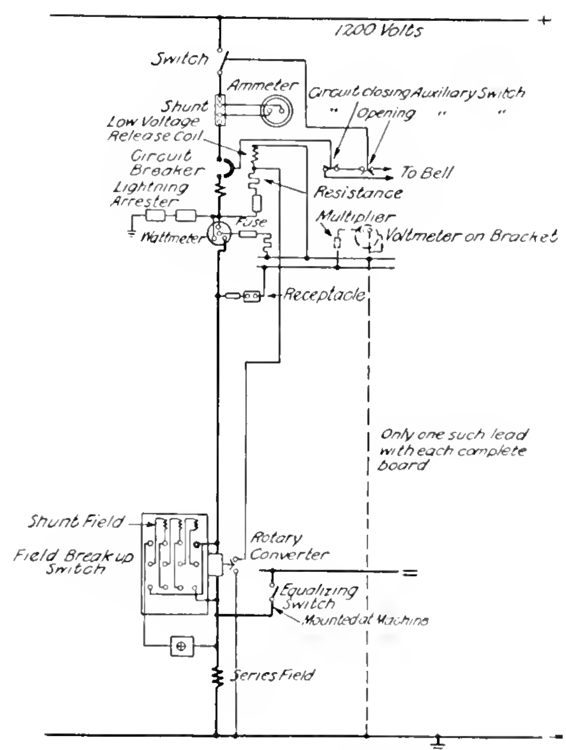


Fig. 4. Switchboard for 1200 Volt Railway Service, Rotary Converter Panel

contact with current carrying parts be prevented. When the design of the 1200 volt direct current panels was laid out, it was realized that many systems now operating at 500 or 600 volts would change over in part to the higher voltage, and that the same switchboard attendant would be called upon to operate panels of high voltage as well as low voltage; and it was therefore necessary that the same method of operation should be used for both.

The following descriptio and accompanying illustrations will give an idea of the design and construction of these 1200 volt switchboard panels.

The panels are nine inches higher than the ordinary 90 inch railway panels, and it will be seen from Figs. 1 and 2 that the circuit breaker and main switch are located at the top. The appearance of the assembled switchboard is shown in the photograph which appears on the cover of this issue. The main operating handles are similar to the standard oil switch handles and are mounted in about the usual position. They are connected to the circuit breaker and single pole main switch by means of bell cranks and levers carried at the back of the panels, the necessary provision being made to insure that the operating handles are efficiently insulated from the live parts of the circuit breaker and switch.

With regard to the instruments, the ammeters are provided with a moulded compound insulated cover; the watt-hour meters are fitted with a special cover having no connection with the live parts of the instrument; while the potential receptacles are provided with bushings designed to pre-

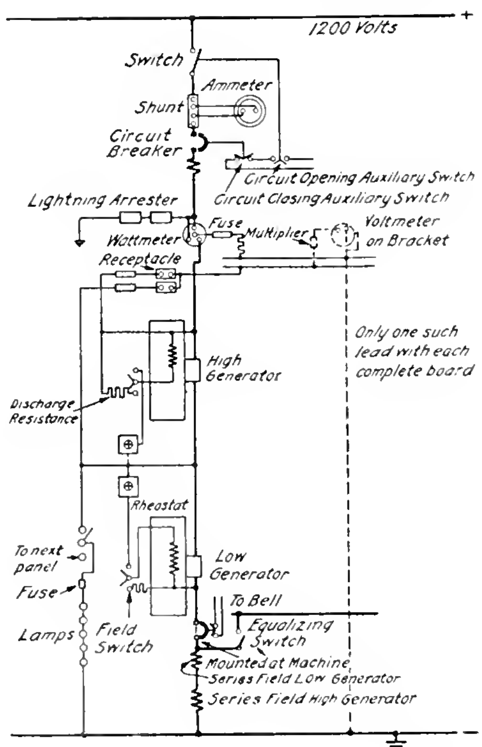


Fig. 5. Switchboard for 1200 Volt Railway Service, Generator Panel, Two Machines in Series

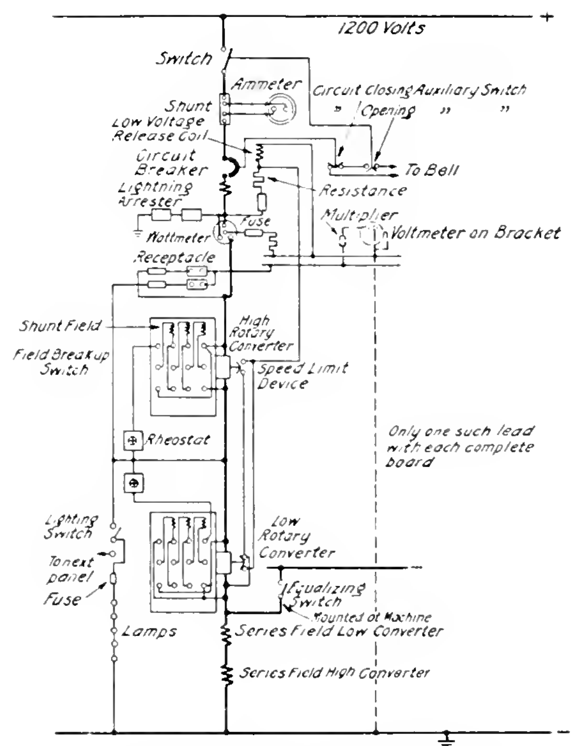


Fig. 6 Switchboard for 1200 Volt Railway Service, Rotary Converter Panel, Two Machines in Series

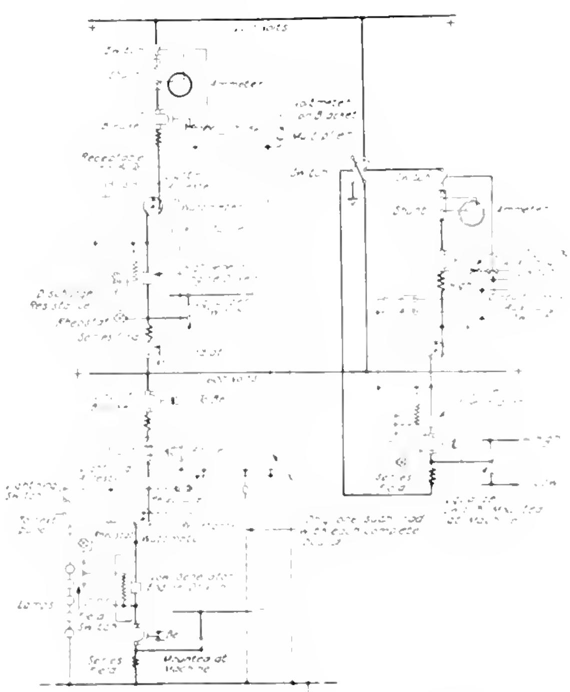


Fig. 7. Switchboard for 1200 600 Volt Railway Service Generator Panel, with One Spare Generator on 1200 or 600 Volt Side

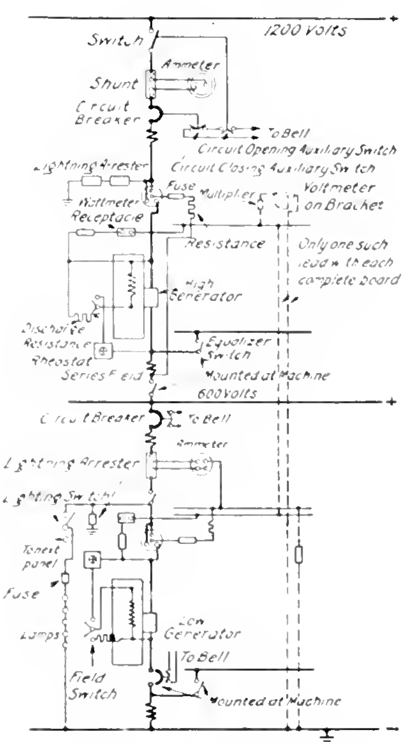


Fig. 8. Switchboard for 1200-600 Volt Railway Service, Generator Panel

vent accidental contact. The field switch (where such is provided) is mounted at the back of the panel with the operating handle in front; and the whole design is such as to render the front of the panel entirely safe from the operator's point of view.

The back of the board is designed to obtain sufficient clearance between live parts, and in some cases where it is deemed advisable, the connecting strips are taped with suitable insulation.

From the diagrams of connections will be seen the method of connecting resistances in

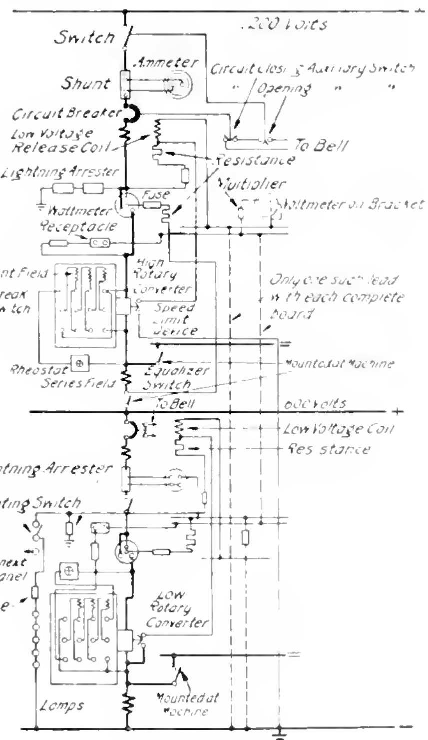


Fig. 9. Switchboard for 1200-600 Volt Railway Service. Generator Panel

series with circuit breaker low voltage release coils and wattmeter potential coils, to obtain the minimum strains on insulation.

It has been found possible to use natural black slate for 1200 volt switchboards without any special means of insulating the live parts from the panel; but it would be unsafe to use any other known grade of slate on account of the possible presence of metallic veins. For voltages above 1200, where slate is desired, insulating bushings must be used. Marble may be used without insulating bushings up to about 2000 volts.

There are varying conditions to be met with in these high voltage systems and Figs. 3 to 9 show the connections for the following sets of conditions:

(a) Generators or rotary converters of full voltage, Figs. 3 and 4.

(b) Generators or rotary converters of half voltage operated in series, Figs. 5 and 6.

(c) Same as (b) with provision for connecting a spare machine to either the high or low side, Fig. 7.

(d) Same as (b) with provision for operating at 600 or 1200 volts, Figs. 8 and 9.

In connection with switchboards for 1200 volts and above, the question as to whether the switchboard framework, etc., should be grounded or not is a matter which has been difficult to decide, there being advantages and disadvantages for both plans. The practice has been on 500 volt switchboards to insulate from ground, thereby reducing the chances for short circuits caused by accidental contact or from leakage to ground. On the other hand it is argued that there is less chance for shocks to switchboard attendants if all non-current carrying parts are grounded. On 1200 or 1500 volt switchboards, it is possible to ground such parts without experiencing great difficulty as regards the insulating of live parts; but on higher voltages, the expense of and space occupied by this insulation increases considerably.

There has recently been ordered for foreign installation a high voltage railway switchboard, to operate in connection with generators giving 2400 volts, and boosters to bring the voltage up to 3500 volts. It has been possible with slight modifications, such as the introduction of porcelain insulating bushings, to use the same design as laid out for 1200 volts, although certain special features have been required on account of the necessity of operating the feeders either with or without the boosters. One very interesting feature is the curve drawing ammeter, which is being designed so that the chart can be safely changed while the instrument is connected in circuit. Watthour meters are not included in the equipment of the panels on account of the difficulty of insulating the parts and the large resistance which would be required in series with the potential coils. The curve drawing ammeter seemed to fill the requirements, in view of the fact that the generators were waterwheel driven and a record of energy generated was not so essential as a record of load fluctuations.

It is hoped to publish a fuller description of the 3500 volt direct current switchboard in an early issue.

CURTIS TURBINES FOR TRAIN LIGHTING ON STEAM RAILROAD SUBURBAN SERVICE

The use of turbine driven generating sets represents an almost ideal system for train lighting on suburban service. Danger from fire is practically eliminated, cleanliness and brilliant and steady illumination are practically assured, while the first cost and operating costs are low.

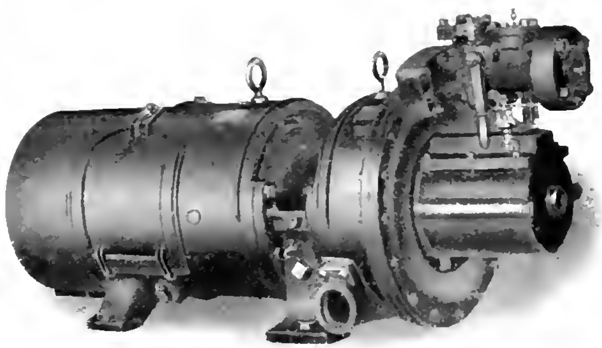


Fig. 1. Curtis Turbine-Generator Set for Train Lighting

Fig. 1 shows a turbine-driven generating unit which consists of a high pressure Curtis turbine running at a speed of 1500 r.p.m. and direct connected to a continuous current compound wound generator fitted with commutating poles. The standard ratings of these generators are 20 kw. and 25 kw., the lighting supply being 60 80 or 110 125 volts.

The unit may be located either on the boiler, where a saddle casting with suitable pads and bolt holes corresponding to the feet of the turbine is provided, or on the smoke box. In the latter case, a heavy lagging must be placed under the turbine set to prevent the generator from becoming over-heated through its proximity to the hot smoke box: and the design of the locomotive in question will determine which location will be the better. If possible, a short connection should carry the exhaust close to the stack, where it can enter the locomotive exhaust and cannot interfere with the view of the engineer. High pressure steam is used directly in the turbine without the use of reducing valves. Live steam is taken direct from the dome, and is controlled by a suitable valve having an extension handle terminating in the cab.

The two main cables from the generator are run in conduit back to the switchboard panel mounted on the side of the cab, this conduit also containing the field connection to the rheostat, which is located under the cab roof within easy reach of the engineer. The cable from the turbine has a special oil filled asbestos insulation, to withstand the high temperature due to its proximity to the hot boiler. The switch panel for the control of the lighting supply is mounted in the cab in any convenient place, the equipment of the panel including circuit breaker, snap switches, voltmeter, etc. The voltmeter is provided with special jewels and shock absorbing base, and is thus peculiarly suitable for train service.

Train Cable

The train cable, consisting of three conductors which may be made up into a single cable, runs through the train, connected from car to car by flexible cables and connectors. The train cable should be installed in conduit to prevent injury by water and abrasion. This three-wire system, called "loop system," is necessary in order to avoid an excessive voltage drop, and consequently dim lights in the last car. One of the outside cables is connected to the positive side of the generator, the middle cable to the negative side; and in the rear connector on the last car this cable is connected to the other outside cable by winding a ratchet wheel in the female connector. The lamps are connected between the outside cables.

In order to insure that the corresponding cables on each car shall be joined properly irrespective of the position of the car or the connector, it is necessary that the outside cables on each car and connector be transposed once, the middle cable running straight through.

Connectors

Special connectors are required for connecting from car to car. One male and one female three finger connector constitutes one pair, and two pairs of these connectors are necessary per car. A female three finger connector is rigidly fastened to each end of each car, either just beneath the platform or under the platform hood, depending on the construction of the cars. The jumper for use between cars consists of two male heads, connected together with three flexible cables. These cables are about 48″ long for open cars and 40″ long for standard vestibule cars.

A male three finger connector with flexible cables is used to connect the train cables to a train shed connector in the station circuit, if lighting is required before the locomotive is attached or after it is detached from the train. This train shed connector is also used between engine and tender and on rear of tender for the train cables.

RESEARCH AS A FINANCIAL ASSET*

By W. R. Whitney

Director Research Laboratory, General Electric Company

It is only in our century that there could be much significance to such a title as "Research as a Financial Asset." This is an industrial century, and, whether we are proud of it or not, we are an industrial people. For some reasons it may be thought unfortunate that so large a proportion of man's energies should be devoted solely to the industries. In some eras we find that there was a predominance of art over industry; in others literature was predominant, in still others war and conquest. Once territorial discovery and acquisition predominated, and now, in our own times, the principles of community interest have so greatly developed that we are accustomed to seeing many people who, instead of directly producing their own necessities of life, are more generally producing some one little article which contributes in the lives of others. This we recognize as a natural tendency to a higher efficiency. Our intricate and delicately balanced system of work is becoming continually more complex, but is certainly still covered by the elemental laws of demand and of survival. New discoveries in our day are largely mental, instead of geographical, and the old battles of conquest have become wars with ignorance. They are struggles to overcome inefficiencies, attempts to broaden the common mental horizon, as our ancestors broadened their physical horizon. Very few people realize the rapidity with which technical advances are being made. Few realize how the way of this advance has itself advanced. I might make this more clear by an illustration.

Consider for a moment the increasing uses of chemical elements and compounds. New combinations in alloys, medicines, dyes, foods, etc., and new uses and new materials, are being produced daily. For a more simple comparison, consider only the advances in our technical uses of the metallic chemical elements.

Copper, iron and five other metals were known and used at the time of Christ. In the first 1800 or 1900 years of our era, there were added to the list of metals in technical use (pure or alloyed) about eight more. There has been so much industrial advance made within the past twenty to thirty years that fourteen new metals have been brought into commercial use within this period. This is almost as many in our quarter century as in the total preceding age of the world. Of course, this rate, as applied to metals, apparently can not continue, but there is no reason to question the possibility of the general advance it indicates. For centuries a single metal was made to serve for all uses which that metal could fill. Then two metals divided the field, each being used where it was preferred for any reason. Alloys began to displace metals to a limited extent. While the engineer still uses iron for his railroad, iron for his buildings and iron for his tools, these irons are different and have been specially developed for those uses. The electrical engineer prefers copper for his conductor, certain irons for the frames of apparatus, other special irons and steels for the shafts, the magnetic fields, etc., and the specialization to best meet specific wants is still under way. I suppose that this kind of complex development is largely responsible for research laboratories.

A research laboratory is a place where men are especially occupied with new problems, presumably not too far in advance of technical application. This group, by devoting its entire attention to the difficulties, of meeting already well defined necessities, or of newly defining and meeting together, increases the efficiency of these processes.

* Presented before the Congress of Technology at the fiftieth anniversary of the granting of the charter of the Massachusetts Institute of Technology.

Men specially trained for this very purpose are employed and they are usually just as unfitted for successfully manufacturing as those who efficiently reproduce are of discovering or inventing. It is merely an extension of the principle of the maximum efficiency. A man with his entire attention devoted for months or years at a time to the difficulties of a single problem should be better able to reach a solution than the man who can devote only irregular intervals to it. He should then also be the better prepared for a second problem.

A research laboratory is also a place equipped with apparatus specially designed for experimental work. In a busy manufacturing plant, if a foreman has an idea pointing towards an improvement of his product he frequently has great difficulty in finding the time, the necessary idle apparatus, the raw materials and the incentive to try it. In the laboratory all of these are combined and there is added a system of co-operation, of permanently recording results, and an atmosphere of research.

The mathematics of co-operation of men and tools is interesting in this connection. Separated men trying their individual experiments contribute in proportion to their numbers, and their work may be called mathematically additive. The effect of a single piece of apparatus given to one man is also additive only, but when a group of men are co-operating, as distinct from merely operating, their work rises with some higher power of the number than the first power. It approaches the square for two men and the cube for three. Two men co-operating with two different and special pieces of apparatus, say a special furnace and a pyrometer, or an hydraulic press and new chemical substances, are more powerful than their arithmetical sum. These facts doubtless assist as assets of a research laboratory.

When a central organization, such as a laboratory, has access to all parts of a large manufacturing plant and is forced sooner or later to come into contact with the various processes and problems, the various possibilities and appliances, it can hardly fail to apply, in some degree, the above law of powers.

As a possible means of illustrating the almost certain assistance which one part of a manufacturing plant may give another when they are connected by experimenting departments or research laboratories, and how one thread of work starts another, I will briefly review part of a single fairly connected line of work in our laboratory.

In 1901 the meter department wanted electrical conducting rods of a million ohms resistance. These were to be one quarter inch diameter by one inch length. In connection with this work we had to become fairly familiar with published attempts at making any type of such high resistances. Some kind of porcelain body containing a very little conducting material seemed a fair starting formula after the resistance of almost all kinds of materials had been considered. Our own porcelain department was of great help in showing us how to get a good start. We learned how and what to mix to get a fair porcelain, and we found that small quantities of carborundum or of graphite would give us the desired resistance about once in a hundred trials. The rods could be made, but the difference in their resistance when taken from the porcelain kiln and when they were made as nearly alike as we could make them, was often so many thousand fold that something new had to be done to make a practical success. A small electric furnace was then devised for baking the rods and this was so arranged that the rate of rise of temperature, the maximum temperature reached and the duration of heat at any temperature was under control and was also recorded. The desired result was obtained and this work was thus finished. It gave us a certain stock of knowledge and assurance.

At that time a very similar problem was bothering one of the engineering departments. Lightning arrester rods, part of the apparatus for protecting power lines from lightning, were needed. Their dimensions were $^3/_4 \times 6$ inches and they needed to have a definite but, in this case, *low* resistance, and could apparently not be baked in a porcelain kiln. The usual temperature variations in such a kiln are so great that in practice many thousand rods were repeatedly fired and afterward tested to yield a few hundred of satisfactory product. All the cost of making an entire batch would have to be charged against the few units which might be found satisfactory, and in many cases there were none good in a thousand tested. It was evident that regulation and control of temperature was necessary. This was found to be impracticable in case any considerable number were to be fired at one time, as the heated mass was so great that the rods near the walls of the retort received a very different heat treatment from those near the middle and were consequently electrically different. This was still the case even when electrically heated muffles were used. This difficulty led to experiments along the line of a heated pipe, through which the rods could be automatically passed. Some time was spent in trying to make a practical furnace out of a length of ordinary iron pipe, which was so arranged as to carry enough electric current to be heated to the proper baking temperature. Troubles here with oxidation of the iron finally led to substitution of carbon pipes. This resulted in a carbon tube furnace, which is merely a collection of six-foot carbon pipes, embedded in coke powder to prevent combustion, and held at the ends in water cooled copper clamps, which introduce the electric current. By control of this current the temperature could be kept constant at any point desired. When this was combined with a constant rate of mechanical feed of the air dried rods of porcelain mixture, a good product was obtained. For the past seven years this furnace has turned out all the arrester rods, the number produced the last year being over 100,000 units.

In this work we were also forced to get into close touch with the electroplating department. The rods had to be copper plated at the ends, to insure good electrical contact. The simple plating was not enough. This introduced other problems, which I will pass over, as I wish to follow the line of continuous experiment brought about, in part, at least, by the single investigation. The electric furnace consisting of the carbon tube packed in coke was a good tool for other work, and among other things we heated the carbon filaments for incandescent lamps in it. We were actuated by a theory that the high temperature thus obtainable would benefit the filament by removal of ash ingredients, which we knew the ordinary firing methods left there. While these were removed, the results did not prove the correctness of the theory, but rather the usefulness of trying experiments. It was found by experiment that the graphite coat on the ordinary lamp filament was so completely changed as to permit of a hundred per cent. increase in the lamp life or over twenty per cent. increase in the efficiency of the lamp for the same life, so that for the past four or five years a large part of the carbon lamps made in this country have been of this improved type. This is the metallized, or Gem lamp. Naturally, this work started a great deal of other work along the lines of incandescent lamp improvement. At no time has such work been stopped, but in addition to it, the new lines of metallic filament lamps were taken up. In fact, during the past five or six years, a very large proportion of our entire work has been done along the line of metallic tungsten incandescent lamps. In this way we have been able to keep in the van of this line of manufacture. The carbon tube furnace has been elaborated for other purposes, so as to cover the action under high pressures and in vacuo. Particularly in the latter case a great deal of experimental work has been carried out, contributing to work such as that connected with rare metals. In such a furnace, materials which would react with gases have been studied to advantage. Our experience with the metallized graphite led to production of a special carbon for contact surfaces in railway signal devices, where ordinary carbon was inferior, and suggested the possibility of our contributing to improvements in carbon motor and generator brushes. On the basis of our previous experience and by using the usual factory methods, we became acquainted with the difficulties in producing carbon and graphite motor brushes with the reliability and regularity demanded by the motor art. Furnace firing was a prime difficulty. Here again we resorted to special electrically heated muffles, where the temperatures, even below redness, could be carefully controlled and automatically recorded. This care, aided by much experimentation along the line of composition, of proportionality between the several kinds of carbon in the brush, etc., put us into shape to make really superior brushes. The company has now been manufacturing these for a couple of years, with especial reference to particularly severe requirements, such as railway motors. In such cases the question of selling price is so secondary that we can and do charge liberally for delicacy and care of operation in the manufacture.

This carbon work naturally led to other applications of the identical processes or materials. Circuit breakers, for example, are now equipped with a specially hard carbon contact, made somewhat as motor brushes are made.

It is not my intention to connect all of the laboratory work to the thread which seemed to connect these particular pieces of work, but rather to show the possible effect in accumulating in a laboratory, experiences which might affect an inventory.

Among other considerations which appeal to me is one which may be worth pointing out. Probably almost every manufacturing plant develops among its workmen from time to time, men who are particularly endowed with aptitude for research in their line. They are usually the inventors of the company. They are often discoverers in spite of opposition. They are always trying new things. They are almost of necessity somewhat inefficient in the routine production. In many plants they are merely endured, in a few they are encouraged. To my mind their proper utilization is a safe investment. A research laboratory assists in such a scheme. Sooner or later such a laboratory becomes acquainted with this type of men in a plant and helps them in the development of their ideas.

It is not a perfectly simple matter to measure the value of a research laboratory at any one time. In the minds of some, the proper estimate is based on the profit already earned through its work, which otherwise would not have been earned by the company. This is a fair and conservative method which in our generation ought to be satisfactory when applied not too early to the laboratories. It does not take into account what we may call the good will and inventory value, both of which should be more rapidly augmenting than any other part of a plant. The experience and knowledge accumulated in a general research laboratory is a positive quantity. In our own case we expended in the first year not far from $10,000, and had little more than expectations to show for it. Our expenses rapidly rose and our tangible assets began to accrue. Perhaps I can point to no better criterion of the value of a research laboratory to our company than the fact that its force was rapidly increased by a company which can not be particularly interested in purely acedemic work. Our annual expenditures passed the $100,000 mark several years ago. My own estimate of the value would probably be greater than that of others, for I am firmly convinced that proper scientific research is practically required by the existing conditions of our technical age.

Without going into exact values, which are always difficult to determine, consider for a moment the changes which incandescent lighting has witnessed in the past ten years. In this field our laboratory has been active, in contributing to both carbon and to metallic filaments. Moreover, all of the improvements in this field have been the product of research laboratories of trained men. In the case of our metallized carbon filament, which has now been in use several years, the efficiency of the light was increased by about twenty per cent. Among the carbon lamps of last year these were sold to the extent of over a million dollars.

A broader, but admittedly less accurate impression of changes recently produced, may be gained by considering the economy now possible on the basis of our present incandescent lamp purchases in this country and that which would have resulted if the lamps of only ten years ago were used in their stead. On the assumption that the present rate of lamp consumption is equivalent to about eighty million 25 watt tungsten lamps per year, and on the basis of one and a quarter watts per candle-power as against 3.1 of the earlier lamps, with power at 10 cents per kilowatt-hour, we get as a result a saving of $240,000,000 per year, or two thirds of a million per day. Naturally, this is a saving which is to be distributed among producers, consumers and others, but illustrates very well the possibilities. It is interesting to note that we are still very far removed from a perfect incandescent illuminant, when considered from the point of view of maximum theoretical light efficiency.

I see from advertisements that 65,000 of the magnetite arc lamps, originally a product of the laboratory, are now in use. These must have been sold for something near $2,000,000. The supplying of electrodes, which we make and which are consumed in these lamps, should amount to about $60,000 per year.

Our study of the properties of the mercury arc produced our rectifier, which has been commercially developed within the past few years. Of these, about 6,000 have been sold. As they sell for not far from $200 per set, it is safe to say that this also represents a sale of over a million dollars. The advantage of these outfits over other available apparatus must also be recognized as not far from $200 for each hour through which those already sold are all operating.

In such a complex field as insulations and molded materials there have been many changes produced. As far back as 1906 we were using annually, in a certain apparatus, 30,000 specially drilled and machined soapstone plates, which cost $1.10 each. As the result of experiments on substitutes for such material, it was found that they could be molded by us in the proper shape, with holes in place and of a material giving increased toughness, at a greatly reduced cost. As the result of this fact, the price of the purchased material was reduced to us from $1.10 to 60 cents, which in itself would have paid for the work. But further developments proved that the new molded material could be made for 30 cents, which the foreign material could not equal, so we have since produced it ourselves. This caused a saving of approximately $24,000 annually for this one molded piece. I have heard of other cases where prices to us have gone down, when we have obtained a little promise from our experimental researches.

In considering the research laboratory as a financial asset there is another view which might not be visible at first sight. It is the question of the difference between the value of the useful discovery when purchased from competitors in the business and when made by one's own company. It is not usually pleasant to have to purchase inventions after their value is known, no matter from whom, but to have to pay a competitor for such a discovery is doubly irksome. One is naturally unduly fearful of its value to the competitor, and he, in turn, is over-estimating another's power to use it. The purchaser's profit is apparently limited to the differences between his efficiency of operating it and that of the original owner.

I was recently informed by an officer of another large manufacturing company, where much chemical work is done and where a research laboratory was established several years ago, that the most important values they got from their laboratory was the assurance that they were keeping ahead and are at least prepared for the new, if they can not always invent it themselves. Incidentally, he said that from one part of their research work they had produced processes, etc., which had saved $800,000 a year. They are at present spending in their several research departments a total of about $300,000 a year.

We hear frequent reference to the German research laboratories and a brief discussion may be in place. For the past fifty years that country has been advan ing industrially beyond other countries. Not by newly opened territories, new railroads, new farm lands, new water power cities, but by new technical discoveries. In fact, this advance may be said to be largely traceable to their *apparent* over-production of research men by well fitted universities and technical schools. Every year a few hundred new doctors of science and philosophy were thrown on the market. Most of them had been well trained to think and to experiment; to work hard, and to expect little. The chemical manufactories began to be filled with this product and it over-flowed into every other calling in Germany. These well educated young men became the docents, the assistants and the professors of all the schools of the country. They worked for $300 to $500 per year. They were satisfied so long as they could experiment and study the laws of nature, because of the interest in these laws instilled into them by splendid teachers. This condition soon began to make itself manifest in the new making of things—all sorts of chemical compounds, all kinds of physical and electrical devices. I might say that pure organic chemistry at this time was academically most interesting. Its laws were entrancing to the enthusiastic chemist and consequently very many more doctors were turned out who wrote organic theses than any other kind. What more natural than that organic chemistry should have been the first to feel the stimulus? Hundreds, and even thousands of new commercial organic products are to be credited to these men and to that time. All the modern dye stuffs are in this class. Did Germany alone possess the raw material for this line? No! England and America had as much of that. But Germany had the *prepared men* and made the start.

It seems to me that America has made a start in preparing men for the research work of its industries. For example, it is no longer necessary to go abroad to get the particular training in physical chemistry and electro-chemistry which a few years ago was considered desirable. Advanced teaching of science is little, if any, more advanced in Germany today than it is in this country. In my opinion the quality of our research laboratories will improve as the supply of home trained men increases, and the laboratories of this kind will be increasingly valuable when analyzed as financial assets. I am certain, too, that the industries will not be slow in recognizing the growing value of such assets. They merely want to be shown.

Probably in most industries there are what I may call spots particularly vulnerable to research. For example, the efficiency of steam boilers, based upon the heat energy of the coal used and the efficiency of the engine using the steam, are continually being raised. We may expect, until the maximum, calculable efficiency is reached, that this advance will continue. The reason is not far to seek. It is a vulnerable spot. Improvement is possible. A small increase in efficiency of a power plant is an ever-continuing profit. Great numbers of steam power plants exist and so inventors are influenced by the fact that new improvements may result in enormous total economies. Every rule of the game encourages them. I can make this clearer by illustrations.

Artificial light is still produced at frightfully poor efficiency. Electric light from incandescent lamps has been greatly improved in this respect, but there is still room for greater economies. It is still a vulnerable spot.

In the case of iron used in transformers, we have another such vulnerable spot. A transformer is practically a mass of sheet iron, wound about with copper wire. The current must be carried around the iron a certain number of times and the copper is chosen because it does the work most economically. No more suitable material than copper seems immediately probable, nor is there any very promising way of increasing its efficiency, but in the iron about which it is wound there is a vulnerable spot. The size of the iron about which the copper is wound may possibly be still much further reducible by improvements in its quality. In other words, we do not yet know what determines the magnetic permeability or the hysteresis of the iron, and yet we do know that it has been greatly improved in the past few years and that it can still be greatly improved.

Let us make this vulnerable point a little clearer by considering the conditions in Boston. I assume there are approximately 50,000 kw. of alternating current energy used here. Nearly all of this is subject to the losses of transformers. If the transformers used with this system were made more than ten years ago, they probably involve a total loss, due to eddy and hysteresis, of about $1,000 per day, at the ten-cent rate. Transformers as they are made today, by using improved iron, are saving nearly half of this loss, but there still remains over $500 loss per day, to serve as a subject for interesting research work.

It should also be noted that Boston uses only a very small fraction of the alternating current energy of this country.

Consider for a moment two references to the sciences and industry in Germany and England. Dr. O. N. Witt, professor in the Berlin Royal Technical High School, reporting to the German government in 1903, says: "What appears to me to be of far greater importance to the German chemical industry than its predominant appearance at the Columbian World's Fair, is the fact which finds expression in the German exhibits alone, that industry and science stand on the footing of mutual deepest appreciation, one ever influencing the other," etc. As against this, Professor H. E. Armstrong, of entirely corresponding prominence and position in England says of England: "Our policy is the precise reverse of that followed in Germany. Our manufacturers generally do not know what the word research means. They place their business under the control of practical men, who, as a rule, actually resent the introduction into the work of the scientifically trained assistants. If the English nation is to do even its fair share of the work of the world in the future, its attitude must be entirely changed. It must realize that steam and electricity have brought about a complete revolution, that the application of scientific principles and methods is becoming so universal elsewhere that all here who wish to succeed must adopt them."

So long as motors burn out, so long as subways are tied up by defective apparatus, so long as electric motors run too hot, so long as street cars may catch fire from so-called explosions of the current, so long as the traffic of a whole city can be stopped by defective insulation or a ten cent motor brush, there will probably be the equivalent of research laboratories somewhere connected with the electrical industries, where attempts will be continually made to improve.

ALTERNATING CURRENT APPARATUS TROUBLES

Part II

By D. S. Martin

In Part I of this series under the heading "Failure of an Alternating Current Generator to Generate," we considered a failure of the exciter to build up its voltage. Before leaving exciters, we will consider other defects to which they are liable, the first of these being sparking.

Sparking

The causes for bad commutation of the exciter may be divided under three headings. The trouble may be due, firstly, to any factor which will cause imperfect contact and variable contact resistance between each individual brush and the commutator; secondly, to an incorrect setting of the brush rocker or incorrect spacing between a pair of brush studs; thirdly, to a defect in the armature circuit or field circuit of the machine. These causes may be further sub-divided, and the following analysis considers them in detail in the above order.

Some of these defects may be present when the machine is first set to work, while others will show up only after the machine has been running in service for some time. In making the following analysis under the headings of cause, symptom and remedy, we would point out that the word symptom is not used in its medical sense, but must be taken as representing suitable tests which should be applied to locate the trouble and the directions in which observation should be made.

Cause 1. Bad commutation may be due to a brush or brushes not being bedded true to the curvature of the commutator.

Symptom. This defect will be obvious upon inspection after removing brush from brush-holder.

Remedy. It should be an invariable rule that when a machine is set to work, an inspection of the face of the brushes be made, and in cases where the whole face of the brush is not truly bedded, the sandpaper method should be resorted to, the paper being placed face upwards on the commutator and drawn across the face of the brush with the latter pressed well down, the process being repeated until the brush face has taken the correct curvature.

Cause 2. Incorrect ten ion of brush springs.

Symptom. If the tension is very slack, the trouble may be detected by testing the springs of all brushes by hand, but this should not be relied upon in every case. As a general rule, carbon brushes require a pressure of $2\frac{1}{2}$ pounds per sq. in. while in some cases brushes of special composition are employed requiring a pressure of 5 to 6 lbs. The exact pull which the spring is giving should be measured on a spring balance. Loose tension will cause sparking through high contact resistance, while too great tension will cause excessive friction and a resultant heating of the commutator.

Remedy. The required adjustment should be made on the spring release, depending on the particular device employed.

Cause 3. Dirty surface of commutator.

Symptom. This will be obvious upon inspection.

Remedy. It will usually be found that where the surface has been slightly blackened through poor commutation, the trouble may be remedied by running the machine and cleaning the surface of the commutator with sandpaper. In cases where the dirt is the result of injudicious lubrication, it will be necessary to remove the excess with some dry waste. In cases where the surface has become thoroughly blackened through vicious sparking, it will be best to remove the brush rocker and thoroughly to stone the commutator. During the application of the stone or bath brick, a great quantity of finely divided powder will be given off as the stone is ground away, as well as copper dust. Therefore, all possible care should be taken to prevent this dust lodging in the armature or field windings of the machine, as this may cause obstruction of the ventilating passages; and after the method has been applied, the exciter should be thoroughly blown out with a compressed air cleaner or a vacuum cleaner, or failing these, with hand bellows. When applying this remedy, if the brush-rocker is not removed, at least the brushes must be removed from the holders, as the copper dust given off during the process is sufficient to form a distinct copper coating over the whole face of the brush, if these are left on the commutator.

Cause 4. Loose setting of brushes due to loose rocker, loose studs, or loose brush-holders, an undersized brush, or an oversized holder.

Symptom and Remedy. Such defects as these will be obvious upon going over the parts and feeling with a spanner and screw-driver, and any loose nuts or screws should be tightened up. Evidence of a loose fit of any one brush in its holder would be given by the appearance of the brush face after running for some time. Although properly bedded at the start, the bearing surface will gradually become reduced, as the tilt of the brush in its holder makes itself evident.

Cause 5. Grooves in commutator.

Symptom. These may be seen on careful inspection at slow speeds. Also in view of the fact that grooves are often caused through lack of continuous end play, the test may be made by running the exciter on a small load and holding the armature pressed against one end with a stick. If the pressure is then applied at the other end, the grooves in the commutator will cause a "climbing" of the brushes, and this, owing to the imperfect contact formed, will cause sparking.

Remedy. Commutator should be trued in a lathe. Grooves may be caused by unequal mechanical pressure of all brushes, or by the fact that the brushes are not properly staggered, this causing an unequal distribution of pressure over the whole active surface of the commutator. These points should be taken care of when the initial trouble has been remedied.

Cause 6. High commutator bars. It occasionally happens that one or more of the commutator bars will work loose during running service. This is in all cases due to a defect in one or the other of the mica cone insulating rings, which are placed around the inside of the assembled commutator before the end-tightening rings are placed on the commutator. As these latter rings are tightened up, the mica cone rings are subjected to compression and a weakness at any one point will cause a diminished pressure on the corresponding copper segment, with the result that this segment may become loosened when the machine is running and will be thrown out possibly two or three hundredths of an inch—sufficient to kick each brush as it passes. In the manufacture of exciters, it is usual to apply a "whirling" test to the commutator before assembly on the armature shaft, in order to ascertain whether any bar has a tendency to be thrown out. This is performed by rotating the commutator by itself at a high speed, say 50 per cent. above normal, for a period of a few minutes.

Symptom. A test for a high commutator bar may be made with a wooden stick about twelve inches long. The machine is run up to speed and the stick touched upon the commutator; when the tester places his ear to the other end of the stick, any high bar will cause a distinct kick at each revolution.

Remedy. Commutator should be trued up in a lathe. If the same trouble develops again, probably the only satisfactory solution will be to replace the defective mica cone ring with a new one.

Cause 7. High mica insulation between segments. This may often be detected by hand, although the test with a wooden stick, mentioned under Cause 6, may also be applied.

Remedy. Commutator should be trued up in a lathe. Trouble from this cause is usually the result of working the commutator to an excessively high temperature. In the remote event of one mica insulating strip being thoroughly defective, it may be necessary to take down the whole commutator and replace the strip in question with fresh mica.

Cause 8. Commutator out of true.

Symptom. The armature should be rotated slowly and careful watch kept upon the position of any one brush in its holder. An eccentric commutator will cause a gradual rise and fall of a brush in its holder once during every revolution.

Remedy. Commutator should be trued up. This trouble is very often caused by excessive heating of the commutator, while it is also sometimes due to a structural defect.

Cause 9. Incorrect position of brush rocker, giving incorrect lead to each stud of brushes.

Symptom. Commutation will be bad or good as the brush rocker is shifted backward or forward.

Remedy. The position of the brush rocker should be adjusted to the point of best operation. Nowadays this adjustment will seldom be necessary as the machines are shipped from the factory with the correct brush position marked upon the rocker, and this marking should usually be adhered to.

Cause 10. Incorrect spacing between individual studs, although rocker may be set in correct position.

Symptom and Remedy. This may be ascertained by placing a strip of paper around the surface of the commutator and thus obtaining the length thereon of one-quarter of the entire periphery (one sixth in the case of the 6-pole exciters) and by then adjusting spacing between individual studs in accordance with this measurement. The same result may be achieved by counting the number of segments in the entire commutator, and making adjustment in this way.

Cause 11. Although position of rocker and spacing of individual studs may be correct, *the setting of the brushes may be incorrect with reference to the direction of rotation of the armature*, depending on the particular type of holder used and the angle which each brush must make with the commutator.

Symptom. This defect will usually be obvious upon inspection. When the exciter is running any inequality or roughness in the surface of the commutator will cause a chattering of the brushes and slight sparking, while frequently the brushes may become chipped.

Remedy. Correct adjustment should be made by changing position of brush-holders on studs and moving the rocker if necessary.

Cause 12. Open circuited coil or coils in armature winding.

Symptom. This defect will cause violent sparking, even when the machine is rotated at a slow speed. In certain cases where there is a break in one coil, the circuit will become open only when the machine is rotated at full speed. The best method for exactly determining the position of an open-circuited coil is by the potential drop test. We have no space here to describe this test in detail, but briefly it consists in applying to the whole armature a low voltage current, measuring the drop in millivolts across each pair of segments. Ordinarily this current would divide at the leading-in point and would have two paths open to it in parallel with one another, but where one of these is open circuited, only one path will be taken. In this path there will be a small voltage drop across each pair of segments, this being the same for each pair, and the aggregate of all these small deflections will equal the voltage drop as read across the leading-in points. In the other or open-circuited path of the armature winding, no voltage drop will be recorded during the bar to bar test, since there is no current flowing; but when the two segments are reached which hold the open circuited coil, there will be a deflection equal to the total drop across the leading in points.

In the case of an open circuit in the armature, it will rarely be found in the winding itself, but is more likely to occur at the end connection between conductor and commutator. This connection should therefore be closely inspected when the defective coil has been located.

Remedy. Replacement of defective coil or coils by new parts. In the case of faulty end connections the trouble can usually be remedied without difficulty by resoldering the conductor and the end connecting pieces. In cases of an open circuited armature coil, where it is essential that the machine be run on load and it is not possible to repair the fault at once, the difficulty may be temporarily tided over by connecting together the two commutator bars which hold the open-circuited coil. This may be done by a layer of solder run over the mica insulation, placed on the bars to clear the brushes and smoothed down as nearly flush with the surface of the commutator as possible. In this manner the open-circuited coil will be cut out and the continuity of the armature winding maintained.

Cause 13. Short circuited coil in armature.

Symptom. The exciter will require considerable power to drive even on no load, and provided the machine is giving its full voltage with no external load, a short circuit circulating current may be set up in the defective coil rising to many times the normal full load value, so that probably the first indication of this trouble will be given by the smell of burning varnish. Under such conditions, the exciter should be shut down and the defective coil located by feeling around the armature with the hand. In cases where this is not sufficient to determine a short circuited coil, resort should be made to the potential drop test referred to under Cause 12. In this case when the voltmeter reading is taken across the two segments which hold the defective coil, a low drop will be indicated on the meter, owing to the low resistance between these points.

Remedy. Replacement of defective coil or coils by new parts. A short circuit of one or more armature coils is frequently caused through particles of copper lodging between the commutator segments and thus bridging across from one segment to the other. Constant inspection is required in order to insure that this trouble does not develop.

Cause 14. Reversed armature coil.

Symptom. The presence of a reversed armature coil will generally not show itself when the machine is running on open circuit, and will probably only cause slight sparking when the exciter is running on full load. For determining the position of the reversed coil, it is necessary to make a bar to bar test of the commutator, in order to find out the direction of the induced current in each armature coil. This may be performed by applying an excitation current to the field winding and noting the direction of the kick on a galvanometer needle at the instant of applying the field, taking observations as the leads are moved from bar to bar. In this case the armature should be held at rest but must be rotated between readings sufficiently to obtain approximately similar conditions of field magnetism for each individual coil. When the reversed coil is reached, it will be found to give a deflection on the instrument in the opposite direction to those given by adjacent coils.

Remedy. It may be necessary to remove several other coils in the process of reversing the coil in question.

Cause 15. Ground in armature circuit. A single ground will not, of itself, cause trouble unless the exciter is operating on a grounded system. This practice is followed in certain cases where the exciter is used for supplying current to other points besides the alternator; and the ground in the armature winding will therefore be equivalent to placing an excessive external load on the exciter, with consequent overheating and sparking.

Symptom. A grounded armature may be tested for with magneto and bell, and when detected the following method may be applied for determining the exact location of the defective coil. A low voltage current, sufficient to give a readable deflection on a galvanometer or millivoltmeter, is passed through the armature winding from one commutator bar to one adjacent to it. A connection is made from one side of the galvanometer to ground, the lead from the other terminal of the instrument being placed on one of these two commutator bars. The supply leads and galvanometer lead are then passed from segment to segment until first a full deflection is obtained, and then zero reading when the leads are moved one segment farther. The grounded coil then lies between the bars for which full deflection was obtained.

Remedy. Replace defective coil. Several other coils may have to be removed in the process.

Cause 16. Unequal distribution of field owing to short circuit of one field spool.

Symptom. In the case of one field spool being wholly or partially short circuited, the result is often seen in local sparking at one brush stud, the commutation at the others remaining black; but in order to determine whether this is the cause of the trouble, resistance measurements of all field spools should be made, when that one having some of its turns short circuited will naturally show a smaller voltage drop than the others.

Remedy. Replacement of defective spool by new part.

Cause 17. Unequal distribution of field, due to inequality of the air-gap under different poles.

Symptom. As in the case of a short-circuited field spool, the result of this defect may often be seen in local sparking at one brush stud. If this cause is suspected, measurements of the air-gap should be made under all the poles.

Remedy. Correction for inequality of the air-gap may be made by adjustment of the shims on the pole pads, which should be removed or inserted as required at the individual poles, in order to give an equal distribution of flux in the armature.

Note on commutation of exciters fitted with commutating poles.

A considerable percentage of all the exciters built at the present time are fitted with commutating poles, and sparking difficulties may sometimes be encountered due to defects in the interpole circuit. The function of the interpole is to provide a flux opposite to and greater than the flux which produces the reactance voltage in each individual armature coil. Another way of putting this statement is that the interpole flux causes the inductance of the armature coil to be reduced, and hence reduces the reactance voltage. If, therefore, any condition arises to negative the effect of one or more of the interpoles, the defect will usually manifest itself in local sparking at one or more of the brush studs, the commutation at the other studs remaining good. A short circuit of one commutating pole will act with this effect. The resistance test may be applied in order to locate the trouble, and the remedy will consist in replacing the defective spool.

The same effect will be produced by reversal of one interpole, although in this case the effect on the operation at one particular brush stud will be to cause even worse sparking than if the coil were merely short circuited, since the effect of reversing the interpole will be to increase instead of diminish the reactance voltage in the armature coils at that point. The polarity test may be applied to the commutating pole circuit to determine which is the defective pole, and the remedy will be to reverse the connections in order to maintain the series of interpoles alternately *N* and *S* around the periphery.

When making connection of the interpole circuit care must be taken that the polarity of this field is correct with reference to that of the main shunt field, *i.e.* the connection must be such as to place a *N* pole of the commutating field ahead of a *N* pole of the main field, *i.e.*, beyond it in the direction of rotation.

Reversal of the entire interpole field may sometimes cause heavy sparking at small loads, although cases are recorded in which the exciter, although having its commutating field reversed, carried full load with sparkless operation and showed excessive sparking only on heavy overloads. It may therefore be necessary to place considerable load on the machine before the reversed connection manifests itself, in view of the fact that the interpole field current is a series current and that therefore the effect of the interpole, even when this tends to increase instead of decrease the reactance voltage of the armature coils, is not considerable at low loads.

Heating

The remaining exciter trouble is overheating, and this is in nearly all cases the result of abnormal operating conditions; *e.g.* running the exciter at full load below normal speed, or placing an overload upon the machine. If the exciter is running below rated speed, then the shunt field current must be increased to maintain normal voltage and this may cause overheating of the field spools. A short circuit in the alternator field would similarly put an overload current on the exciter armature, and other abnormal conditions might arise. Internal defects of the exciter itself may, however, be responsible for overheating of the machine, and these include short circuit in the armature or in the field winding. These have already been considered under "Sparking," Causes 13 and 16.

With regard to overheating of the commutator, this is usually caused by sparking, but may be also due to excessive brush tension or lack of lubrication of the commutator.

THE MANUFACTURE OF GEARS AND PINIONS AT THE LYNN WORKS OF THE GENERAL ELECTRIC COMPANY

By C. C. Eaton

The manufacture of railway motor gears and pinions at the Lynn Works of the General Electric Company was commenced in 1893 and illustrates the latest development in steel manufacture and treatment as well as modern methods of special machine processes of finishing.

It was soon found that cast iron for railway motor gears and pinions was wholly unsuitable as it possessed no qualities of durability, and great difficulty was also found in casting steel in the perfect form required. At this stage the percentage of rejections was exceedingly large, being not less than thirty-five or forty per cent., but the art has now been so perfected as to reduce the percentage of rejections to an insignificant figure, while the grade of work is so high as to minimize the labor of finishing.

A new and modern factory building has recently been constructed and equipped with machinery of the latest design for use exclusively in the manufacture of steel gears and pinions. The present weekly capacity involves the employment of over 170 machines and a force of more than one hundred men, and may be computed at an approximate value of 125,000 lb. or 65 tons of gears, while the pinions aggregate 50,000 lb. or 25 tons.

The output of the Company began with the development of gears and pinions for light service, for motors not exceeding twenty or thirty horse power; but it now provides gears for motors ranging as high as 250 horse power and of especially heavy construction for starting and stopping heavy cars. The gears are designed with reference to the horse power and load for which they are to be used, a gear of 69 teeth for 40 h.p. being lighter than a gear of 69 teeth for a 60 h.p. motor. Gears rated for certain classes of work are provided with teeth of three pitch and are made of low carbon steel, while others are made $2\frac{1}{2}$ pitch of high speed steel. The use of split gears is chiefly confined to the smaller railroad lines, while the larger roads employ the solid.

The progress of the development of this product is aptly illustrated, together with some of the problems which have met the engineer, by reference to the service conditions of one of the large interurban Atlantic seaboard roads. For this class of work solid gears and large pinions were originally designed of $2\frac{1}{2}$ pitch. It was found, however, that with this design the number of breakages

Fig. 1. Gear Moulding Machine

was considerable and it was therefore changed to a rim, shrunk on a hub. It was soon found necessary to make the rim, as well as the pinion, of a hardened tool steel with a stub tooth. The wisdom of the proceeding is demonstrated by the negligible quantity of breakages and the fact that it is now possible to guarantee the product even under the severe conditions imposed. Gears and pinions, as now furnished, meet a tensile strength test of 110,000 to 120,000 lb. and an elastic limit of 80,000 to 85,000 lb.

We have already alluded to the difficulties of casting steel gears. The nature of the work, the small spaces into which the metal must flow, and the necessity of uniformity of metal, required exactitudes of workmanship which were until recently well nigh impossible in the steel foundry. It has long been recognized that there are few castings more difficult to make perfectly sound and uniform than a railway motor gear, and in which uniformity, soundness and strength are more essential. The material is prepared and melted under the direct supervision of a factory chemist, who analyzes each heat previous to the pouring. The making of the moulds is also under the supervision of an expert, while over seven hundred patterns are used in the foundry, many of them containing interchangeable hubs adapting them to a variety of work. Much of the moulding is done by a machine (see Fig. 1) as it has been found that this method gives the most uniform and reliable results. The castings are made with large sprues or "risers" to ensure a thorough permeation of the metal through the moulds. After being poured and snagged, rough castings are sandblasted so that checks or defects can be detected. The castings are then inspected in order that only those shall be sent to the machine shops which prove to be sound.

The essential work of the machine shops includes milling, drilling and tapping, assembling, boring, hubbing, cutting, etc.

Split gears are first milled on the joints by special machines, the milled surfaces being made straight and parallel in order to insure that the assembled parts of any gear will fit perfectly together and will be interchangeable with those of any other of the same size and class. The gears are milled so that the joints shall come in the space between the teeth and never on a tooth, this being accomplished by milling the joints on or off center according to the number of teeth in the gear.

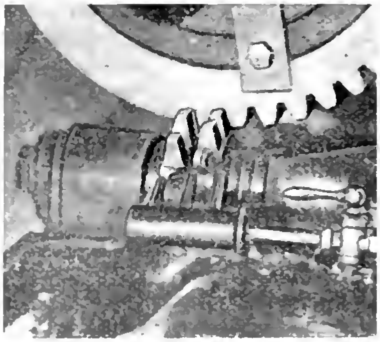


Fig. 2. Cutting Teeth on Railway Gears

In the second operation of drilling and tapping the gears, the castings are placed on specially designed fixtures and drilled by the use of templets with long hardened steel bushings which insure straight and parallel holes.

After each operation is performed the work is carefully inspected. In assembling, steps are taken to ensure the accuracy of every previous operation. It is obvious that there may be no particular difficulty in assembling gears in a machine shop, but very different conditions obtain where workmen handle the gears under a car. To insure tight fits of the bores small shims .014 inches in thickness are inserted between the halves of the gears during assembling, which can be removed when the gear is fitted to the car axle if the conditions render this necessary. The four-bolt type of gear is constructed with four studs which are screwed into one-half of the gear and held securely by nuts on the other end of the studs upon the assembly of the two halves.

The next step in the manufacture is boring by special machinery, this being the first operation in the case of solid gears.

In machining gears, experience has shown that if several operations are performed at a time, the machine is liable to become slightly out of alignment and that, in consequence, it is not possible to ensure an absolutely true form and parallel hole. The several steps of milling, boring, etc. are therefore performed, one at a time on separate machines.

It is essential that the hub face of a gear should be perfectly true as it runs with small clearance to motor linings. Therefore, facing and hubbing, as well as all subsequent operations, are performed by mounting the gear on specially made arbors working from the bore, insuring concentric and accurate-running gears.

Circular milling machines are used for turning the cylindrical surfaces of the gears and special cutters ground accurately to size are employed to insure a proper diameter and width of face. It is only upon the completion of this step in the manufacture that sufficient surplus metal has been removed from the face and sides of the casting to make it apparent whether or not the casting is free from sand, blow holes, checks, etc. Those found physically perfect are passed along for cutting. This is the most exacting operation, as it has been found that no matter how carefully a machine may be built, it is extremely difficult to cut gears without a slight variation in the thickness of teeth. The gears are mounted on arbors the exact size of the bore to ensure a concentric pitch line.

The usual practice of cutting gear teeth with range cutters has been abandoned, owing to the fact that they were found to be correct theoretically only. The practice in making range cutters is to make for each pitch a set of eight cutters, these being divided so that they will cut from 12 teeth to rack, one cutter, for instance, being designed to cut from 55 to 131 teeth. These cutters, however, would be

Fig. 3. Testing Gears and Pinions

only theoretically correct for the lowest number, i.e., 55 teeth; and it is the practice of this factory to order cutters to cut a specific number of teeth—that is, for a 67 tooth gear, a cutter made only for 67 teeth would be employed and not a range cutter. The gear-cutting process is illustrated in Fig. 2.

The product of the factory is now subjected to several further refinements, all burrs and rough or sharp edges, for instance, being removed by filing. The inspection consists of examination for quality and soundness of material and for mechanical defects of bore, keyway, face, hub and each individual tooth. All measurements of gear teeth are made with Vernier gear tooth calipers, but as the construction of this gauge necessitates measurements from the outside or face of the tooth, it is obvious that such measurements will not be positive if the face is not concentric with the pitch line: that is to say, the gauge might show false variations in teeth if it struck at points slightly above or below the pitch line. The possibility of such an error is therefore avoided by giving each separate gear a running test. In the case of standard gears a standard motor is used, but for special gears a testing frame is employed in which the gear with its proper pinion is run backward and forward several times.

After passing the various tests and inspection, the gears are painted with a special slushing compound and prepared for shipment.

The fundamental points of difference between the several sizes and grades of gears and pinions manufactured on these lines refer to the kind and grade of steel used. For many of the larger gears a soft machinery steel has been found adequate; these being usually run with unhardened pinions of a similar grade of soft steel or sometimes with those made of rawhide or cloth. Many of the largest gears also are made of a better grade of tool steel used either hard or soft, while often a tool steel hardened rim is shrunk on to the hub.

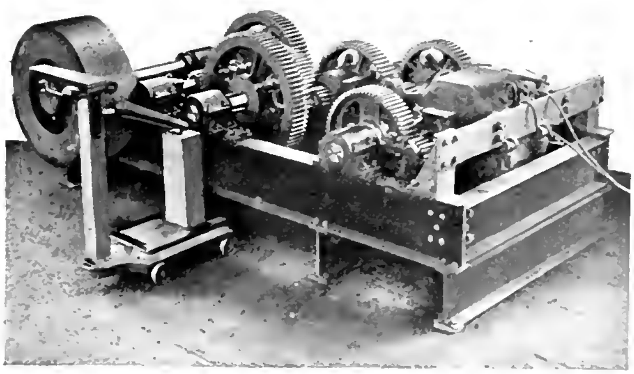


Fig. 4. Gear Breaking Machine

Of all standard stock received at the factory samples of each carload are subjected to a chemical analysis for carbon, manganese and phosphor, and no gear or pinion is allowed to pass the inspector or issue from the factory which fails to comply with the chemical specification.

With regard to the pinions, the blanks are first drilled and the splines cut upon a Knowles splining machine. The turning is performed upon special arbors. The blanks are then inspected to insure accuracy of the taper, and mounted upon special arbors for the cutting of the teeth, the cutting machines giving an accuracy to within a small fraction of one per cent. for pitch and diameter of the teeth; after which the pinions are again tested by running them with their respective gears. The next step in the process of either gears or tool steel pinions is their hardening, after which the product is submitted to further tests.

The first of these consists of a test for hardness in the Brinnel testing machine, (see Fig. 3) where a hardened steel ball of 10 millimeters diameter is forced against the hardened steel pinion by hydraulic pressure of 3,000 kilograms, the resulting dent being measured by a microscopic scale of 1/10 millimeter. The product is then submitted to its final process of re-cleaning, re-boring and final examination, after which it is slushed with vaseline and ready for the market.

The routine of the factory involves a weekly inspection of all completed products by the chemist of the department. Any gear or any pinion, wherever found, may be removed and carried off to the laboratory to be broken and crushed in testing machines, or analyzed chemically.

Fig. 4 shows a gear breaking machine built by the company to test its various products. It consists of a series of shafts geared together and running in bearings supported by a framework of I beams. At one end of the train of gears a standard railway motor is attached to drive the machine, while at the other end is mounted a Prony brake which absorbs and regulates the load transmitted through the gearing. The gear ratios are so chosen that the shaft speeds are successively reduced until the test gear shaft is reached. The speeds are then again increased by levers carrying ratios ending with the brake.

In this manner the loss in speed is balanced by an equal gain in torque so that a high turning moment is obtained without necessitating a correspondingly greater driving power. Brake load is measured by platform scales, the beam of which can be kept regulated with each load.

Measurements are taken with shim gauges before and after each increment of load is applied for the examination of such parts as keyways and clearance between joints in split arm gears, the purpose being to determine in what manner and under what loads deformations will first occur.

With an ordinary car of 40,000 lb. weight a load on the gear tooth of 4300 lb. is sufficient to slip the wheels; on the testing machine loads varying from 20,000 to 50,000 lb. are found necessary to break the gear.

PRESENTATION OF RUMFORD MEDAL TO CHARLES GORDON CURTIS

On April 12th last the American Academy of Arts and Sciences presented the Rumford Medal to Mr. Charles Gordon Curtis for his inventions on the steam turbine and its application to industrial purposes. The presentation was made before a notable gathering of scientists at a meeting of the Academy held in the University Museum of Harvard College, Cambridge, Mass. The meeting was also made the occasion of a series of interesting exhibits by the professors of the University, illustrating the work there being carried on in research and education.

The honor bestowed upon Mr. Curtis on this occasion was particularly appropriate as following the presentation in 1902 of the Rumford Medal by the Royal Society of Great Britain to Mr. C. A. Parsons for his services "in the application of the steam turbine to industrial purposes and its recent extension in navigation."

The meeting in Cambridge was opened by Prof. Chas. R. Cross, of the Massachusetts Institute of Technology, who, in presenting the President of the American Academy, briefly called attention to the progress and development of the steam turbine as an industrial engine. He pointed out that the two earliest steam engines, those of Hero of Alexandria (about 200, B.C.) and Branca of Italy (1629), were both turbines, the former of the reaction and the latter of the impulse type. Because of the ignorance of the laws of expanding steam, practically all effort to utilize either type proved futile until shortly before the middle of the 19th century.

It has, indeed, been only within the most recent years that Mr. Parsons has developed the reaction type and Mr. Curtis the impulse type of turbine into engines of the highest practical value.

In conferring the medals, Professor John Trowbridge of Harvard University, President of the Academy, spoke as follows:

"It is eminently fitting that the ceremony of conferring the Rumford Medals should take place in Cambridge, for Benjamin Thompson—afterwards Count Rumford—came here one hundred and thirty-five years ago to offer his services in the cause of liberty. Although he met with a rebuff and was afterwards an exile from his native land, he entertained no feeling of malice or prejudice, and gave a fund for another great cause—the advancement of science in America. I am sure that if he were present tonight, he would heartily commend the Academy for the bestowal of the medal upon one who has made such a remarkable advance in the application of science to the Useful Arts. I have the honor to present these medals to Mr. Charles G. Curtis."

* * *

Charles Gordon Curtis was born in the year 1861. He is a son of George Ticknor Curtis, an eminent lawyer and legal writer, who was the author of "A Treatise on the Law of Patents," for many years the authority on the subject. Mr. Charles G. Curtis was also a nephew of Mr. E. M. Dickenson, the celebrated patent attorney.

Mr. Curtis received his early training at Columbia University, from which institution he was graduated as an engineer. In his early career he was associated with Francis B. Crocker, later Professor of Electrical Engineering, Columbia University, in the Curtis and Crocker Electric Company, New York (1887-1889). This company developed and placed on the market one of the earliest of the successful electric fan motors, then known as the C & C motor. Mr. Curtis afterwards formed the company known as the Curtis Electric Company, for the manufacture of electric railway equipment. Subsequently, in 1895, he turned his attention to the subject which has since earned for him a world-wide reputation—the improvement of the steam turbine. It was at this time that he brought out his series of brilliant inventions which have since formed the foundation of the present development of the Curtis steam turbine by the General Electric Company.

Mr. Curtis, as president of the International Curtis Marine Turbine Company, is at present devoting his attention to the application of the turbine engine to marine propulsion.

ELECTRIC DRIVE IN THE AUTOMOBILE INDUSTRY

By W. D. Bearce

Although the manufacture of automobiles on a large scale has been undertaken only recently, the conditions under which the factories are operated are peculiar to the automobile industry, rather than being typical of modern machine shop practice, as might be expected. These conditions are due, first, to the phenomenal growth of business since automobiles were first put on the market, and second, to the effect of business conditions from year to year on the annual purchase.

The demand for the product of these factories is even more dependent upon the general prosperity of the country than that of the majority of manufacturing interests, since a large percentage of the cars purchased are intended for pleasure vehicles. It is therefore impossible to gauge accurately the demands upon the operating equipment for more than a year in advance. For this reason the factory apparatus has in a large majority of cases been designed to give the maximum flexibility with a minimum investment; in other words, the factory must be able to supply the demand for a large number of completed cars, and at the same time be insured against heavy losses in off years due to investment.

Electric drive has been adopted almost exclusively for the operation of automobile plants and many manufacturers are purchasing central station power. In most localities low rates are made for power used during the day and customers are thus saved the heavy first cost of generating equipment. There are, however, several isolated plant automobile factories in various parts of the country and a small percentage of these use direct current apparatus.

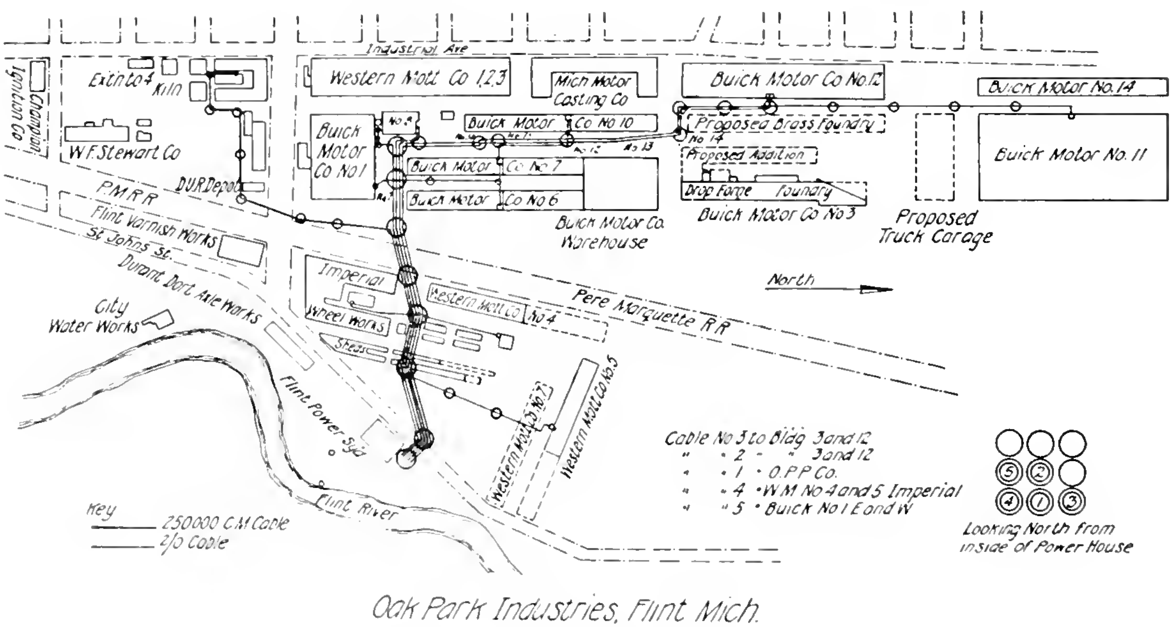


Fig. 1. Arrangement of Buildings and Underground Conduit System

In the main, however, alternating current is used, as recommended by the large electrical manufacturers. This is the most satisfactory source of power, since the factory is enabled to employ polyphase induction motors and to take advantage of the reliable and simple features of construction that are distinctive of this type of motor.

The installations of the Buick Motor Company and the Cadillac Motor Car Company, which are here illustrated and briefly described, indicate the methods of drive employed in the vicinity of Detroit. In most cases the various machines which comprise the manufacturing equipment are driven in groups, since this arrangement requires a somewhat smaller investment than the application of motors to each machine. Individual drive, however, is being installed in many cases where the older equipments have shown excessive operating cost and some change has become necessary.

One of the largest groups of automobile manufacturing buildings in the United States is located at Flint, Michigan, and is known as the Oak Park Industries. The Buick Motor Company is the largest manufacturer of this group, and the allied industries that are employed in the manufacture of automobile parts and accessories, are the Imperial Wheel Works, Armstrong Spring Works, Champion Ignition Works, Flint Varnish Works, Michigan Motor Casting Company, Durant Dort Axle Works, and the Weston Mott Company. With the exception of the last concern, the business of each of these companies is indicated by its name. The Weston Mott Company manufactures axles and transmission parts.

These industries are supplied with electric power by the Flint Power Syndicate, through a modern steam turbine generating station having a capacity of 7000 kw. The generating units consist of two Curtis turbine alternating current, 3-phase, 60 cycle, 5000 volt generators, one of the vertical and the other of the horizontal type. Energy is transmitted at the generator potential to the Oak Park Industries by an underground conduit system composed of five 3-phase lead-covered cables insulated for 24,000 volts, each cable having a normal capacity of 2500 kw. The conduit system is arranged to receive additional cables as they may be required.

This power station is supplied with the most modern equipment throughout and in addition to the Oak Park load furnishes light and power to the city of Flint.

The accompanying diagram (Fig. 1) shows the arrangement of the buildings in the Oak Park reservation, and also the underground conduit through which the power is distributed. The Buick Motor Company, as before mentioned, is the largest concern in the group and when running at its full capacity employs about 9000 men and turns out 180 completed cars per day. The electrical distributing system of this plant comprises nine step-down transformer stations for reducing the potential of the incoming current from 5000 volts to the working voltage of the motor and the lighting circuits. The motors are operated from 3-phase, 440 volt mains, while the lighting is supplied from single-phase, 3-wire, 110-220 volt mains.

The transformer stations are completely equipped with control and distributing apparatus, including large oil break switches for both high and low tension circuits, tubular busbars of seamless copper, and all protective devices. The transformer capacity totals 6375 kw. for power and 1650 kw. for lighting circuits. Fifty-two General Electric K-12 oil break switches, ranging in capacity from 500 to 2000 amperes are employed. Energy is distributed through the buildings in iron pipe conduit.

The factory machinery is for the most part suited to constant speed drive, and the squirrel cage type induction motor is therefore used throughout the plant as standard. In the single story buildings, these motors are mounted in bays at regular intervals, while in the two and three story buildings they are suspended from the ceiling. One hundred and eighty-five motors ranging in sizes from 5 to 100 h.p. and aggregating nearly 5000 h.p. capacity, are installed. The 25, 35 and 50 h.p. sizes predominate, however, and a large number of motors of this size enables the electrical department to make changes on short notice, in case of breakdown or a change in the load requirements. Frequent tests are made on all of the motors arranged for group drive in order to keep the load on each motor as nearly normal as possible. In this way the power-factor of the system is kept comparatively high.

All motors 5 h.p. and above are controlled by the new type General Electric compensator equipped with overload relays and no-voltage release. The automatic features have already effected a large saving in cost of maintenance and labor over the non-automatic type formerly used. With the old method of control several electricians were constantly employed replacing burned out fuses and investigating causes of shutting down of motors in various parts of the plant.

Fig. 2 shows a view in the screw machine department, building 1. A 35 h.p. motor drives the group of machinery on the left, while four other motors drive similar groups of machinery in the same room, all being controlled by five starting compensators mounted as shown in the illustration. The motor equipment in building 1 comprises thirty-nine motors with a combined rating of 1200 h.p.

One of the largest buildings of the plant, known as the sheet metal working department, employs drives similar to that indicated in Fig. 3. Each of these large form

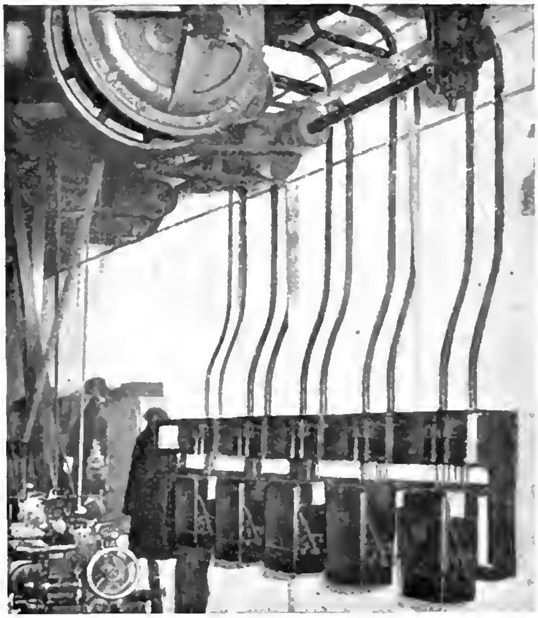


Fig. 2. Starting Compensators in Screw Machine Dept. Buick Motor Works

presses requires a 35 h.p. motor which is mounted in the bay in a manner similar to that employed in the group drive. The electro-plating department is also located in this building, with apparatus for plating the various metallic parts included in the make up of cars. Two generating sets supply current for this purpose, each consisting of a 35 h.p. motor driving a 24 kw. low voltage generator by means of a chain belt. Large copper buses carry the current to the electroplating vats. The motor equipment in this building comprises twelve 35 h.p. and three smaller motors.

The largest building of the group is known as the engine building department. This is a one story building 770 ft. by 350 ft. and contains all the necessary apparatus for machining, assembling and making preliminary tests on the gasolene engines. The motors in this building are installed in bays at regular intervals and the starting compensators are mounted on posts easily accessible by the operatives. Twenty-two 35 h.p. motors are installed in this manner which, together with three 25 h.p. and five smaller motors, take care of all the operations performed in this department.

Both steam and electricity are used in the forging department, building 3, steam being employed for the operation of some of the larger forging hammers. All of the drop forgings for crank shaft, framework, etc., are made in this building and their manufacture necessitates a large amount of machinery especially designed for forging automobile parts. Fig. 4 shows one of the large upsetting machines used for upsetting the ends of the crank shafts. This machine is driven by a 35 h.p. motor and on account of the intermittent service is supplied with a large fly wheel. Nineteen motors, aggregating 748 h.p., are installed in this building; these motors being used for the operation of hammers, shears, presses, blowers and air compressors.

Buildings 6, 7, 10 and 14 are used mainly for the assembly of the different types of cars and require little power. The body building department, bldg. 4, also requires only a small amount of power because of the large proportion of work that is necessarily done by hand.

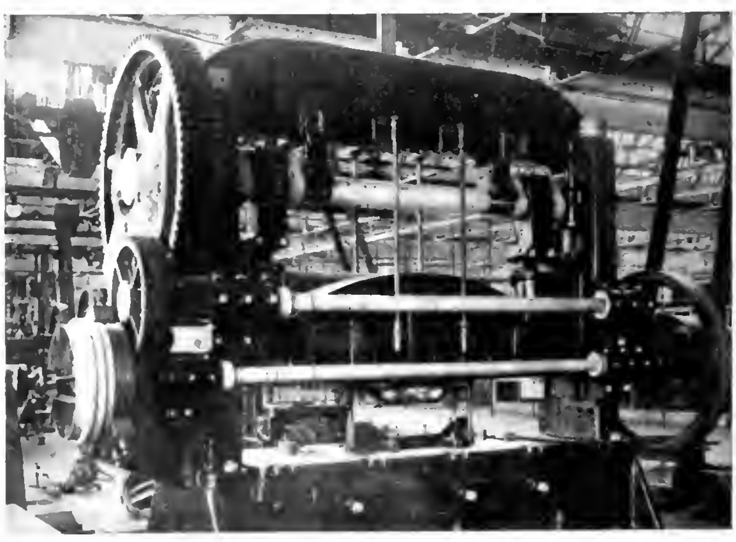


Fig. 3. Form Press in Sheet Metal Department

The entire electrical equipment of the Buick Motor Company, including transformers, motors, control apparatus and underground cable, is of General Electric manufacture.

Cadillac Motor Car Company

The Cadillac Motor Car Company is one of the oldest manufacturers of gasolene motor cars, and because of its extensive experience can predict the annual production more closely than the majority of automobile manufacturing concerns. For this reason their electrical engineer is equipping quite a large proportion of the apparatus with individual drive, the intention being eventually to install a motor on every machine in the plant.

This factory also uses central station power, obtaining it from the mains of the Detroit Edison Company at a potential of 4600 volts. Three 250 kw. transformers step this voltage down to 220 for the motor mains, while one 150 kw. transformer reduces the potential to 110 volts for the incandescent lighting system. The motor equipment, including both group and individual drive, comprises eighty-two General Electric motors, totaling 1520 h.p. On account of the comparatively large number of small motors in use, considerable trouble has been encountered, owing to low power factor. This condition, unless remedied, necessitates a much larger transformer capacity than would be required for a load of unity power factor, and to overcome this difficulty the Cadillac Company has installed

Fig. 4. Upsetting Machine in Forge Shop, Buick Motor Works

a synchronous motor-generator set which is capable of raising the power factor on the supply mains from 65 to about 85 per cent. The generator end of this set is used to supply 250 volt direct current to the adjustable speed motors in the machine shops. The

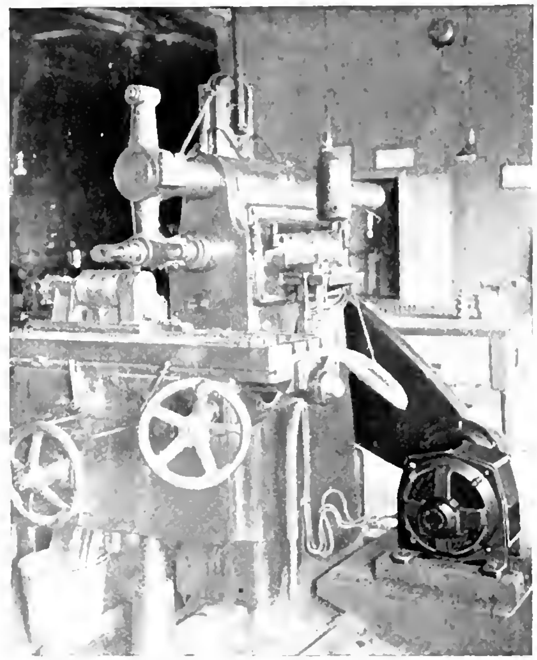


Fig. 5. Machining Automobile Parts

illustration on page 298 shows a view of this set, together with the controlling switchboard. The synchronous motor is rated 170 kv-a. at 220 volts and is designed for operation at 70 per cent. power factor leading current. The direct current machine is rated 100 kw. at 250 volts, and is equipped with commutating poles. Provision is made at the switchboard for switching on the 250 volt direct current supply from the city mains in case of emergency or for night and Sunday requirements.

Four of the turret lathes in the screw machine department are individually driven by direct current motors rated 15 h.p. at 625 revolutions per minute. The majority of the apparatus, however, is driven in groups by three-phase induction motors mounted on the ceiling.

Several grinders in the same department are driven by 5 h.p. squirrel cage type induction motors direct connected to the machine. The milling machine department, where forgings are machined, also employs several individual drives. One of these is shown in Fig. 5, a Cincinnati milling machine being

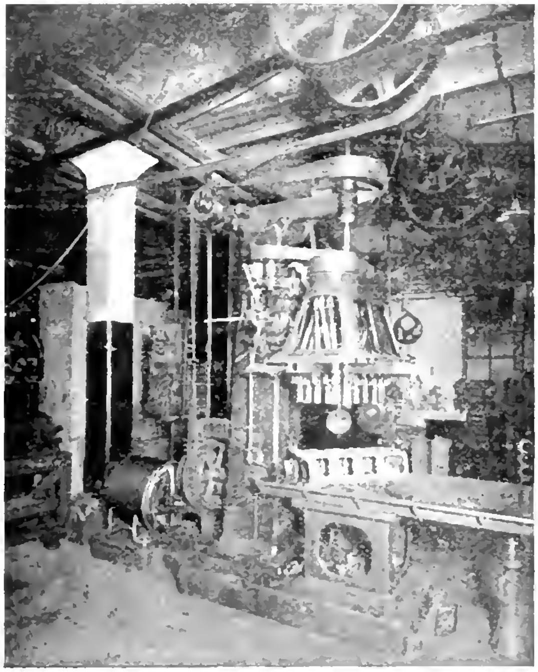


Fig. 6. Drilling Motor Castings, Cadillac Machine Shops

driven by a $7\frac{1}{2}$ h.p. induction motor. The screen protection ordinarily used with the bearing bracket of this motor is removed to show the method of connecting.

In finishing the motor castings several special drilling machines of the multi-spindle type are used, as shown in Fig. 6. A 16 h.p. 230 volt direct-connected motor is employed to drive this drill and is arranged for a speed adjustment from 900 to 1800 revolutions per minute. Fig. 7 shows a special miller driven by a 1 h.p. induction motor, especially constructed to mill off the supporting bosses for reception of the engine. This outfit is easily moved from one frame to another as fast as the machine work is finished, by means of a hoist supported from the track above. Seven milling operations are performed simultaneously by as many milling cutters, all gear driven from the same motor. Special merit is claimed for this apparatus because of the fact that by its use all frames and engines are made interchangeable so that any engine can be placed in any frame without being individually fitted.

In addition to the Buick and Cadillac factories, the following plants in this section are also operated by electric motors, employing in general the same methods of drive as those above described.

Elmore Manufacturing Co., Clyde, Ohio
Cartercar Co., Pontiac, Mich.
Oakland Motor Car Co., Pontiac, Mich.
Welch Motor Co., Pontiac, Mich.
Welch Motor Co., Detroit, Mich.
Northway Motor & Mfg. Co., Detroit, Mich.
Lozier Motor Co., Detroit, Mich.
E-M-F Co., Detroit, Mich.
Chalmers Motor Co., Detroit, Mich.

With the exception of the two last named these factories are equipped entirely with General Electric motors.

The exacting requirements of the automobile manufacturing industry have been very satisfactorily met by electric drive, and this method of power application is of special advantage when overtime work is required or when it is necessary to make additions to the existing equipment. The need for frequent additions to the manufacturing facilities has lead to the general adoption of central station power, as the necessity for additions both to motor and generator equipment is thus obviated.

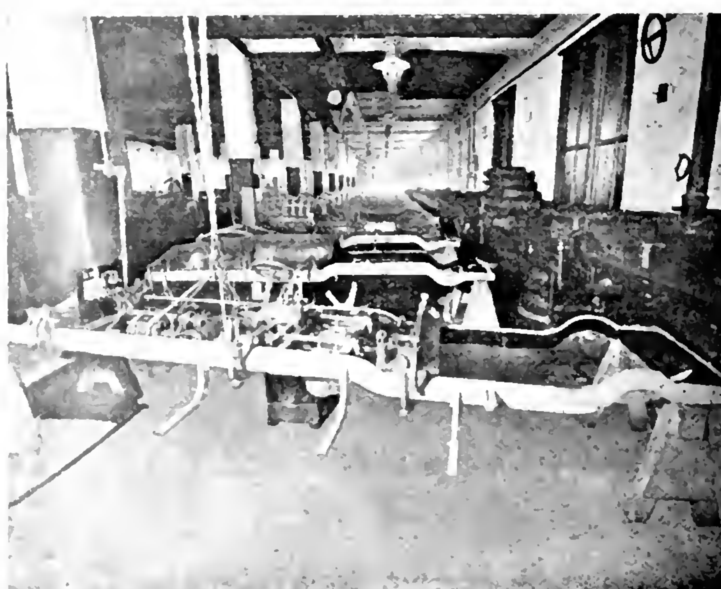


Fig 7 Portable Miller on Assembling Floor, Cadillac Shops

GENERAL ELECTRIC REVIEW

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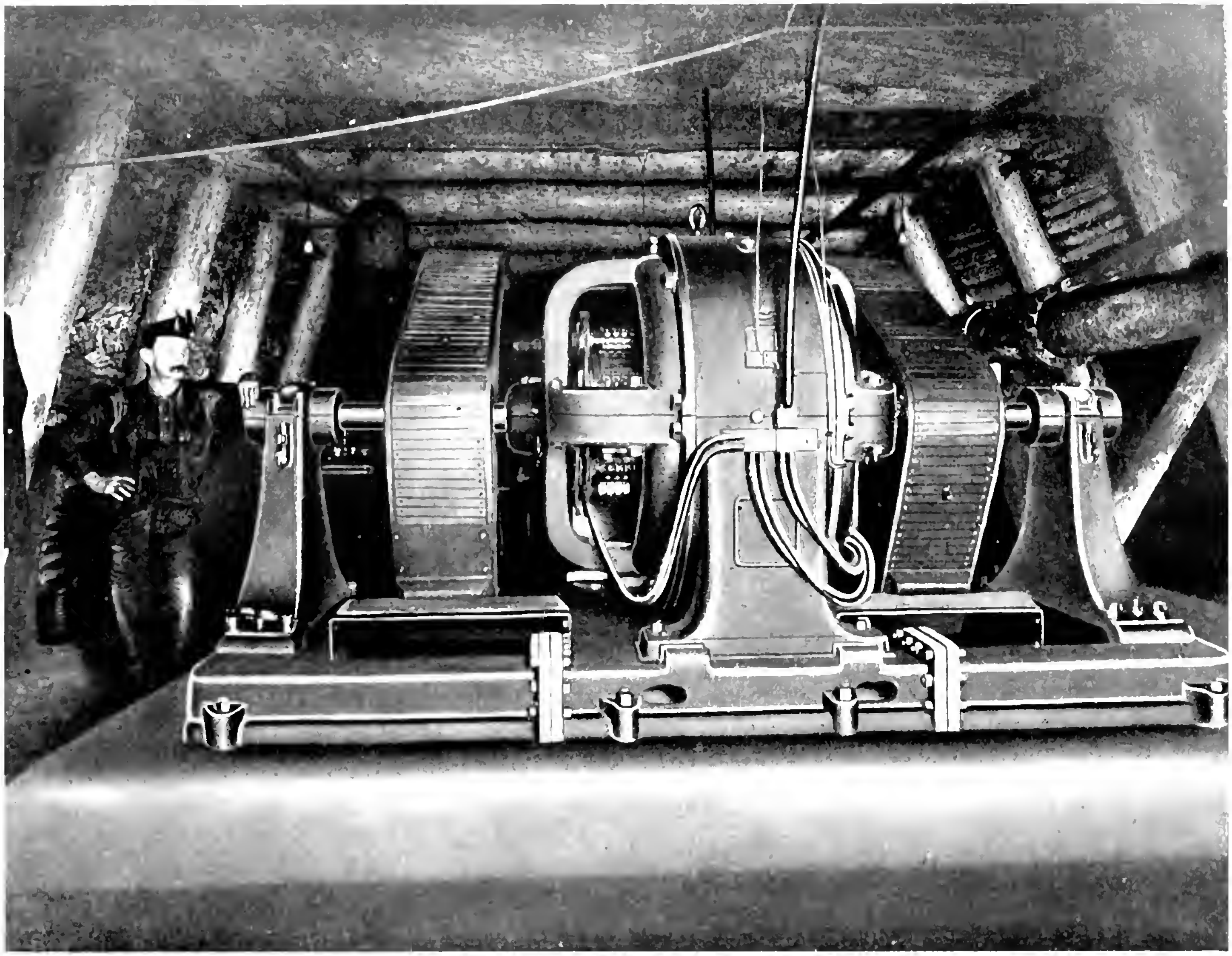


170 H.P. 300 450 R.P.M. Motor Driving 10 In. Quintuplex Pump Through Gears; Operating Head 400 Ft.
Kohinoor Colliery near Shenendoah, Pa.

GENERAL ELECTRIC REVIEW

GASOLENE-ELECTRIC GENERATING SETS

We are able to publish this month several articles dealing with the gasolene engine electric generating sets which have been developed by the General Electric Company. The question of prime movers for isolated installations is of very great interest to all connected with the central station business, as well as to farmers, owners of country estates, and others similarly situated, who require a reliable and efficient generating plant.

Mr. J. S. Button in the first article on page 376 traces some of the history of the subject, describing how the demand for such generating sets was created. Mention is made of some of the specifications which are met by the General Electric sets, both as regards the constructional details and also the general performance; and a substantiation is thus provided for the claim that, for their particular purpose, these sets concede first place to no other similar apparatus on the market.

In the second article on page 380 Mr. B. H. Arnold lays stress on the necessity for simplicity in the design and absolute reliability in the behavior of these generating sets; and gives an account of some of the various factory processes and tests which are performed in their manufacture.

The third article by Mr. John Hay Kuhns on page 383, describes a diminutive central station at Lewis, Ia., where a General Electric gasolene engine generating set is supplying electrical service to a town of 650 inhabitants. This article appeared in the columns of *The Electrical World*, and is now reprinted through the courtesy of the editors of that paper.

The fourth article by Mr. Bonyun on page 387 describes the gasolene-electric installation at the Hotel Indian River, Rockledge, Florida. Apart from the electric service, a point of interest in this installation is the method which is adopted for utilizing in the hotel the hot water taken from the jackets of the engine cylinders.

These articles should fully illustrate the peculiar suitability of the gasolene generating set for isolated plant service; and apart from the obvious advantages which may be obtained by the farmer, hotel proprietor, etc., emphasis should be laid on the service which they are capable of rendering to the central stations themselves. Nearly all central stations experience peak load conditions in which their steam-driven machines may be running at an overload, but are still just unable to supply the maximum of the peak required. Frequently, an additional 10 kw. or 25 kw. would suffice to carry them over their peak, and for conditions such as these, the gasolene engine set has been found admirably suitable for supplying the necessary extra output. The gasolene units for this purpose must of necessity be designed for parallel operation, and this feature is therefore taken care of in their design. The utility of this unit is equally obvious when applied to the valley load which, though small, must nevertheless be supplied by the central station. During the early morning hours this load may be safely carried by a comparatively small gasolene set, allowing all the steam units to be cut off, fires banked and the station run on an efficient and economical basis, the gasolene set requiring no more attention than can be given it by a watchman.

A further field in which the gasolene set has proved its marked usefulness is concerned with the missionary work which it may undertake, in connection with outlying communities beyond the fringe of a central station supply system. In cases of villages without electric service, and where the probable load which would be realized is problematic, a comparatively small expenditure of capital is required to install an isolated set in the village or villages in question. After the interest has been crystallized and the advantages of electricity demonstrated, the central station can profitably extend their lines to take care of it, and the gasolene set may then be installed in another village for the purpose of developing the load there; and so on, until all the districts within a given radius have been tested out as to their ability to furnish profitable central station load. After the gasolene set has proved its service as a missionary, it can then be placed in the central station to take care of the peak and valley loads referred to above. Very great advantages in developmental work may therefore be obtained through the medium of these sets.

MAGNETOS FOR AUTOMOBILE GASOLENE ENGINES

In the days when the battery, used in conjunction with a vibrating coil, was the universal method of ignition for automobiles, breakdowns on the road were of considerably more frequent occurrence than they are today; and although when it was first introduced the magneto was regarded not as a necessity, but more in the light of a luxury, nevertheless today no gasolene car is complete without it, and it has come to be considered as an essential to the modern automobile. The article which we publish in this issue by Mr. H. S. Baldwin, on automobile ignition and the new General Electric magnetos, traces the steps in the evolution of the modern automobile and the magneto system of ignition. Mr. Baldwin notes the point at which the General Electric Company commenced a close study of the ignition problem, and gives a description of some of their more recent models of magnetos.

These may be designed on the alternating current system, high tension or low tension, or the direct current system, using the jump-spark or the make-and-break method of ignition, the choice of the system being governed to a large extent by the type of vehicle in which the apparatus will be installed.

We may here briefly define these two systems, and note the salient points of difference which determine the suitability of each for particular operating conditions. The jump-spark ignition system depends for its action on the passage of the spark across a fixed air-gap, of which both the electrodes are fixed metallic points. The current is generated at a low potential and stepped up to a potential sufficiently high to cause the jumping across of the spark in the compression space; whether the stepping up takes place in the magneto itself, or is performed in a separate transformer coil, does not affect the principle of operation. In the alternating current jump-spark magneto described, the primary winding is short-circuited until the spark is required, when the short circuit is opened and a high voltage secondary current is induced. In this system therefore, the spark is produced when the circuit is complete, the spark itself causing the closing of the secondary circuit.

The make-and-break method, on the other hand, consists in causing a spark at the air-gap by actual movement of one of the electrodes, the necessary timing of this movement being achieved by mechanical means. The spark may result from a "wipe-break," caused by rubbing the surfaces of the electrodes together and then quickly separating them; or a "hammer-break," in which the points are forced against each other and released with a spring. In this case, therefore, the spark is produced when the circuit is opened, and a transforming coil is not required. All that is necessary is a primary induction coil having a large number of turns, so that when the circuit is suddenly broken an induced e.m.f. of high potential will result. With the alternating current low tension magneto described in Mr. Baldwin's article, working on the make-and-break principle, even this coil is eliminated, since the design of the armature winding is such as to give rise to a high induced e.m.f. when the circuit is ruptured at the gap.

The jump-spark magneto may be made self contained, i.e., with the step up coil as an integral part of the magneto itself, this arrangement being particularly suitable for light and medium-sized cars. In the case of larger machines, the coil is generally mounted independently, and the dual system of ignition may be adopted; i.e., the magneto may be used in conjunction with a secondary battery, the latter being used when starting the engine from rest, and the change over being effected by a small double-throw switch. For installations where the wiring must be run in exposed positions, e.g., in motor boats, the make-and-break system is usually found desirable, provided the speed of the engine is sufficiently low to allow of this, owing to the fact that a simple primary induction coil is employed to obtain the spark voltage, and the high tension wiring is therefore eliminated.

ALTERNATING CURRENT APPARATUS TROUBLES

PART III

BY D. S. MARTIN AND T. S. EDEN

In this article we shall first consider the failure of an alternating current generator to produce and maintain its rated voltage. Certain defects may exist in the machine, such as an open-circuit in the field, open-circuit in the armature, and reversed coils in the field or armature, which will render it impossible for the generator to develop its normal voltage even on no load, and such defects will fall under the head of Failure to Generate. If it is found that the generator is not suffering from these defects and is able to develop its rated voltage on no load, it may on the other hand be found that there is an excessive drop in voltage as load is applied to the machine, this trouble coming under the head of Regulation. We shall here consider all the reasons which may be responsible for voltage failure, or voltage variation, of an alternator, either in the machine itself, or in the external circuit, and shall for the present deal with the performance of a single generator, parallel operation of generators being considered in a separate article. It should also be understood that these notes are intended to apply to alternators built with stationary armature and revolving field.

FAILURE TO GENERATE

Cause 1. Open-circuit in field winding.

With full excitation voltage provided at the collector rings, and with the generator running at full speed, it should be possible to obtain normal voltage at the armature terminals by adjustment of the field rheostat and without exceeding the normal excitation current of the machine. Considering the case of a three-phase generator, a total absence of voltage at the terminals of all three phases will point to an open-circuit in the field winding. In view of the fact that the field coils of nearly all alternating current generators consist of turns of copper strip wound on edge, an open-circuit in the actual winding is of very rare occurrence and will usually be found to take place only where the copper has been burned right through. This may be caused by a short-circuit between adjacent field turns, or by a ground, and an open-circuit may result. In such cases the faulty coil will have to be replaced. An open-circuit in the field is, however, more likely to be found in the connections between adjacent spools, and these should therefore be inspected to see whether they furnish the cause of the open-circuit.

Cause 2. Reversal or short-circuit of individual field poles.

In cases where with full excitation a voltage reading is given across all phases less in value than the rated voltage, but the same value for all phases, or conversely if full voltage can only be obtained with an excessive excitation current, this will point to a defect in the field circuit. Such a defect may consist in incorrect connection of the individual spools causing reversal of polarity, or to a short-circuit in one or more spools. A resistance test should be taken of the field windings, the drop being read across each individual spool. A short-circuited spool will show correspondingly reduced drop. If the resistance of all spools is found to be the same, this will indicate a reversal of one or more of them; and test for this may be made with a compass to obtain the correct alternation of N. and S. poles around the periphery. The reversed spool condition is one that would not be met with outside the factory, unless for some reason the field connections had been taken down during service in dissembling the machine, etc., and had then been incorrectly re-made.

Short-circuits in the field winding, however, are of rather more frequent occurrence. Sometimes in the case of high-speed turbo-generators they may be the result of some mechanical defect; pieces of the field laminations have been known to break off, cutting through the insulation between turns, while dislodgment of a balance-weight has sometimes acted with the same effect. A more common cause of this trouble is the excessive potential which may be induced across the terminals of the field winding when the field current is suddenly broken. This may be avoided by the provision of a field discharge switch and resistance; but in cases where such a switch is omitted or is inoperative, the induced voltage between turns may rise to a value many times greater than the breakdown value of the insulation, and thus cause a short-circuit between adjacent turns.

Cause 3. Open-circuit in armature phase. Another factor which may affect the ability of the generator to give its normal voltage, but which will only apply in the case of Y connected armatures, is open circuit of an armature phase. A Δ wound armature having one phase open-circuited would continue to show full voltage across all terminals; over-heating of the two effective phases would, however, result, and further reference to this defect is therefore made under the heading of Overheating of the Armature. In the case of a Y connected armature, an open-circuit in one phase would be indicated by zero voltage across two of the three pairs of outgoing lines. A test for this trouble may be made with a magneto and bell, ringing through from the neutral to each terminal in cases where the neutral is brought out.

REGULATION OF A GENERATOR

By regulation of a generator is meant the percentage rise in voltage between full-load and no-load, this percentage being greater for full-load inductive than for full-load non-inductive.

The terminal drop in voltage of a generator as load is applied is due to two causes, first, the impedance drop in the armature winding, and, second, the distortion of the field due to the armature reaction. It is the second of these factors which causes the impaired regulation when an inductive load is applied, owing to the fact that the phase displacement between current and e.m.f. brings the magnetic field set up by the armature coils into the most favorable position for reacting on the main field. The resultant distortion of the field is directly responsible for a fall in terminal voltage, while conversely to maintain a constant terminal voltage it is necessary to increase the excitation on the main field. The arrangement of the armature windings may be designed to reduce to a minimum the resultant field distortion due to armature reaction; but with the best design a regulation of 20% with say 75% power-factor is difficult of attainment.

In view of the fact that most alternators that are built at the present time have to supply power for both induction motors and lighting, it has now become standard practice to employ an automatic voltage regulator for holding the voltage steady at all loads by control of the field circuit. This is mounted at the station switchboard, and in many installations regulators are also installed on the several distribution circuits.

In cases where such automatic regulation is not provided, all voltage control must be made by hand regulation in the field circuit. When a generator is designed it is, therefore, necessary to know whether it will be used in conjunction with an automatic regulator, as in that event some degree of self regulation may be sacrificed with a corresponding gain in efficiency. In certain cases, too, a generator may be intentionally designed with poor regulating characteristics, instances of this being generators for supplying current for series arc lighting systems, electric smelting, etc.

All these factors must be considered when the design of the machine is laid out; and if under service conditions a machine is found apparently to fail in its regulation guarantee, the source of the trouble may frequently be found in the fact that a highly inductive load is being placed on the machine, which was not allowed for when the generator was designed. It may not be possible to remedy the trouble by removing the cause; and if it is essential that such a load be taken care of, it may be necessary to rewind the generator to meet the inductive load conditions.

In many systems where there is a heavy motor load that has of necessity to be carried by the alternator, with a very low resulting power-factor, the trouble has been cleared by the installation of a synchronous condenser. The operation of these has been fully described in the May, 1911, number of the General Electric Review. Their effect is to take a leading current from the supply, thus improving the power-factor of the circuit and hence the voltage regulation of the generator. It should be noted that such condenser installations have usually been made especially with a view to avoiding the necessity of generating and transmitting a wattless current on systems carrying heavy inductive loads, but their effect on the voltage regulation is often of vital importance.

OVERHEATING

The next alternator defect which we will consider is overheating of the various electrical parts, these being dealt with under the headings of rotor or field, stator or armature, and collector rings.

Overheating of Rotor or Field

In discussing overheating of the field, it will be as well to state exactly what part the field plays in enabling the alternator to perform its guarantee with regard to full load output and permissible heating. This guarantee is expressed in terms of voltage, kilowatt output, power-factor, speed and time.

In order that a terminal voltage may be provided, the armature conductors must cut the lines of force of a magnetic field. At no load, this field is simply the field provided by the poles on the rotating element; under a load, it is the resultant of this field and the distorting field which is set up by the current in the armature conductors. The resultant flux must have such a value that when the lines of force are cut by the armature conductors, a certain specified voltage will result in accordance with the terms of the guarantee. The component provided by the main field or rotor must, therefore, be sufficiently strong to provide this resultant field when compounded with the distorting armature field. To provide this main field flux, a certain definite exciting current is required in the field winding, the value of this current depending on the degree of saturation of the iron in the pole pieces; and the heating guarantee, as far as the field is concerned, will be met if the field winding will carry this current for the specified time and with the specified temperature rise.

With this explanation, it will be more easy to locate possible sources of trouble if the generator field reaches a temperature outside the guaranteed figure.

Cause 1. Short-circuit of one field spool.

A short-circuit of one field spool or of a portion of one field spool will render a certain number of turns on the field inoperative; and therefore in order that the main field component and hence the main field ampere turns may be the same, the current flowing in the remaining spools must be increased. The amount of this increase will depend on the number of turns which have become ineffective through being short circuited, and in given circumstances this may result in considerable overheating of the effective spools. This trouble is best located by taking a resistance test of the field system. Further remarks in this connection will be found above under heading of "Failure to Generate."

Cause 2. Generator run above rated voltage

Under certain circumstances a generator is intentionally run above its rated voltage in order to compensate for excessive line drop; while in other cases, through defective reading of the voltmeter, etc., the machine may be actually giving a greater terminal pressure than is indicated on the instruments. This increase in voltage can only be obtained by increasing the field flux, referred to above as the resultant field; and with the component due to armature reaction remaining the same, the component due to the main field must be correspondingly increased, requiring a greater exciting current in the field winding with consequent overheating.

Cause 3. Generator run below rated speed.

Since terminal voltage is a function of the rate at which the lines are cut, as well as the number of lines, the effect in this instance will be the same as in Cause 2; and with the armature reaction remaining the same, the component of the main field must be increased. This can only be obtained by increasing the excitation current in the field winding.

Cause 4. Generator run on a load having excessive inductance.

As pointed out above in our remarks on the regulation of the generator, the effect of an excessive current lag is to increase the distortion of the field due to armature reaction. The effect of this is to weaken the resultant effective field; and in order that the terminal voltage may be maintained at the rated value, a heavier field must be provided by the main rotating element, in order that the resultant field may be kept at the required intensity. This again will call for a greater exciting current.

Cause 5. Generator overloaded.

The effect of this will be similar to the effect of running the alternator on a load having considerable inductance, in that it will increase the armature reaction component of the resultant effective field; and, therefore, to compensate for the distortion thus produced, the component of the main field must be increased with a resulting overload on the field winding.

It will be noticed that Causes 2, 3, 4 and 5 above do not relate to defects in the machine itself, but are concerned with abnormal load conditions which may arise. It is difficult here to indicate any methods whereby such conditions may be recognized and the trouble remedied; but the foregoing, it is hoped, will serve to make clear the directions in which such abnormal conditions may affect the operation of the machine.

It is to be presumed that in cases where the generator is intentionally run under abnormal conditions with regard to load, speed, etc., due care will be taken to relieve the machine from these conditions before the consequent overheating can reach a dangerous point. Where these conditions are not the result of intentional overloading, etc., i. e., in cases where the generator is actually developing a greater output or higher voltage, etc., than that indicated by the switchboard instruments, due to incorrect calibration, or where the generator is running below normal speed, due to incorrect tachometer readings through belt slippage, and overheating results, repetition of the trouble may only be avoided by regular calibration of the meters, including ammeter, voltmeter, wattmeter and tachometer.

Overheating of Collector Rings

Any of the causes which are responsible for causing an overload current and consequent overheating in the field winding may be responsible for overheating of the collector rings, since the latter constitute an essential part of the field system and carry the main field current. Overheating of the rings will, therefore, usually be found to be the result of carrying an overload current, while sometimes the trouble may be the result of excessive friction between the rings and the brushes. This would be caused by excessive pressure on the brushes, due to incorrect adjustment of the spring tension, or to a dirty or uneven surface of the rings, causing imperfect contact with the brushes, and therefore excessive contact resistance.

The process of locating the cause of the overheating must be one of elimination; and it should be first ascertained by an ammeter in the exciter circuit whether the rings are carrying an overload current. If it is found that the source of the trouble does not lie in this direction, careful inspection should be made of the condition of the brushes and the rings, with a view to ascertaining if there is excessive friction, uneven bearing surface, etc., between brushes and rings.

We come next to overheating of the stator or armature. This subject may best be considered under two headings; first, overheating of the core or iron, and second, overheating of the winding or copper.

Overheating of Stator Core

First, with regard to the stator core, it will be a simple matter to appreciate the various sources which may be responsible for overheating, if it is borne in mind that the iron of the armature really constitutes an essential part of the field system and that, therefore, *the causes which will be responsible for overheating of the field winding will also lead to overheating of the stator iron.* In dealing with overheating of the field winding above, we pointed out that the field copper should be designed for carrying a full load current, sufficient in value to provide a certain definite flux from the main field poles, this flux representing one component of the resultant field, of which the other component was furnished by the field due to armature reaction.

The function of the stator iron, besides forming a support for the copper conductors, is also to complete the field magnetic circuit; and the area of the iron must therefore be designed sufficiently large to carry the resultant flux which is necessary to enable the generator to give its specified voltage under normal load conditions. Any factors which cause an increase in this flux will therefore cause an increased flux density in the stator iron with a correspondingly increased temperature rise; these factors being, *first, generator running above normal voltage; second, generator running below normal speed; third, generator carrying inductive load greater than the specified amount; fourth, generator carrying overload;* and it will be seen that none of these four causes relates to defects in the generator itself.

As stated above, when dealing with overheating of the field, regular attention should be paid to the meters and speed indicators, to ensure that they are giving accurate indications of the values which they are supposed to measure.

Cause 5. Defective insulation between stator laminations.

The only factor in the design of the machine which can be responsible for overheating of the stator iron concerns the insulation between laminations of the core. This insulation is provided to minimize the energy loss in the iron due to hysteresis and eddy currents, and in cases where this becomes defective due to overheating, vibration, etc., overheating will further be caused as the result of the increased energy loss in the iron due to these causes.

Overheating of Stator Winding

Cause 1. Overheating of the armature winding is usually occasioned by overloading of the generator, i.e., by taking a heavier current from the winding than the value for which it is designed. This may be sometimes occasioned by the fact that the indications on the ammeter or wattmeter give an under-rated value of the load under which the generator is operating, although it will more often be found to be the result of intentional overloading.

Cause 2. Conduction of heat from the armature iron. This may result in cases where the stator core has become overheated through any of the causes given above.

Cause 3. Short-circuit of one or more coils in armature phase or phases.

Whether the armature be Y or △ connected, the effect of a short-circuit in one armature coil will usually result in burning out the coil, since a heavy circulating current is set up in the defective coil, and therefore the first indication of this trouble will usually be given by the smell of burning varnish. It will be possible sometimes to locate the short-circuited coil by feeling around the end connections with the hand, where these are accessible; but a certain proof of a short-circuit in any one phase will be given by making a resistance test. In the case of Y connected machines with the neutral brought out, a direct comparison of the voltage-drop readings will show which is the phase having short-circuited turns; while in the case of △ armatures and Y connected armatures with insulated neutral, where each resistance reading involves two phases, the defect will be shown in two of the three voltage-drop readings, and the defective phase may be traced by a comparison of the three results.

It is difficult to lay down any rules for the avoidance of such short-circuit troubles. The design of the generators is laid out in such a manner as to prevent the possibility of their occurrence, as far as is possible. Sometimes a bar winding for an armature may be such as to render insulation of the end connections difficult, and the substitution of a coil winding may give greater safety in certain cases; but it would be unsafe to generalize from this and say that the coil winding should always be adopted to prevent such short-circuits occurring.

Similarly, in armatures having a winding of two coils per slot, cases have been known in which the insulation between coils in the slots charred due to the fact that the heat generated could not be carried away sufficiently rapidly. In such cases it has been found that a winding of one coil per slot may be substituted with advantage, provided the characteristics of the machine render this course possible.

Cause 4. Grounding of one armature phase. In the case of △ connected machines, a ground in one armature phase will not of itself cause trouble, until the appearance of a second ground, which would result in short-circuiting a portion of the armature winding. This applies also to the case of a Y connected machine with insulated neutral; but in the case of a Y-connected armature with grounded neutral, the effect of a ground in any part of the armature winding will be to short-circuit a portion of the windings. In cases, therefore, where the resistance test mentioned for locating short-circuit is not successful in determining the cause of the trouble, a ground should be tested for with magneto and bell, or by taking an insulation resistance test.

Cause 5. Reversal of one or more coils in one armature phase. This defect should be considered separately for △ connected and Y-connected machines; and in order to give point to the trouble which may be caused from this source, it may be well to conceive a case in which half the coils of one phase were connected so as directly to buck the other half of the winding. In the case of △ connection owing to the fact that the defective phase would generate of itself no potential whatever across its terminals, a heavy circulating current would be set up around the △ sufficient to cause considerable overheating of the winding. In the case of a Y-connected armature, the effect of zero voltage across the terminals of one phase, produced in the manner indicated, would result in a reading of normal voltage across only one pair of outgoing lines, while the voltage reading across the other two pairs would be equal to normal voltage divided by $\sqrt{3}$.

This, of course, is an extreme case and will probably never be met with in practice; indeed, the trouble from a reversed coil is one which would not be encountered outside the factory, since defects of this nature are detected when the machine is tested. Probably the only method of ascertaining whether a reversed coil is the source of the trouble will be by checking up the winding with the drawing, and if necessary rewinding in accordance with the correct winding diagram.

Cause 6. Open-circuit in one phase. The effect of an open-circuit in one phase will show itself as regards overheating only in the case of a △ wound armature. With a △ winding open-circuited in one-phase, it will be possible to read normal voltage across the three armature terminals; but as regards overheating, the result of one phase becoming inoperative through being open-circuited, will be to place a heavy overload upon the two effective phases, as these will then carry the entire load on the machine, and will, in consequence, become overheated. Test for an open-circuit should be made with a magneto and bell, or by applying to the armature winding a low voltage with an ammeter in circuit. It will then simply be a matter of common intelligence to compare the results obtained in order to detect which is the open-circuited phase.

A WORD ON AUTOMOBILE IGNITION AND THE NEW GENERAL ELECTRIC MAGNETOS

By H. S. Baldwin

In order to discuss the subject of ignition, it will be necessary first to review briefly the growth of the modern gasolene automobile.

Early Gasolene Automobiles

Some fifteen years ago a new industry sprang into existence, the way for which had been prepared by Otto and Daimler, who contributed the four-cycle gasolene engine that plays such an important part in the automobile of today. Daimler built his first successful engine in 1884, and a year later applied it to a motor bicycle. In the same year Benz made a tricycle which he patented in 1886. Daimler continued to develop the engine, and both his patent right and services were acquired by Panhard and Levassor, who, after several years of experimental work, brought out in 1894 a four-wheel car having the engine, clutch, transmission and other driving elements, in substantially the same relative positions now almost universally used by gasolene automobile manufacturers.

In this country the experiments of Chas. E. Duryea were nearly contemporaneous with those of Daimler and Benz, beginning about 1886. In 1891–92 he built his first carriage, which was a remodeled horse buggy propelled by a one cylinder four-cycle engine with counter-shaft and double chain drive. This machine not proving wholly satisfactory, Duryea built a second and improved model in the winter of 1894, employing a two-cylinder engine of about four horse-power, the drive to the rear axle being by bevel gear. This is generally considered the first practical gasolene automobile built in the United States. With it he won the first endurance race attempted in this country, which was held at Chicago under the auspices of the *Times-Herald*. There were a number of early runs which marked the beginning of the new era, and the following table of these classics will be of interest:

Petit-Journal	Paris	July, 1894
Paris-Bordeaux	Paris	June 11, 1895
Times-Herald	Chicago	November 28, 1895
Cosmopolitan Run	New York	May 30, 1896
Paris-Marseilles	Paris	September 24, 1896
"Liberty Day" Run	London	October 14, 1896

Duryea then built a number of 5 h.p. cars, three of which were the only machines to reach Irvington in the Cosmopolitan run of 1896. Thirty cars were entered, and as none completed the 52 miles from New York to Irvington and return, the run was considered a fiasco at the time; however, looking back, it marks an important step in the progress of the industry. It may be mentioned as an interesting and significant side light, that the writer saw the winning Duryea car in a street parade of Barnum and Bailey's circus in Middletown, Conn., June 12, 1896. The following is quoted from the "Penny Press" of that date:

> "The Duryea carriage which was seen on the streets this morning is the first to appear in this city. It is the same vehicle which won the race for horseless carriages in New York a few weeks ago."

It is indeed difficult to realize that an automobile was shown in a circus parade as a curiosity along with elephants, camels and wild animals, as recently as 1896.

Elwood Haynes (1893–94) and Alexander Winton (1896), with Duryea, were pioneers in the American development of the automobile, but to mention their activities in this line would be to digress unduly from the subject.

The events of the intervening fifteen years are of too recent occurrence to require any detailed statement of fact; a few figures, however, may be given that are most significant.

Statistics

The report of the Department of Commerce and Labor under date of April 25, 1911, states that the census bureau's preliminary report on the automobile industry for 1909 shows forty times the product of ten years ago, and that the number of automobiles manufactured increased from 3723 in 1899 to 127,289 in 1909. Further figures are taken from an article by Mr. E. M. West in a recent number of the *Review of Reviews*.

In 1910, it is reported, 185,000 cars of all kinds were built in the United States, having a valuation of $240,000,000, and representing a capital of $275,000,000. To accomplish this enormous output, 140,000 persons were directly employed in building complete automobiles. Adding those required for allied industries depending directly on the automobile for existence, and also selling agents and their employes, the total becomes over 1,500,000. When the families of this great army are taken into account, some conception can be had of the magnitude of the interests involved in the rapid rise of the automobile industry.

Now consider for the moment that a large percentage of the 185,000 cars, and also of the thousands of cars built before 1910, are propelled by gasolene engines, and that each of these machines requires ignition apparatus of some kind, either with or without a magneto! A great demand for auxiliaries has been created and a large contributing industry has been built up to meet it.

Ignition

It has been aptly said that the carburetor is the heart of the gasolene engine; granting this, and carrying the figure a step farther, the electric spark may be called the vital element or soul, essential to life and movement. The early engine builders used flame and hot tube ignition, and also a combination of slide or poppet valve and hot tube to give more definite timing. It is interesting to note, however, that Lenoir in 1860 and Benz in 1885 employed the electric spark, although in somewhat different ways.

Lenoir's engine was of the double acting type, the igniter being placed in a pocket in the cylinder wall, midway of the stroke. An electric spark from a Ruhmkorff coil jumped continuously between platinum points and exploded the mixture when the piston uncovered it. Benz used a battery, vibrating spark coil, and contactor operated by the engine. Daimler, on the other hand, used a hot tube in his engine of 1884 and in those of many years later.

As has already been pointed out gasolene automobiles of American design began to appear in the early 90's, and during the developmental period of ten years which followed, many interesting and successful cars were built. There were, however, no well-formed ideas at that time as to how an automobile should look, and it is only natural that most of them followed the lines of horse-drawn vehicles, and in fact were called "horseless carriages." Engines and transmission mechanisms were of great diversity of design, and were arranged in almost as many different ways as there were cars. Ignition was unsettled, but it is safe to say that mechanical make-and-break, with battery, or a low tension magneto, was the most popular. The hot tube was used in some cases, however, and the writer assisted in the design and construction of a light two-cylinder four-cycle air-cooled car which was successfully operated in 1898 with this form of ignition.

About this time the De Dion-Bouton tricycle and quadricycle began to appear in America. These were equipped with high tension or jump spark ignition having a mechanical vibrator on the engine and a separate step-up coil. The De Dion system was very successful, especially for fairly high speed engines, and did much to hasten the adoption of the jump spark. As has already been pointed out, however, Benz and other early builders used the jump spark.

Dating from the second automobile show in Madison Square Garden, December 1901, American gasolene cars began to follow more mechanical lines in appearance, and to adopt the arrangement of engine and transmission already established in foreign practice. Ignition was about evenly divided between mechanical make-and-break, and jump spark, but with a growing tendency toward the latter.

Electrical energy for the ignition spark has been required from the beginning, and has been supplied either by a primary or a secondary battery, direct current generator, magneto generator, or some combination thereof. All but the high tension form of magneto have been available from the inception of the industry, and it is difficult to state which was most employed during the early years. The low tension magneto was always favored for make-and-break ignition. It generated alternating current and the break was made at a high point on the wave. Sometimes the magneto was arranged so that the position of the poles could be changed with relation to the cranks, permitting the point of ignition to be advanced or retarded as required by the speed of the engine, and still be of high voltage. A battery was frequently provided with this system as an auxiliary.

When extensive manufacture of automobiles was really begun in this country, the jump spark battery system with vibrating coil was adopted by most builders, and for a number of years was practically the standard equipment. In the meantime the magneto was being developed to meet the growing demand for a source of supply which would not run down and require either renewal or re-charging—in other words, a mechanical generator rather than one depending on chemical action.

About five or six years ago the high tension magneto appeared in a number of American cars, and it has steadily advanced in public favor, until today its use may be said to be general.

Through custom high tension magnetos have been divided into two classes, one called

Fig. 1. First High Tension Magneto Developed by General Electric Company

"true high tension," or "straight high tension," the other "low tension." It is a fact, however, that in both cases the primary current generated in the armature is of low potential, this being necessary in order to permit the interrupter to open the circuit for the purpose of timing. Obviously, the results are practically the same, so far as the nature of the spark is concerned; consequently a distinction is made

Fig. 2. New High Tension Magneto, with Separate Coil

where there is little essential difference. In one case the secondary winding, condenser and safety gap form an integral part of the magneto; in the other, they are placed in a separate box and connected to the magneto by wires. It is claimed for the former that the effect of the combined windings in the armature adds to the strength of discharge. In the opinion of the writer, the terms "true high tension" and "low tension" in this connection are misnomers, causing confusion to the popular mind; and that any magneto which can operate jump spark ignition should be called a high tension magneto. Many thousand of both types are in daily successful use, and each has certain advantages from an operating standpoint.

The self-contained high tension magneto is well adapted for light cars, where its simplicity and small size cause it to meet with favor. In the case of medium and large cars, a storage battery is usually available and designing engineers frequently adopt the dual system whereby the engine can be run on one set of spark plugs by either the magneto or battery independently. The dual system, based on the so-called "low tension system," is peculiarly fitted for large cars, owing to the sturdy construction and liberal space available for insulation of the secondary windings and condenser. Large safety factors are much to be desired where the tension may be from 5,000 to 10,000 volts.

The self-contained magneto can be arranged for dual ignition by adding an extra cam and lever to the timer and duplicating the armature with its windings and condenser. The second armature is enclosed in a cylindrical box with a switch attached, the

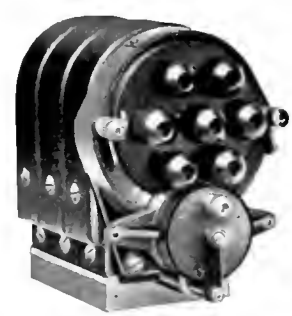


Fig. 3. New Six Cylinder High Tension Magneto, with Three Magnets

whole being mounted on the dash. It will be seen that a dual system of this kind requires practically the same number of wires, a separate coil (as in the case of the system already described) and an additional timer.

Development of Ignition Apparatus by the General Electric Company

A few years ago the General Electric Company decided to investigate the ignition problem, and since then exhaustive experiments and tests have been carried out in all branches of the work. Magnetos of many forms have been built and submitted to practical test, and the manufacture of high tension coils, magnets, special insulating material and all mechanical devices pertaining to the magneto have been thoroughly studied.

Low Tension Magneto

At an early date low tension magnetos were built by this company, and these have now been in use for several years with excellent results. Particular attention was given to the development of magnets, several thousand of the highest standard having been supplied to one of the leading American automobile manufacturers.

High Tension Magneto with Separate Coil

The first high tension magneto developed was particularly adapted for use on gasolene lighting sets which were being built for the U. S. Government. After comparative tests it was approved and has now been part of the standard equipment for a year and a half. It was also successfully used on various other engines for lighting sets, and experimentally on a number of automobiles. A description of this magneto follows: (Fig. 1) A primary current of low voltage is generated by a Siemens wound armature of high permeability, grounded at one end and revolving in a two-pole field consisting of 3 compound permanent magnets. For a portion of the cycle just previous to the occurrence of the spark, the armature current is short-circuited, thereby increasing its intensity. This short circuiting is accomplished by a mechanically operated interrupter, the break occurring between two platinum-iridium contact points. At the instant of sparking, the contacts are opened and the current then flows to the spark-coil where it is transformed into sufficiently high voltage to jump the gap in the cylinder. It may be noted that the interrupter can be advanced 40 deg. The secondary current is returned to the magneto where it is distributed in proper sequence to the spark plugs. The distributor consists of a block of high insulating compound into which are moulded brass segments. A revolving arm carrying a single brush closes the secondary circuit at correct intervals. This magneto was built for dual or single ignition.

Fig. 4. Interrupter Box Showing Adjustable Contact

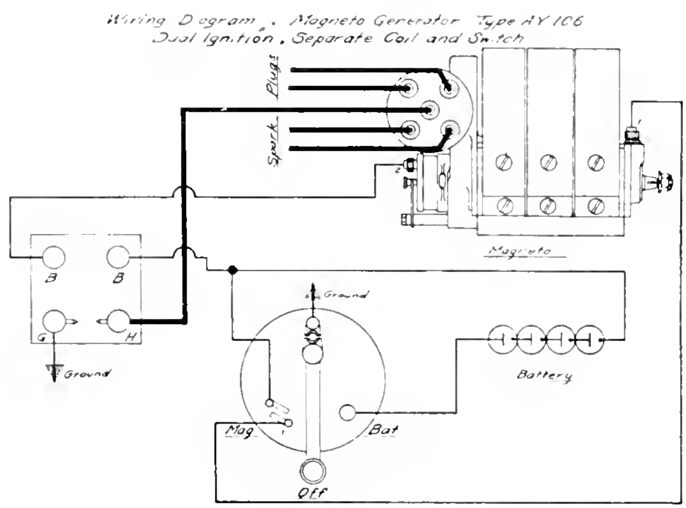


Fig. 5. Wiring Diagram for Dual Ignition, New Magneto

New High Tension Magneto with Separate Coil

In operation, the high tension magneto shown in Figs. 2 and 3 is similar to the one just described. It is built in two sizes, two-magnet and three-magnet, for engines of 1, 2, 4 and 6 cylinders. The separate transformer coil can be encased in a wood or metal box of various designs. Fig. 2 shows the coil in wood box with the standard switch. A metal coil box has been developed with a metal kick switch flush with the dash, to meet a certain demand for this construction. The armature winding differs from that of the first magneto considered, in that one end is not grounded, but is led out through an insulating bushing; the advantage being that the loss of current due to poorly made grounds on the engine frame is minimized. The other end of the armature winding is brought to an interrupter, which differs from that previously described in that all elements except the cams revolve with the armature.

Special attention is called to the form of adjustable contact. (Fig. 4.) It will readily be seen that the adjusting screw is of large diameter, and that it is securely clamped in the interrupter block by a screw which is accessible from the front of the magneto.

Fig. 6. Self-Contained High Tension Magneto

This construction does away with the small lock nuts frequently employed in other magnetos, and permits easy adjustment of the gap without the necessity of a special wrench.

The armature and secondary shafts are mounted on ball bearings, and the magnets are of the highest grade tungsten steel. It can be furnished for dual or single ignition. (Fig. 5.)

The new high tension magneto, above described, has been adopted as standard and will hereafter be used on all General Electric commercial gas motor sets, with the exception of the 3 kw. size.

short-circuited until the spark is required in the cylinder, when the short-circuit is interrupted and a high voltage secondary current is induced; this current being brought to a collector ring, from which it is led to the distributor and thence to the proper cylinders. This form of winding eliminates the necessity for the separate step-up transformer and allows a clear dash. The machine can be furnished for 1, 2, 4, and 6 cylinder engines, but is not supplied for dual ignition.

Low Tension Alternating Current Magneto

A low tension alternating current magneto has been designed for motor boat and stationary engines using make-and-break ignition. (Fig. 7.) The current is generated by a Siemens wound armature and is of sufficiently high voltage to continue to flow across the gap created by the mechanical make-and-break device. The inductive effect of the break is created by the large number of turns of the magneto armature, thus eliminating the necessity for a primary wound induction coil.

One end of the armature winding is grounded, the other end being brought through an insulated hollow shaft and thence through a carbon brush to a lead. This magnet must be driven in direct relation to the engine.

Low Tension Direct Current Magneto

Where it is found practical to drive a magneto by either a belt or friction pulley, the direct current magneto generator recom-

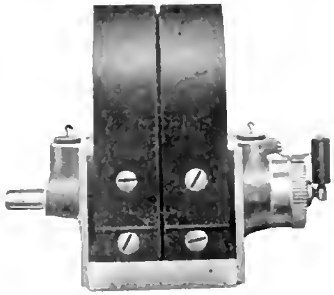


Fig. 7. Low Tension Alternating Current Magneto

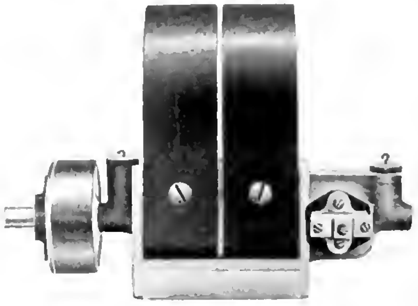


Fig. 8. Direct Current Low Tension Magneto

Self-Contained High Tension Magneto

For engines of small and medium cars, a high tension magneto has been designed. (Fig. 6.) This is of the self-contained type, that is, both the primary and secondary windings are mounted in the armature. As in the other types, the primary current is

mends itself. (Fig. 8.) This consists of a two-pole field of permanent magnets in which revolves a drum wound armature. The commutator is of ample size to carry the heavy current and to insure long life.

The current is collected by metal compound brushes, two to each pole. These machines are built for either make-and-break, or jump spark ignition. When furnished for jump spark a vibrating spark coil and timer are necessary.

For make-and-break ignition a non-vibrating primary wound coil is used to increase the voltage by self induction at the time of the break in the cylinder. These machines are driven by a centrifugal friction coupling which throws out at high speeds, in order to prevent engine racing and burning out of the armature due to too heavy current.

FREIGHT HANDLING AS A FIELD FOR ELECTRICITY

By R. H. Rogers

Between the driving of the last nail in a package by the shipper and the removal of the first one by the consignee, there transpires a most complex and interesting series of events. We are familiar with the great ships that plow the seven seas, safe-guarded by the marvels of science and provided with deep, roomy harbors at great public expense. We are familiar with the modern locomotive and its long train of heavy laden freight cars traversing the best road-beds that money and engineering skill can provide. The pre-intermediate and final handlings of the units making up these tremendous loads are not well understood or appreciated, though this intricate work is going on all around us, easy of access and worthy of much study.

The terminal—the "limiting feature" of all this traffic flow—through which our shipments pass not twice but twenty times, has not kept pace with its radiating and converging arteries; in fact, the terminals have become positive strictures in the ebb and flow of freight traffic. No better proof of the truth of this statement is needed than the fact that freight cars average only twenty-three miles per day. At twenty-five miles per hour a car would make 600 miles in a day; hence in order to maintain the above average it must be snarled up in terminal yards for the next twenty-five days. Plotting the two million freight cars in this country against this twenty-three mile average, we find that if the terminals could be so improved as to allow a twenty-four mile average, 100,000 cars would be added to the dividend earning rolling stock.

The same condition prevails at the marine terminals, where ships may be held for days before a space can be cleared for unloading. For instance, a pier 1400 ft. long by 150 ft. wide will berth six 10,000 ton ships. A marine ton is 40 cu. ft., so that allowing for aisles and for tiering the cargo 5 ft. high, we find two ships will fill the pier. Not less than forty-eight hours must elapse before a third ship can begin to unload. The matter is further complicated by the arrival of 400,000 cu. ft. of cargo for each of the unloaded ships, tending to greater congestion, confusion and loss of time. It is not unusual for a ship, having a stand-by-charge of three hundred dollars per day, to "mark time" for ten days. To this must be added port charges and wharf rental; making it little to be wondered at that the cost of loading and unloading a ship exceeds the cost of a 3000 mile voyage.

Bulk freight in carload or cargo lots is very well cared for in the way of electrical machinery. Package freight, however, forms four-tenths of the railroad freight business and eight-tenths of our exports and imports, and, on account of the much higher freight rates per ton, pays three quarters of our two billion dollar annual freight bill. Thus it costs us one and a half times our national debt, every year, for transporting our package freight.

The question immediately arises: What proportion of this great sum is susceptible to reduction by electrical machinery? We find that the terminal charges on a ton of package freight at New York and Chicago exceeds the cost of hauling it between these cities. The terminal charge is constant regardless of the distance hauled and the average haul is less than 250 miles; therefore it is clear that where large cities are involved the terminal cost is much more than half of the total cost. When shipments pass between small towns, numerous transfer terminals add their quota to the already heavy handling cost. Water-borne freight can be moved at a cost of only seven-tenths of a mill per ton mile, while railroad freight cannot be moved at less than three mills per ton-mile; but the water-borne freight must carry the heavier terminal charge. We may infer then that the terminals are responsible for much over half of our freight bill; and eliminating fixed charges on terminal property, supervision and accounting, we still find a billion dollars per year expended mainly for hand labor.

Here, then, is an enormous field for electric applications tending to reduce this amount by direct elimination of hand labor, prevention of congestion, extension of working room, and quick release of rolling and floating stock.

In order to make a satisfactory showing in the electro-mechanical handling of package freight, we must be able to transfer great numbers of small unit loads through widely varying distances, horizontal and vertical, and in fact in all directions. How complicated and extensive the unit movements are at a single pier, is shown in the following tabulation:

of incoming and outgoing packages in a space only large enough for 800,000 cu. ft., so that each will be independently accessible.

Shipments of package freight by rail undergo an incredible number of rehandlings in outgoing, transfer and incoming terminals. A typical shipment has been shown which was hand-trucked nine different times. Congestion is as frequent here as in the piers. A single truck will usually carry a whole consignment. Of four thousand consignments observed, three thousand were under three hundred pounds weight; so that large units are out of the question and high speed is limited by safety to operators and goods.

As may be inferred, there are scattered along our coasts and all across the country squads, companies and regiments of men armed with hand trucks doing daily battle with our food and raiment, to say nothing

UNIT MOVEMENTS OF FREIGHT

BUSH TERMINAL, NEW YORK

From any of the following	By means of one or more of the following	Through one or more of the following	To one or more of the following
Ships	Men without aids	Pier storage	Warehouses
Lighters	Men with 2-wheeled trucks	Outside storage	Pier storage
Cars	Men with 4-wheeled trucks	U.S. Customs' weighing and inspection	Outside storage
Drays	Boys with horses and 3-wheeled trucks	Consignee's weighing, inspection and sampling	Factories (Bush)
Factories (Bush)	Electric hoists	Preparatory processing	Drays
Outside storage			Cars
Pier storage			Lighters
Warehouses			Ships

Textile, bales, 300–1200 lb.
Liquids, casks, 100–3500 lb.
Fibres, bales, 250–500 lb.
Sugar, coffee, bags, 100–400 lb.

Spices, etc., boxes, 10–100 lb.
Miscel. packages, 10–1800 lb.
Minimum, single handling, 10 ft.
Maximum, single handling, ½ mile.

A consignment of 2000 bales of jute may have 120 "marks," or consignees, and has to be disposed of in almost as many ways. Single consignments from a single cargo vary from a single ten-pound box to 45,000 bags of sugar. Export freight has to be located on the pier and in the ship with reference to its destination, this becoming a science in itself when among a ship's ports-of-call may be two hundred ports on the island of Java alone. The arrival of ships cannot be arranged or predicted with sufficient accuracy to insure uniform activity at a given pier; "peaks" occur at frequent intervals when three or more ships arrive from the Far East on the same day at the same pier. At such a time it is desirable to stow 2,400,000 cu. ft.

of the thousand and one other things that our complex way of living demands. This army is vastly larger than that of fifty years ago and its pay per unit has greatly increased, but its equipment has not changed in half a century. The magnificent trains and steamships, and the lavish expenditure of money and thought to expedite their movement, is in marked contrast with the scenes here pictured.

We find, then, two circumstances happily related:—the terminals are chargeable with the heavier portion of transportation cost, and are at the same time the more susceptible to marked reductions in that cost.

A survey of the industrial world reveals many types of conveying apparatus and a multitude of variations of these types. Industrial service is, however, vastly different from the work we are discussing and radical changes are necessary to handle freight in terminals successfully. A broader view of this problem must include sweeping changes in the system of entering, traversing and leaving terminals, their distribution and their environments. Broad electrification of yards and approaches is essential, including traction, signals, lighting and fire protection. Electric subways for city freight, electric trucks for street freight, and corporate ownership of the delivering agent to prevent congestion and to insure economic use, are suggested aids.

Great economic principles, decentralization, localization and mutual organization promise relief, but must be slow of attainment, while the need is immediate, pressing and increasing. While the population of this country was growing 30 per cent., its freight traffic was growing 90 per cent. The yearly increase in traffic through the New York docks would warrant the building of three miles of piers per year. The fact that this is not being done simply means steadily increasing congestion with consequent increase in cost to the consumer.

Consolidation of marine and railroad terminals, warehouses, and factory buildings, as exemplified by the Bush Terminal in South Brooklyn, has done much to reduce the overhead costs. The great warehouses act as flywheels between the periodic crops of the world and the constant demand of consumers. When storage space is vacated by the product of one part of the world some new crop is arriving from the antipodes to take its place, thereby keeping the warehouses filled to capacity at all times. Samples from importations form the basis for sales in the market place, and orders are filled by shipment from the terminal without the usual expensive street hauls to and from private warehouses, which at best would be empty half the time. The same is true of the factories where raw materials are made up or processed and re-shipped, without in the meantime having left the terminal enclosure.

The 60 miles of freight subway in Chicago, with its 125 electric locomotives and 3500 cars, is freeing the streets of 4000 tons of freight traffic per day, but there still remains twenty-five times that amount subject to usual street delays, which is annoying the public with noise, dirt and danger.

Shipments and re-shipments for processing, such as the practice of having New York publications bound in Boston, and the shipping of leather from the West of Pennsylvania for tanning, thence to the Boston market and return to the West for manufacture, could be eliminated to a great extent. Likewise, the shipment of wool, cotton and other staples to great market places, to be re-shipped after sale, indicates that too much shipping prevails.

Conferences, interviews and discussions with men in every rank of the traffic army serve to confirm the belief that broad revision of general traffic relations, coupled with electrification of the terminals, is the only solution for this problem, and that the electrification will come about rapidly because it offers the relief nearest at hand.

In this day of great achievements we are taking up new and greater projects. The completion of that masterpiece of engineering, the Panama canal, will re-locate the arteries of the world's commerce. How will the new terminals at Colon, Panama, New Orleans and San Francisco measure up by comparison? Our own state barge canal is looming up with its vital terminal questions. The Pennsylvania system contemplates a great nearer-Europe marine and railroad terminal at the eastern extremity of Long Island. The Jamaica and Newark Bay projects near New York will exceed any previous terminal enterprise.

Will the double-track lines continue to choke themselves to single track capacity through inadequate terminals? Can the Federal treasury be drawn upon for deeper channels and harbors while every pound of freight is man-handled, as at the building of the Egyptian pyramids?

The great highways of commerce will not reach their capacity for traffic for many generations to come, but the terminals hemmed in by twenty story office buildings are overloaded, inelastic and entirely inadequate today. What of the future? The continued neglect of these vital obstructions in the arteries of commerce must result in great economic loss to us as a nation, but the greater loss and the whole responsibility falls to us as individuals.

THE ACTION OF OZONE ON AIR

By M. O. Troy, Supply Department

Perhaps one of the most universal applications of ozone will be in the treatment of air for the destruction and removal of noxious odors, organisms and emanations. This subject has received some attention in America where the matter of ozone application is a new one, and much attention in Europe, particularly in France, where ozone has long been recognized as a valuable agent of sanitation.

The general consideration of ozone, per se, will not be dwelt on here, the subject having been extensively treated in various publications.*

Necessarily what follows must partake somewhat of the nature of a disquisition on the immolation of the bacterial content of the atmosphere; for notwithstanding the arduous and exhaustive researches of such men as Erklentz and Flügge, Atwater, Heyman, Paul, Dr. Leonard, Hill and others, we are not in possession of a great deal of unquestionable information respecting anything noxious in the atmosphere, with the exception of moisture and bacteria.

Ozone acts on the air as a bacteriacide as well as a powerful agency of deodorization. For the purpose of studying the power of ozone to destroy noxious odors, Scoutettin chose a ward of the hospital at Metz, having a magnitude of about 1100 cubic meters. In this hall he placed 2 piles of manure about 10 meters apart. These manure piles were permitted to remain for 48 hours, during which period the room became filled with a pernicious odor indicating an advanced stage of putrefaction, as shown by the evidence of the ammonia evolved.

When this had been accomplished, 2 vessels of 8 liters capacity were opened in the hall, permitting their contents of ozonized air to diffuse therein. The ammoniacal odor diminished considerably, though it did not disappear completely. The manure was then removed and the experiment repeated. This time the odor disappeared completely and rapidly, the noxious gases, hydrogen sulphide, carbon bisulphide and ammonia having been destroyed.

According to Schoenbein 60 liters of air containing 13 mgs. of ozone will disinfect 324 cubic meters of air. This figure is somewhat equivocal, however, as the quantity required in any given case will depend on the nature and condition of purity of the air.

It will not be out of place to describe briefly the fundamental routine of bacterial culture, the reader being referred to special books on the subject for further details and information.

The various germs differ among themselves in many ways, a most important difference being their growth and behavior on the organic culture media which are used for the purpose of studying them. It is necessary to choose culture media which are habitable by the various germs studied. Briefly the procedure consists in applying the bacteria, which are of microscopic dimensions and totally invisible to the unaided eye, to the surface of a medium on which they can thrive, and in the course of a given period of time to count the number of colonies which have appeared on this surface.

Bacteria proliferate by a process known as segmentation; i.e., they divide at the middle into two smaller cells which grow and in turn divide each into two others, etc.; the process repeating itself continually about every thirty minutes.

The plates consist of shallow glass dishes into which is poured the culture medium, which is permitted to jell in a horizontal position. These dishes, which are called "Petri dishes," have a diameter of from 10 to 20 centimeters, with straight sides.

The culture medium consists of gelatin, gelose or agar agar, specially prepared and rendered perfectly sterile before use.

From what has been said of the rapid proliferation of the germs, it will be seen that at the end of a comparatively short time the surface of such a culture plate which has had germs strewn upon it will be shot with colonies of bacteria, the number of these colonies representing the number of original germs, providing they are sufficiently sparse to fall singly. The planting of the germs on the sterile plate is technically called "inoculation."

The experiments of Chappuis on bacteria in air have demonstrated the bacteriacidal value of ozone. He prepared sterile cotton wadding plugs through which air was drawn, and then exposed one half of these plugs to

*See article by Dr. M. W. Franklin, General Electric Review, Vol. No. 6, June, 1911.

the action of ozonized air, the other half being kept as checks. The plugs collected the dust in the air.

A culture medium of yeast bullion was prepared in some test tubes, and into these were introduced the cotton plugs. The yeast bullion exposed to the ozonized cotton remained clear, while that exposed to the untreated plugs became turbid, demonstrating the presence of numerous micro-organisms in the dust collected from the air. This shows that the germs of the air, or at least those capable of growing on yeast bullion, are destroyed by ozone.

Various experimenters have made tests with the more dangerous disease germs, and De La Coux reports experiments with *bacilli carbonis* (black-leg disease of sheep, cattle and goats) *typhoid bacillus*, *staphlococcus*, *spores of aspergillus niger* and *diphtheria bacillus*, in which these germs failed wholly to grow in air containing 1.5 to 2.0 mgs. per liter, i.e., from 0.6 per cent. to 1 per cent. of ozone by volume.

Some experiments have tended to show that ozone does not possess a germicidal action. Prof. Oudin has investigated this subject and has found that if the cultures of bacteria grow deep within the culture medium, the action of ozone seems not to be inhibitive. He has shown on the other hand, that where a sample of a culture colony, taken from such a deep seated growth which had previously been exposed to ozone, is from the exposed layer at the surface, no inoculation of a second plate can be obtained.

If the ozone concentration of the air be high; e.g., 8 to 10 gms. per cubic meter, the germicidal action will be found to be quite powerful even in deep seated cultures.

Experiments with cultures of the *tubercular bacilli* have shown that these grow with only one fourth the rapidity of check cultures, when exposed to the action of ozonized air..

These results show that where ozonized air comes in contact with the living colonies their development is impeded; but that when the bacterial colony grows deep within the culture medium, the action of ozone applied to the surface only is less marked, if not altogether imperceptible.

This is what should be expected according to Ohlmüller, who has demonstrated that the bacteriacidal action of ozone is greatly interfered with in the case of colonies growing on organic matter; for the oz ne oxidizes the organic medium, thus destroying itself, before it makes sensible its action on the bacteria. Ozone destroys itself in oxidizing organic matter and coagulates albuminous matter.

It may be deduced from the foregoing that any extraneous organic matter found in air which it is desired to sterilize, will diminish the action of ozone by combining with it; and in consequence, the air should be first filtered whenever practicable. Many failures to produce sterilization in researches on ozonizing air have resulted from the presence of a relatively large amount of organic matter in the air.

Ozone will find an application in the sterilization and deodorization of the air of hospitals, apartments, studios, schools, etc., wherever there is likely to be large crowds.

In stables, chicken coops, toilets and factories, where there are evolved noxious emanations, ozone will greatly ameliorate the conditions. In particular, the shops for assorting rags, manufacture of fertilizers and factories which work gelatin, glue, hides, hair, fat, bones, horn and other slaughterhouse by-products, and those which are a source of emanations dangerous to the public health, will find in ozone a powerful ally.

Wherever pure sterile air is of value in the factory either before, during, or after the completion of the product, e.g., distilleries, breweries, wine houses, etc., the use of ozone should be resorted to.

Experimental installations of ozone apparatus have been made by the engineers of the General Electric Co. for the purpose of studying the applicability of ozone to the purification and deodorization of air under various conditions.

The Art Theater on State Street, Schenectady, a moving picture show, had experienced difficulty with its ventilation. The theater consists of a hall about 30 by 100 feet, and the ventilation is provided by a suction blower capable of aspirating about ninety thousand cubic feet per hour. The management were very desirous of providing the best ventilation possible, as is evidenced by the elaborate and expensive system cited. It was found, however, that notwithstanding the magnitude of the blower, "crowd odors" persisted in the room. The blower was as large as could be used, for anything larger would have produced obnoxious draughts.

As a solution to the trouble, an ozonator. was installed above the front entrance to the theater, in such a way as to permit the ozonized air to diffuse into the current of ventilating air drawn toward the aspirator. The instantaneous effect of this was remarkable. The theater has been entirely deodorized and even during the hottest weather of the present summer the air within the theater has been fresh, cool and odorless, excepting for the faint and rather pleasant smell of the slight excess of ozone.

The next case which we may cite provides an even more remarkable instance of the efficacy of ozone in deodorizing obnoxious air, since this case relates to a factory in which, through the nature of the work carried on, emanations are evolved, which constitute a vehicle of certain volatilized diluents and solvents of the varnishes and adhesives used. In a workshop some fifty feet by one hundred feet upwards of two hundred girls are employed in the preparation of various articles of pasted mica. It is easy to realize that the problem of providing clean air under such conditions will always be a difficult one, and in the present instance a considerable expenditure of money and ingenuity was incurred before the correct solution was found. In order to obtain a sufficient supply of fresh air to counteract the effects of the noxious fumes it was necessary at all seasons of the year to have all the windows of the building open to their fullest extent. This plan was feasible during the summer months, but, during the winter, when temperatures below zero were encountered outside, it was necessary to provide a very costly system of heating, in order that the temperature of the room might be sufficiently high to make the place endurable. Many thousands of dollars were also expended in providing draught pipes of large diameter for conducting to the outside atmosphere the fumes diffused by each machine. A point was reached at which it became imperative that some less costly and more efficient system of cleansing the air be adopted, and it was at this point that resort was made to the ozonator.

Two of these were installed and were placed on the center line of the room, each one being some twenty-five feet from each of the two end walls. The effect of their action was that during the winter months, the windows, which formerly had to be opened to their fullest extent, required now to be opened only to the extent found necessary in ordinary living rooms. The costly draught pipe system for conducting away the noxious fumes from the machines was removed, and the atmospheric conditions, as far as the comfort of the employees was concerned, were every bit as good as are to be found in any other workshops.

Previously, there were occasions during which the atmosphere became so befouled that the whole staff were compelled to leave their work through general malaise; while at the present time if through any abnormal condition such as failure of current supply, the ozonators are unable to operate, the reversion to the old state of affairs is instantaneously noticed.

A third instance which we may quote illustrates the use of the ozonator in purifying the air of buildings which have become burdened with smoke and fumes of combustion. Messrs. Charles Holtzmann and Son are the proprietors of a large store on State Street, Schenectady, for the supply of clothing, furnishing goods, etc., and were recently put to considerable inconvenience as the result of a fire, which broke out in a stable located towards the rear of Messrs. Holtzmann's premises. Clouds of smoke from this fire invaded the clothes store to such an extent that not only were the rooms on the various floors rendered untenable, but the goods with which these floors were stocked became, in many instances, impregnated with the odor of smoke. A delay of several days disastrous to the interests of the management might very easily have been occasioned; but at this juncture an ozonator was installed on each floor with very gratifying results. In the almost incredibly short space of twelve hours the atmosphere of each floor was purified and brought to its normal condition. At the same time the ozone seems to have acted upon the stock, which was carried on these floors, as a deodorant and fumigator, to the effect that all odor of smoke was immolated. This instance illustrates the utility of the ozonator in directions which up to the present have not perhaps been very generally recognized.

It would be an easy matter to multiply instances affording remarkable evidence of the beneficial uses to which the ozonator may be commercially applied, but the foregoing will probably suffice to give an indication of some of these uses.

In the sterilization of air, the ozone should be blown into the apartment, or the air should be drawn through a special chamber in which the ozone is mixed with it. It is important that the ozone come freely into contact with each individual particle which it is desired to destroy.

The machine for producing the ozone should not produce any *nitrous oxide* or any other gas having an untoward action on the human organism.

The generation of ozone should continue until the air, as determined by experimental test, is thoroughly sterilized, and the machine should produce this result without loading the atmosphere with ozone to an injurious concentration.

The General Electric Company's "Ozonator" has been especially designed to meet these conditions. It produces ozone at a concentration of 6.0 mg. per cubic meter, and when placed in a closed room the concentration increases with the time, so that the "Ozonator" is suitable for producing ozone proper for breathing or in concentrations powerful enough for producing sterilization.

GROUNDING OF NEUTRALS WITH PARTICULAR REFERENCE TO THE GENERATOR AND TRANSFORMER CONNECTIONS

By E. W. Allen

The neutral of an alternating-current system of generation and distribution may be grounded for one of the following reasons:

(1) To limit the strain on generator windings, when auto-transformers are used for stepping-up the generator voltage to the busbar voltage. This arrangement is sometimes found desirable in the case of large high voltage turbo-generators, the generator being wound for one half of the busbar voltage. In such cases the neutral point of the generator winding must be grounded and connected to the neutral point of the auto-transformers, in order that the potential strain may be limited.

(2) To secure selective action on underground feeders supplied from a set of three-phase, three-wire busbars. When this connection is used, a limiting resistance is sometimes installed in series with the neutral wire. It is the opinion of the men who operate large underground cable systems, that breakdowns occur first from line to ground or to the lead sheath of the cable, that this trouble spreads and is soon followed by a severe short circuit between all phases. If a non-inductive resistance is installed in series with the neutral wire, to limit the flow of current at the time of this breakdown to a value that is just sufficient to trip out the feeder switch, the damaged cable may be disconnected before the trouble is communicated to all phases.

(3) To limit the voltage strain in overhead systems from line to ground, and still permit distribution at reasonably high voltage between phases, as evidenced by present-day 2300/4000-volt, three-phase, four-wire systems.

When the neutral is grounded, a large amount of current can, under certain conditions, flow in the neutral wire and cause overheating of the generators, transformers, etc. It seems well, therefore, to point out some of the reasons for the neutral current and the connections which should be used to eliminate it. For convenience they will be discussed in the following order:

(1) Third harmonic or triple frequency voltage.

(2) Unbalanced single-phase load.

(3) Stray current.

The Effect of Third Harmonic Current

Commercial alternators generally have a complex wave form consisting of other harmonics than the fundamental wave. The third harmonics of each phase of a three-phase generator are in synchronism with one another, and for that reason may cause trouble when certain connections are used.

If the generator armature is connected Y without a neutral connection, the third harmonic currents in the three branches will obviously flow to the middle point and neutralize each other. If the armature is connected delta, the third harmonic currents, since they are in phase, will circulate within the delta, but will not appear in the external circuit. If, however, the armature is connected Y and the neutral brought out the third harmonic current can flow, and may appear in the external circuit, if there is a connection through the windings of apparatus having different wave forms. Whenever this connection causes trouble, the neutral bus of a station, or of a group of generators, should be connected to only one of the machines operating on the bus at that time; but in order to secure a flexible arrangement means should be provided for connecting the neutral to any of the machines in the station.

The neutral wire of a three-phase, four-wire feeder should not be connected to three-phase transformers, or banks of three single-phase transformers, if their primaries are in Y and their secondaries in delta, as this connection provides a path of low impedance for the third harmonic current. One group of transformers so exposed may take the entire third harmonic current of the system, and thus be forced to carry a heavy current in addition to that imposed by the load on its secondaries.

Unbalanced Single-Phase Load

The current in the neutral wire caused by unbalancing of the load is supplied to the system by the generating station, and represents energy as distinguished from the circulating idle current previously considered. A three-phase transformer, or bank of three single-phase transformers, with their secondaries in delta and their primaries in Y, may, if the neutral is connected, act as an equalizer or balancer for the single-phase load; and the heating of transformers when so connected will be determined not only by the load taken from their secondaries, but also by the neutral current they must handle.

The combined capacity of single-phase transformers on most commercial lighting and power circuits is considerably greater than that of the three-phase transformers, and a relatively small amount of unbalancing may, therefore, be sufficient to overload several three-phase transformers. These two causes, viz., third harmonic and unbalanced single-phase load, have probably been responsible for a number of failures of transformers.

The remedy for these troubles is to omit the neutral connection from banks of three-phase transformers or three single-phase transformers, connected as outlined.

Stray Current

The neutral wire of a three-phase, four-wire feeder should be grounded only at the main station. An additional ground outside of the station may form a return path of low resistance for currents outside of the system, while it may also create conditions unfavorable to telephone service.

THE ELECTRIC METER

By H. W. Richardson

Ever since human beings have been dependent upon one another, a unit has been necessary to determine relative value when anything is exchanged, bartered, bought or sold; until to-day every line of trade has its units of measure, and devices to indicate the number of these units. Coincident with the development of electric generating and distributing apparatus, there was created a demand for some sort of a device to measure the amount of electricity generated or sold. Now why is an electric meter of importance to an electric plant?

Usefulness of the Electric Meter

The meters on the panels of the station switchboard measure the output of the plant, and, in conjunction with the figures for operating expenses, thereby furnish a means for determining accurately the cost per unit generated. The cost may then be separated into the cost per kilowatt-hour for fuel, labor, oil, waste, repairs and various sundries. With these data before him, the manager can tell if too much coal is being used to produce a kilowatt-hour of energy, or if the labor item is too high; they may show that the quality of labor and wages should be increased in order to secure better economy; they certainly do show on what items to economize in order to secure minimum cost of production.

Further, the sum total of the consumers' meter readings, divided by the kilowatt-hour output of the plant gives the efficiency of the distributing system. If this ratio is low, it means that the meters, line losses and transformer losses should be investigated; and meters, therefore, are of great assistance in determining where and when to stop leaks and losses.

Systems of Charging for Electric Service

In the early days of electric lighting, current was sold on a flat rate basis. Although this system is still used to-day to a greater or less extent, it is unsatisfactory for a variety of considerations. The consumer of electric energy should be charged not only for the amount used, but consideration should also be paid to the length of time during which energy is consumed. This is just both to the consumers and stockholders.

If the meter system is adopted, additional lamps may be installed for the sake of convenience in hallways, closets, bedrooms, porches, etc.; heating devices can be connected at any time, and the consumer pays only for the current actually used. If he desires to substitute a 32 candle-power lamp for a 16 candle-power, he will pay for the extra current.

Under flat rates, on the other hand, he pays neither on the basis of amount nor length of time used; he pays for each additional outlet installed, whether he uses it or not; or, in other words, he is penalized for installing extra lights. The company, therefore, operating under flat rates is defeating the very object of its existence.

With meters, the plant and distributing system are not unnecessarily and artificially loaded, as is the case under flat rates, since the load is that actually required by the consumers. The result is less line drop, better lights, more uniform quality of service, and minimum dissatisfaction. Less line drop spells more line capacity, and this, in turn, means that it is unnecessary to invest in more copper. Meters cause a healthy increase of business. When the peak load necessitates additional equipment, it is due to actual demands and not to an artificial peak, such as produced by flat rates. It is, therefore, cheaper to invest in meters than in additional generating and line equipment. Experience has proved over and over again that the earnings per kilowatt output are greater on a meter basis than on a flat rate basis. With meters the connected load on the station may exceed the generating capacity by 60 to 100 per cent., although experience has shown that on flat rates it should never exceed 30 per cent. above the generating capacity.

The Edison Chemical Meter

All of the earliest types of meters have now become obsolete. The one that attained the widest commercial importance was the Edison chemical meter, which comprised two plates of zinc immersed in a solution of zinc sulphate. Current flowing from the positive plate decomposed it and deposited the zinc on the negative plate. It was known that one ampere would deposit a certain definite amount of zinc in one hour; so that by knowing the weight of the two zinc plates at the beginning of the month, and then weighing them at the end of the month to determine the loss in weight of one and the gain in weight of the other, the amount of current could be calculated in ampere-hours. The zinc plates and solution were contained in a glass tumbler, two tumblers being sometimes used to serve as a check on one another. These tumblers were connected across a shunt which was in series with the circuit being measured.

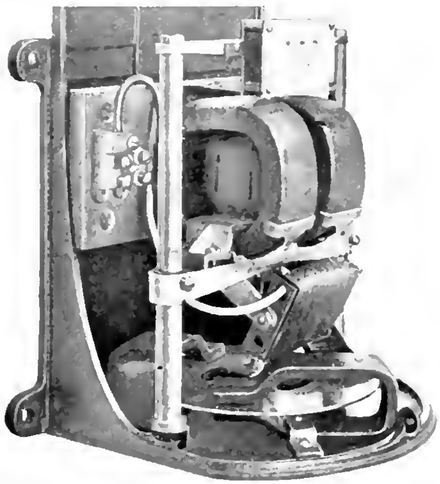
While this meter was fairly accurate for a given voltage and served its purpose at the time it was used, it had many objections. It gave a record, not of watt-hours, but of ampere-hours; if it was calibrated for a given voltage it was incorrect for other voltages; its accuracy was poor at light and full loads; while if the glass jar was broken during the month, no record was left. It was found moreover that after standing unused for some time the weight of the zincs increased due to oxidation; the labor of cleaning each month and maintaining the meter was excessive and the details cumbersome, while the consumer, since he could not follow the method of measurement, felt that he was at the mercy of the electric company. There was no means to determine if it had changed its accuracy; and a further objection was that the meter could only be used on direct current; so that with the rapid growth of alternating current distribution a different type of meter was needed.

The Thomson Motor Meter

As is usually the case, necessity was the mother of invention and caused the motor type of meter to be invented. This was produced by Prof. Elihu Thomson of West Lynn, Mass., and great credit is due to him for the efficient electric design and arrangement of the parts. The meter was of the commutating type, and meters of this type are virtually the same today as when the first motor meter was placed on the market, the improvements being essentially mechanical rather than electrical. The first Thomson recording wattmeter to be sold for commercial use was tested at the factory of the Thomson Houston Co., West Lynn, Mass., Sept. 18, 1889. From that day to this the motor meter has proved its value over all others.

The Thomson meter consists of a shunt and a series circuit. The shunt or armature circuit is wound with fine high resistance wire; it is connected across the line and thereby measures the voltage. The series circuit, or series field coils, as they are sometimes called, are connected directly in series with the line and hence measure the current. The watts in a circuit are proportional to the amperes and the voltage, and hence this motor can be adjusted to measure the energy.

In order to regulate the speed of the motor it is directly connected to a generator of miniature dimensions. This generator consists of a disk or short-circuited armature, and a field produced by permanent magnets,



First Thomson Watt-hour Meter Built

and serves as a load for the motor. The faster the motor runs the more work the generator does, so that the work done varies directly with the energy running the motor. It is therefore a simple matter to adjust the meter so that it records the true watt-hours.

During the first decade the Thomson meter was on the market, every known law of physics that could be applied was employed by various inventors in the design of meters, and about 190 distinct types were produced. During the second decade there was a process of elimination of these various types, until today the motor-meter is the only watt-hour meter remaining. This brings us to the consideration of some of the requirements of a meter.

The Requirements of the Electric Meter

The requirements placed upon the electric meter as regards its operation and the scope of its service are probably as stringent as those exacted from any device; and yet, when properly installed and regulated, its accuracy will be found to be greater than that of almost any other commercial measuring apparatus in use; notwithstanding this, if it fails in any particular, it is looked upon as a terrible offender.

The meter must first of all be initially accurate on all loads, from the smallest to the heaviest within the range of the meter, and must maintain this accuracy under all ordinary conditions for a long period of time and without attention. It must be small in size, light in weight, easy to transport from place to place, and able to withstand reasonably rough usage; it must not be cumbersome and must remain unaffected and its adjustment unchanged; it must be fool-proof and mischief-proof, as well as being proof against dust, moisture, and insects. The internal parts of the meter must be accessible for adjustment or repairs, the casing of the meter must be easily sealed, and the register must be clear and legible, reading direct in kilowatt-hours.

After leaving the manufacturer, the meter may be installed under ideal or adverse conditions, in a moist cellar or the overheated garret of a house. It may be in a kitchen or laundry where it is subjected to moisture, it may be in the high temperature of an engine room, or it may be out-of-doors exposed to all conditions of the weather and elements. It may be subjected to widely varying temperature and climatic conditions from day to day and from season to season. After meeting all these variable conditions it must record accurately under a multitude of varying electrical conditions, such as fluctuating voltage and variation of frequency and temperature. On direct current systems of distribution the voltage one-half mile from the plant is much lower than near the plant, but meters carried in stock at the same voltage rating must be good for either end of the line, provided the line drop is not too great. The meter should record accurately upon a load of lamps or motors, or mixed load producing variable power-factor; while it must also be unaffected by change of wave form such as may be produced by different types of alternators, or various classes of connected loads. It must have minimum friction, high torque, permanent magnets and easy means of calibration.

What other device is there that has to meet such widely varying conditions? Some people suggest that a clock or watch remains accurate for a long time, even years. Why not a meter? The work of a clock is different from a meter in that it has a strong driving force of constant value and runs always at the same load and speed. Not so with a meter; its driving force as a motor is very small and varies from almost zero up to any load it may be forced to carry.

The Prepayment Meter

Aside from the ordinary meter there is the prepayment meter, which has in one sense a distinct field of application. The prepayment gas meter has proved very popular, and there is no reason why the prepayment electric meter should not enjoy the same distinction, since today a good prepayment meter is available.

I stated that this type of meter filled a distinct field of usefulness. It is particularly adapted to apartment houses, summer resort homes and other places where the tenants are usually more or less transient; their credit is unknown, but they are a class who generally spend money freely, and hence furnish very desirable business when handled on a cash-in-advance basis. It is very desirable for Chinese laundries, restaurants, fruit stands, etc.

In a category apart from these there are many prospective consumers who do not feel that they can afford to pay a monthly bill, but who nevertheless do not mind the payment of 25 cents at a time into a slot meter. This class of consumer usually has but few lights, but burns them more regularly than the consumer who has 30 to 100 lights in his residence, and this small consumer therefore tends to furnish a better load factor.

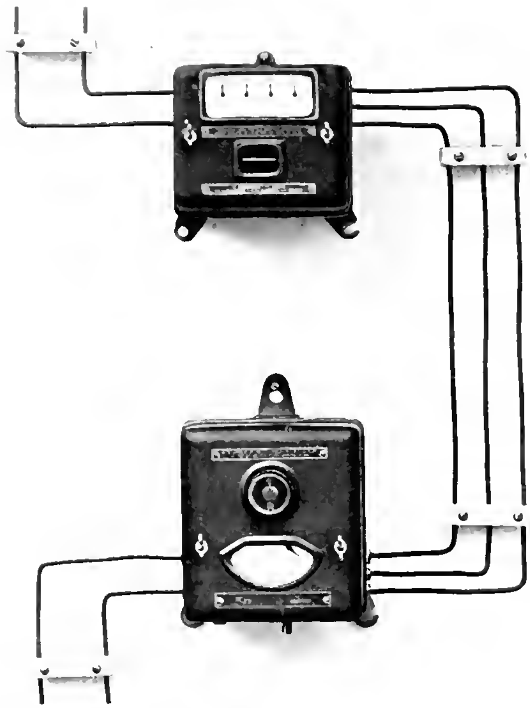
With the prepayment meter the service is strictly cash in advance, there are no bills to make out (and hence no delinquent bills) and no mailing expenses. The expense of auditing and billing is thus materially reduced.

Real estate operators, furniture dealers and other merchants by the thousands, have developed prosperous businesses because of the desire of many people to purchase on the instalment plan, and there is no reason why the sale of electric current cannot be increased by going after it on this basis.

Requirements of the Prepayment Meter

The prepayment device must necessarily comprise at least four principal parts, the escapement train of gears, the automatic line switch, a coin box and a rate device.

The prepayment meter, as well as the ordinary meter, must be fool-proof and mischief-proof. It must work with new coins or coins slightly worn; if a counterfeit coin or slug is inserted it should be impossible to withdraw it, for once it is in the coin box, the dishonesty of the consumer can be detected; it must allow several coins to be inserted at a time, thus eliminating the necessity of frequent visits to the meter. The automatic switch must not open until all the energy paid for has been consumed, but it must open as soon as the energy has been used. The operations which the consumer performs must be extremely simple, and if he does not operate the mechanism correctly,



Thomson High Torque Watt-hour Meter with Separate Prepayment Device

it must not be thrown out of adjustment. The device should have an indicator to show how many coins remain to the credit of the consumer, thereby telling if it is necessary to insert more money. The meter proper must have a dial to register the kilowatt-hours used, which will serve as a check on the coins in the box as shown on the indicator. The rate gearing should be capable of being changed without affecting calibration. The coin box should be accessible without the collector having access to the interior of the meter, since the collector is often unfamiliar with the internal parts of the meter. The cover should be removable to permit testing and inspection without access to the coin box. The coin slot should be designed so that a small coin like a 10 cent piece, inserted instead of a quarter dollar, will pass through without being registered.

Criteria for the Selection of a Suitable Meter

Having covered some of the various features which a meter should possess, what additional characteristics must be looked for in the selection of a proper meter?

To decide upon the type of meter to be adopted is a simple or difficult matter, depending upon how one goes about it. If prices are requested and publications secured, and then the lowest price meter selected, the task is extremely simple. To decide the type upon its merits even with samples before one is not always an easy proposition; testing the meters will help. Experience from handling various meters, and a knowledge of what results can probably be secured if the meter is constructed along certain lines, are of extreme importance. Ordinary tests are easy to make, but tests extending over a considerable period of time under actual service conditions are also of value; it is by the long time tests that the defects are discovered, and it is also necessary always to make an intelligent investigation of the mechanical and electrical design and construction of the meter. What then are some of the important mechanical and electrical features?

Electrical and Mechanical Features Which Affect a Meter's Operation

Maintained accuracy over a considerable period of time is unquestionably the most important thing a meter is called upon to accomplish. There are so many things that determine maintained accuracy that virtually the entire mechanical and electrical design is involved. High torque, minimum initial friction, minimum increase of friction, permanency of the magnets, proper alignment of parts, and suitable weight of moving element, are among the most important features. Of these torque, friction and magnet drag are so closely interlinked that it is impossible to discuss one without reference to the others.

High-Torque and Low-Torque Meters

The force operating the meter must be directly proportional to the energy being metered, so the speed of the disk must vary directly with the load. Torque is the measure of the force that makes the meter operate, and high torque therefore is synonymous with good meter operation. As meters are built today high torque is the most important feature in the entire electrical design.

The importance of high torque, and its relation to maintained accuracy and revenue returns, is not generally appreciated. In order to illustrate this relation we may consider the case of a high and a low torque meter whose ratio of torques is 3 to 1. Both meters measure the same house-lighting load, consisting of twelve 50 watt lamps. The meters are 5 amperes, 110 volts capacity and are adjusted initially correct. The lamps in the house are found to burn as follows:

6 lamps burn ½ hour, this equals	150 watt-hours
4 lamps burn 1 hour, this equals	200 watt-hours
2 lamps burn 1½ hours, this equals	150 watt-hours
1 lamps burn 2 hours, this equals	100 watt-hours
Total daily consumption	600 watt-hours

For 30 days this is 18.0 kilowatt-hours.

Since both meters measure the same load and operate under the same conditions, the friction increase should be the same in each meter; but owing to the difference in their relative torques they are found after a considerable time to be recording the above energy as follows:

	High torque meter		Low torque meter	
No. of lamps	per cent. recorded	watt-hours	per cent. recorded	watt-hours
6	99.6	149.4	98.8	148.2
4	99.2	198.4	98.2	196.4
2	98.8	148.2	93.73	140.6
1	97.6	97.6	92.8	92.8
Total daily consumption		593.6		578.0
Per cent. total energy recorded		98.93		96.66

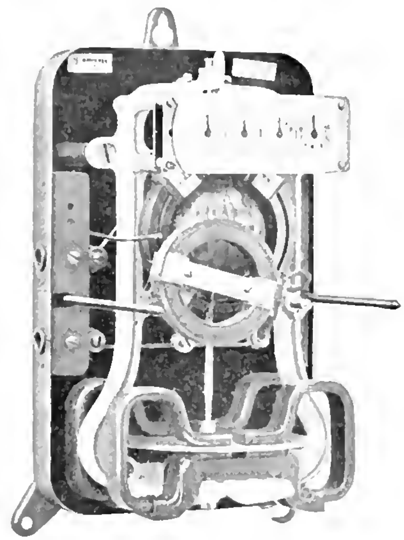
At $0.10 per kilowatt-hour the monthly bill should be $1.80. The actual bill rendered for the high torque meter is $1.78 and for the low torque meter $1.74. Here is a loss of 4 cents per meter or 48 cents a year, which on 1000 meters would mean a loss of $480.00. The amount saved per year by the high torque meter in this case was found to be 48 cents. If this represents interest at 6 per cent. then $8.00 is the capital. In other words, it would be a good policy for a plant to invest $8.00 more in a high torque meter rather than to purchase a low torque meter.

Retardation Determined by Magnetic Drag and Friction

The ideal meter from the standpoint of accuracy would be one which, once adjusted correct, would not change its calibration. It is, however, a law with mechanical devices that friction exists wherever motion exists. Friction, then, is present in all meters, and it is the aim of the designing engineer to reduce its effect to a minimum. If there were no friction the speed could be controlled wholly by the permanent magnets.

In practice there are then two factors which determine the retardation of speed, the magnetic drag and that produced by friction. The accuracy depends upon the relative value of these two factors, because the torque is equivalent to the sum of these two opposing forces. If the torque required to overcome the magnet drag is very large compared with that required to overcome friction, it is evident that friction will produce very little disturbing influence. The excess of magnet drag over friction is then a measure of the meter's ability to maintain accuracy. Friction in many devices is highly variable and in a meter an increase of several hundred per cent. is not unusual. The frictional wear of the jewel bearing, register, top bearing and, in direct current meters, the brushes on the commutator, all tend to increase this factor. Friction will of course produce its greatest effect on light loads, and in order that it may not become a source of serious error the ratio of the magnet drag to the friction must still be high. The most prominent meter manufacturers endeavor to build their product so that friction will be a minimum initially and will remain so.

The magnetic drag is dependent upon the disk conductivity, magnet strength and speed of rotation, varying directly with the conductivity and speed, but with the square of the magnet strength. If then, there is a slight change in the magnet strength the accuracy will be materially affected. With the increased knowledge and experience in the composition and physical properties of steel, methods of handling the steel, and treating the magnets, their permanency under commercial conditions is to-day an actual fact.



Direct Current Commutator Watt-hour Meter

Effect of Friction and Necessity for Light Load Compensation

Meters in residence lighting operate for a majority of the time at less than 15 per cent. of their full load. The factor of friction, therefore, becomes an important feature for electrical companies to consider, since it affects directly the revenue received. Friction on heavier loads is such a small proportion of the total retarding force that its influence may be regarded as negligible.

Friction will be variable due to vibration and the conditions of installation. In order that the meter may be best adapted for accurate registration at the point where it is installed, it is necessary that the friction compensation device be adjusted to meet the local conditions. A meter without light load compensation, or means of adjustment for prolonged service, is incomplete and should never be adopted.

The effect of friction may be illustrated best by an example showing the relation of the retardation of speed, due to magnet drag and to friction. It will be observed that the ratio of friction to magnet drag is greatest on small loads.

Per cent. load on meter	Relative amount of retardation Due to magnets	Due to friction
100	6000	1
50	3000	1
25	1500	1
10	600	1
5	300	1

Analysis of the above table shows that if no means is provided to compensate for friction, on 5 per cent. load friction produces 1/300th of the total retarding force, and the resulting error is approximately $\frac{1}{3}$ per cent. slow. If now the friction increases ten-fold the ratio will be 10/300ths on 5 per cent. load. The error will then be approximately $3\frac{1}{3}$ per cent. slow on this load. The ratio of torque to friction increase is then the measure of a meter's ability to maintain accuracy, and it is thus seen that friction increase is the chief factor militating against maintained accuracy.

High Torque More Important Than Weight of Moving Element in Minimizing Friction Effect

In order to render its effects a minimum two schools of design have arisen. One school developed their meter by the reduction of weight of the moving element and along lines of extreme refinement, and were soon in the province of the watch-maker. The other school recognized the relation of the weight of moving element to friction increase, but also gave due consideration to the importance of the mechanical strength and electrical characteristics in connection with the design of the meter. They gave most importance to high torque, and it is scarcely necessary to mention that the latter type of meter has established its superiority over meters of more delicate construction.

It is claimed by some people that the weight of moving element, and type of bearings employed, constitute good criteria for determining the ability of a meter to maintain accuracy. This is true only within certain limits. For instance, the weight of moving element in the commutating meter, on account of the very nature of its construction, is several times that of the induction meter, and the jewel wear is more destructive. If, however, we compare induction meters of different types, we find that the weight of moving element, in itself, has less to do with maintained accuracy than the nature of the installation or the normal difference in the quality of stones used for jewels. Cases are known where the lighter weight of moving element in an induction meter will vibrate under the effect of the rapidly alternating flux, and will produce greater drilling action on the jewel than will a heavier and steadier moving element. This is particularly noticeable on heavy loads.

The friction in the lower bearing of a meter is the result of two factors, the pressure downward due to weight, and the nature of the bearing surface. Since the weight is constant it can be compensated for; and the function of the light load device is to compensate for this weight and, at the same time, to compensate for friction at other points, for example in the register, top bearing and commutator. Once the weight is compensated for, all the torque of the meter is available for overcoming any increase of friction. It is well here to call attention to the fact that the friction compensation, when adjusted, will take care of static friction; in other words, a heavier element will respond just as readily to a fluctuating load as a lighter element.

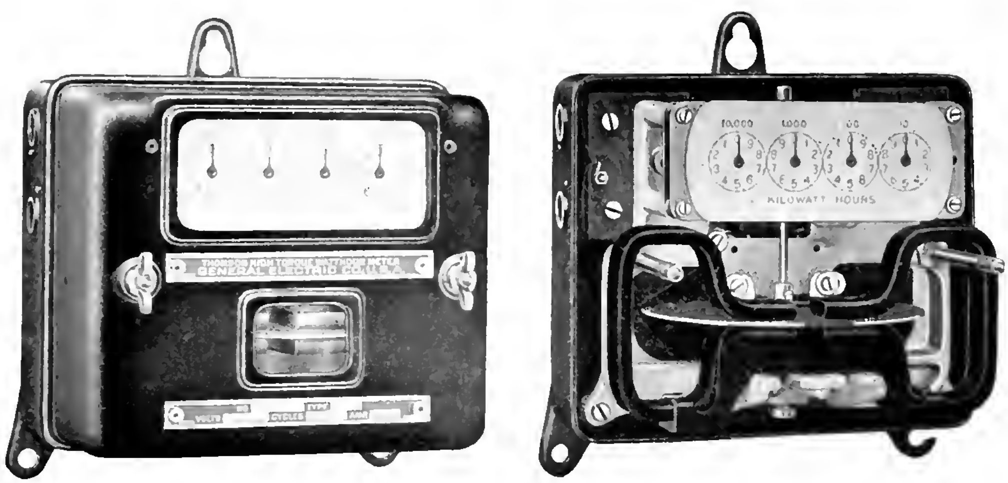
The argument may be advanced that a heavier element will cause the jewel to wear more rapidly even after the weight has been compensated for; but actually at the present stage of the development of the meter art, the nature of the jewel stone and its quality have far more to do with the jewel life. This is demonstrated every day. In certain instances meters which have been in service for several years without being opened since first installed, do not show errors larger than four or five per cent. even on 1/20th load; while again other meters, of the same identical type and construction, in service less than a year, have errors much in excess of five per cent. This certainly is not due to the weight of the moving element, but rather to the nature of the installation or jewel stone.

Ball-bearings and Pivot-bearings

There is little to be said one way or the other in reference to the type of bearings, whether the ball or pivot is to be preferred. Service tests which have been analysed, covering thousands of induction meters, show no advantage of one over the other from the standpoint of maintained accuracy. If a meter tests slow on light load, attempt should always be made to locate and remove the cause, and this sometimes necessitates an inspection of the lower bearings. To remove the ball bearing, inspect it, and then replace it without losing the ball, requires considerable skill; and it will often be found that meter testers who handle and are familiar with both types of bearings, rather than remove the ball bearing to locate the cause of increased friction, will adjust the friction compensating device, and leave the meter without having removed the cause of trouble. On the other hand, the meter tester will invariably inspect a pivot bearing, because the same conditions, and distribution of wear, exist in both types of bearings.

There is, however, this objection to the ball type of construction. Wear once started on one jewel will soon be communicated to the other jewel by the ball, and hence wear will exist at two points and it will be necessary to replace two jewels. In the pivot bearing on the other hand it is necessary to replace only one jewel. If the jewel is found injured the ball or pivot should be replaced by a new one, as the particles of abraded sapphire will have impregnated this part of the bearing, and will injure the new jewels which may be inserted.

Some time ago attention was directed to a test made on a considerable number of meters



Induction Type Single-Phase Watt-hour Meter

it is the simplest and easiest type of bearing to handle.

Everything considered, the pivot bearing is more satisfactory from a central station point of view. Advocates of the ball bearing claim that the ball does not rotate at one point in the jewel cup of induction meters, but, owing to the "side thrust" of the disk, moves about at different points on the cup, thus distributing the wear and increasing the life of the jewel. It is true that the ball moves about on different points of the cup, but it should be remembered that the same side thrust exists in the induction meter using the pivot bearing; the pivot rotates on the jewel surface at different points, and thus the full load wear is removed from the light load running point. It is therefore evident that

equipped with the ball bearing, the object of the test being to determine the merits of this bearing. The meters in question were run slightly above full load over a considerable time, the moving element making approximately ten million revolutions, that is, 3000 kilowatt-hours. After the test the meters were checked up with the result that all were found to be within 2 per cent. at full load, while one half were within 2 per cent. on 2 per cent. load. None of the remaining meters showed errors exceeding 5 per cent. at 2 per cent. load.

Such a test is valueless, and many million revolutions accomplished by the meters as secured are meaningless figures, and are apt to create a wrong impression. First, because the meters were run continuously above full load, and anyone at all familiar with meters knows this fails to represent commercial working conditions. Second, when running on heavy loads, the wear on the jewel is at a different part of the jewel cup from the light load running point; hence good results at light load would naturally be expected on a test like the one described. Third, the claims for the test failed to state the initial accuracy before the test was started.

Exaggerated Importance of Shunt Losses

The question of shunt losses in meters is exaggerated entirely beyond its importance. Meters as built to-day have a very small shunt loss; a high efficiency 16 candle-power carbon lamp consumes ten times as much energy as the potential circuit of a Thomson commutating meter, and 25 to 30 times as much as good induction meters. Was anyone ever known to figure extra capacity for his transmission lines in order to take care of the meter shunt losses? The only time such loss could possibly produce any effect on the distributing system is at peak load on the plant, and then its relative amount to the station output is insignificant. When the plant is operating on its minimum load, its effect on the coal consumption would be too small for a fireman to regulate, even if a means could be provided for cutting off the shunt loss. The shunt loss should be low, but it does not follow that because a meter has the smallest shunt loss it should be adopted. Low shunt loss often means low torque, and consequently poor light load accuracy after a period of time. Shunt loss should be considered in the selection of a meter, but there is a tendency to emphasize its importance at the expense of far more important features.

Care in Selection of Location of Meter and in Installation

The accuracy of a meter depends not only upon the merits of its design and workmanship, but upon its location and upon intelligent use. The necessity of maintaining apparatus of a delicate nature on premises not controlled by the electric company makes the problem somewhat difficult. Care must be exercised in selecting the best possible location on the consumer's premises. The meter should be in a dry place, as far removed as possible from vibration, as it will give better service, longer life and more accurate results. If conditions exist such that more or less jar or vibration is inevitably present, it will be found advantageous to place soft rubber washers under the heads of the screws which clamp the meter to the wall, and between the meter and the wall itself. It is well to select a location free from sudden and wide changes in temperature variations, since change of temperature causes expansion and contraction of the fine wire windings. This tends to chafe the insulation and may eventually result in an open circuit.

It is strange that more attention is not paid to the proper setting of meters, especially when so much expense and engineering are devoted to generator locations. Both have moving elements and depend upon freedom from vibration, dampness, chemical fumes and dirt, to insure proper operation; both require greater or less adjustment before being placed in service; and in addition a meter must maintain its accuracy when the generators and distributing systems are not maintaining satisfactory conditions of potential, frequency and power-factor.

Meters for incandescent lamps should be installed between the line switch and the load, while in motor installations they should be located between the line switch and motor switch. This arrangement prevents the inductive kick of the motor from burning out the meter shunt circuit. In the past if a contractor wired a building, all that was required of him, in many instances, was that a meter loop be left so that an ordinary station wireman, with a blow torch, tape etc., could complete the meter connection. The central station should have an understanding with all contractors that a definite arrangement of meter leads be maintained, that the meter be installed in a place easily accessible for reading and testing, well lighted, and at a given distance above the floor. While this may slightly increase the initial cost of the installation it reduces the expense of maintenance, reading and testing. A direct current meter should never be installed in a service box lined with sheet iron; in fact sheet iron, or other magnetic material, should always be removed as far as possible from direct current meters, although this precaution is not so essential in the case of induction meters.

Importance of Regular Inspection and Testing

If electric operating companies expect the best results from electric meters, the meters should be inspected and tested periodically. Probably the most important thing to consider in connection with the subject of testing is the frequency with which tests should be made. Most operating managers believe, as a matter of policy, that meters should be tested at least once a year. The periodicity of testing is best determined from an analysis of local conditions, the expense per meter, the revenue per meter, and a study of the conditions which affect accuracy. Some of these are wear of the brushes and commutator, roughening of the jewel bearings, changing of the permanent magnets, etc.

Life of Jewels

With regard to wear of the jewels, one million revolutions of the meter shaft is sometimes taken as the limit of wear of a sapphire jewel in commutating meters. This seems rather low for the present meters, but will apply to those of the older types. A given number of revolutions of the meter shaft cannot be definitely taken to represent the jewel life, since it varies with the nature of the installation, jewel stone, etc., and many sapphires are to-day giving a longer life than one million revolutions. The diamond jewel may be conservatively estimated to give eight times the life of the sapphire. At present its life is undetermined. Out of 17,000 diamond jewels used in meters only 57 were eliminated due to losses in fires, breakage, rejections and other causes. The revolutions of the meter shaft had reached almost fifty million with some of the jewels, and there was little or no evidence of wear. All commutating meters built by the General Electric Co. of 50 kilowatt capacity and larger, are equipped with the diamond jewel. Several of the larger central stations are adopting the diamond jewel, not only for the large size meters, but also for the smaller ones and for the older types.

Frequency of Testing

It would seem advisable to adopt some classification for testing meters, on similar lines perhaps to the following:

Annual tests 15 ampere sizes

Semi-annual tests 25 to 50 ampere sizes

Quarterly tests 75 amperes and larger

Meters making over one million revolutions between tests should be changed to the more frequent class. It is usually unnecessary to test oftener than quarterly, although some companies make it a practice to test all switchboard and other exceptionally large meters every month. Commutating meters for 550 volts should be tested more frequently than 110 volt meters, because they are subjected to more strenuous service conditions, and hence do not hold their accuracy as well. If a meter fails to hold its accuracy for a period of 3 months investigation should be made, when it will often be found to be due to vibration, heavy overloads, short-circuits, etc.

Induction meters, owing to the absence of a commutator and to their lighter moving element, will give an accuracy on 18 months test equal to that of the commutating meter under quarterly tests. Induction meters giving large revenue returns should be tested oftener than once a year; if they show over, say, three million revolutions between tests, it may prove advisable to test twice a year, or perhaps once every few months.

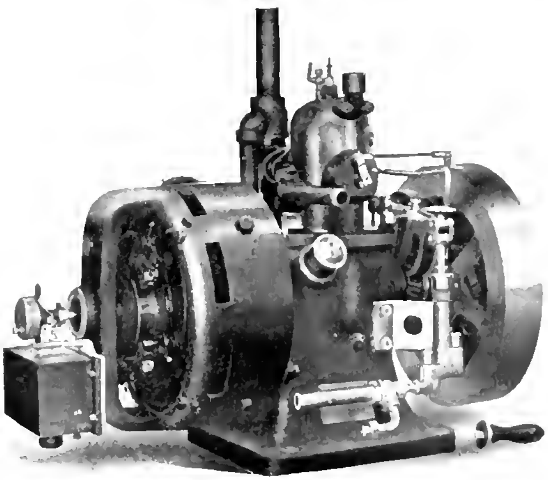
It is very essential that bills rendered to a consumer be correct, especially if he be a new one. It is, therefore, wise to test a commutating meter within two weeks after it is first installed on the consumer's premises. With induction meters there is no commutator to become oxidized, and hence this initial test on the consumer's premises is not so important. Induction meters should be tested, as a matter of general policy, either at the meter room or on the premises at the time of installation; an installation test in no way questions the accuracy of the meter, but may be regarded purely from a commercial standpoint. If a customer subsequently complains, it may then be pointed out to him that the meter was positively correct when it was installed.

It is of vital importance that the standards used for testing be accurate. The use of the portable test meter or rotating standard is now recognized as the best method; this instrument reduces the chances for errors to a minimum, is independent of load fluctuations, and permits of accurate and rapid work.

THE GASOLENE ENGINE AS A PRIME MOVER FOR SMALL LIGHTING INSTALLATIONS

By J. Scott Button

The general subject of the very small isolated lighting plant is one that for many years was overlooked by the large electrical manufacturers, partly because of the rapid development and growth of the large central stations throughout the country, partly because of the lack of demand on the part of the rural residents, but largely because



One Kilowatt Gasolene Engine Generator Set

there was no wholly satisfactory prime mover for an extremely small generating installation.

The city central stations developed and expanded so rapidly that even the most ambitious of the large electrical manufacturers, with all of their enlargement of factories, could not much more than keep pace with the increased demands of this class of customers. The many new applications of electric power in all branches of industry, and the constantly growing army of converts to the utility of electricity for both power and lighting, resulted in problems enough to occupy the time and tax the ingenuity of the engineering corps of these manufacturing concerns, even though these corps were being constantly increased in size.

In the meantime, however, the city man seeking comfort and health for himself and family during the summer months found that the electrical conveniences of city life that had to be left behind, although originally considered luxuries had gradually assumed the importance of necessaries. These conveniences were not to be found in either the summer resort hotels or in the private country estates, and the demand for them became insistent.

The residents of rural communities through which a power transmission line passed discovered, or were apprised of the fact by wide-awake central station or transmission companies, that these lines could be tapped and thereby render their villages more desirable as places of abode and manufacture.

The establishment of interurban trolley lines and the good roads movement, coincident with the development of the automobile, took the city man more frequently and farther into the country, and the country man more readily and consequently more frequently to the city, to the mental and financial advantages of both.

The spirit of competition due both to the education of travel and association, and also the desire to make two blades of grass grow where but one had grown before, had seized the farmer; and many a small country stream was harnessed and made to perform the labor of several "farm hands." Those villages to which access to the transmission lines was denied, and the farmer with no tumbling brook on his property, demanded some satisfactory substitute for the accidental good fortune of their rivals.

The treadmill furnished a means of utilizing animal power—horse, sheep, dog or even human for threshing, churning and other labor. The windmill followed as a means of harnessing a force of Nature to lighten the labors of man. With this power the farmer could perform considerable work without increasing his payroll nor his expenses in the way of fodder or victuals, provided he managed to do this work while the wind was blowing. This did not help much during a spell of calm weather, however; and so the windmill finally found its principal function to be the pumping of water, to be stored in elevated tanks whence it could be drawn when the wind failed. Some even connected an electric generator to the windmill, utilizing a storage battery as a reservoir of electrical energy. But the storage batteries of a few years ago were more expensive and less reliable than now, and this arrangement was more in the nature of an experimental luxury than a reliable convenience.

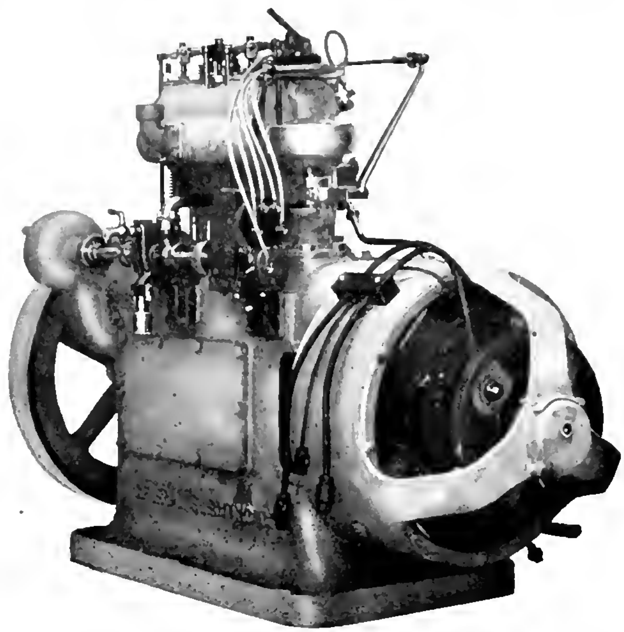
The gasolene engine, from the early days of its development, was seized upon by the farmer as a solution of his mechanical power problem. A few of the more ambitious even ventured to belt an electric generator to their power engines; but the gasolene engine in the early stages of its development was far from being a consistent performer and the experiment was, to say the least, not wholly satisfactory.

This early gasolene engine could turn a grindstone, drive a pump, run a thresher or feed-cutter and do many of the farm operations—sometimes. At such other times as it couldn't, the farmer's time was occupied in tightening up bolts and nuts or taking the engine apart to find and correct the trouble, and so no time was wasted, the owner or his helper being kept busy *all* the time. But when the day's work was over, and our ambitious farmer, he who had belted the generator to his primitive gasolene engine, settled himself down in his big arm-chair to smoke his pipe and read his paper, and the gasolene engine "bucked" and "lay down," the farmer's wife would light the kerosene lamp that she had saved against an emergency; while her lord and master lighted his lantern, changed from slippers to boots, put on his coat and hiked out to the barn to devote the remainder of his evening to tinkering with the "pesky critter" until bedtime.

The worst of the situation was that neither the engine manufacturer nor the generator manufacturer would assume the responsibility for the "light that failed," each blaming that part of the combination that was built by the other.

The small village far away from central station or transmission line contented itself with a series of kerosene lamps set on posts at its principal street corners, some later substituting a gasolene lamp for the kerosene variety; while some of the more progressive were fortunate enough to secure a central gas plant which supplied gas, not only for the street lamps, but for residential lighting. At least this is my personal recollection of the development of the solution of the lighting problem in the New York village in which I was born and passed my boyhood.

Improvements in kerosene lamps, such as tubular wicks, etc., helped somewhat. Gas mantles have more recently improved the lighting conditions of the unelectrified town; but the spirit of progress that has been responsible for the evolution from the blazing pine knot to the tallow dip, and from the kerosene lamp to the gas burner, is not content to stop with the modern light—electric—just out of reach. And yet we all

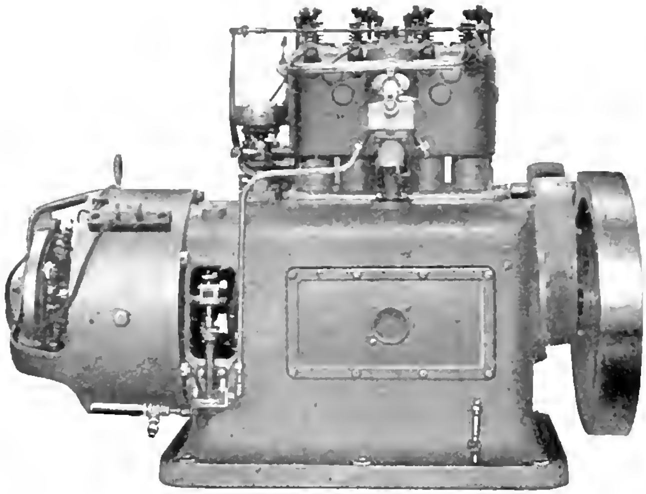


Three Kilowatt Gasolene Engine Generator

know of any number of well-to-do communities that have not yet availed themselves of this invention of modern science. This number is being rapidly reduced; and the gasolene engine of today, the development of which is largely due to the demands of the automobile industry, is playing a very prominent part in the reduction.

Many small towns are enjoying the blessings of electric lights because of a convenient water power that some progressive citizens had faith enough to develop, and many, too, have installed miniature steam-driven central stations. How many places are there, which having once enjoyed electric service, are now without it? I, personally, do not know of any.

This is, I sometimes think, saying more for the advantages of electricity, even at its worst, than for some of the engineering schemes by which the generation of this electricity has been accomplished. I believe that many of the schemes for private and public hydro-electric plants were conceived in the spring of the year, and without much thought of those summer months when the mountain brook hardly manages to run enough water over its "right of way" per day to retain its franchise, legitimately; and many an owner of a small water power plant, private, corporate or municipal, is, particularly during the dry season, in a



Five Kilowatt Set

receptive frame of mind toward a practical reliable, economical substitute.

The objectionable features that developed in the case of the farmer's early gasolene-electric plant are still in evidence among many of the gasolene engine-driven rural lighting sets now being offered to the public. Frequently the engine manufacturer is content to depend absolutely on the generator maker's standard machine most nearly meeting the engine requirements as to speed, capacity and appearance; with the result that in combination, neither the engine nor generator serves the purchaser most efficiently, nor does the combination look as much like a "happy union" as it does a "marriage for convenience."

In some cases the end sought justifies these means, and it would really be poor economy for the purchaser to pay for the refinements of design and manufacture necessary to produce the highest class of apparatus. There are, on the other hand, a great many—and as the rural resident becomes educated up to an appreciation of the facts, there will be more—demands for a gasolene engine-driven electric generating set, of which both the motor and generator units are designed and built especially for this service and with definite reference to the characteristics of each other.

The United States Government was one of the first to demand such a piece of apparatus, and it was a Government specification, containing all of the usual refinements of one of those documents, that impelled the General Electric Company to "produce the goods."

These specifications required direct connected (shaft drive) construction, with high enough speed and frequent enough impulses to produce the even turning movement absolutely essential to steady voltage. They required throttle governing as contrasted with the more economical "hit-or-miss" type, to assure the maintenance of uniform speed on both fixed and varying loads. They demanded positive lubrication, positive fuel supply and positive circulation of cooling water. They demanded not only economical fuel consumption and high electrical efficiencies at the rated capacity of the set, with a minimum of decrease in efficiency and increase in fuel per kilowatt at slight underloads, but also that the set should carry a stated overload for a stated period of time without "stalling" the engine or overheating the generator.

These are but a few of the special conditions that had to be met, and were met, in the design of the four-cylinder, four-stroke cycle, vertical, water-cooled gasolene engines and the generators to which they are direct connected.

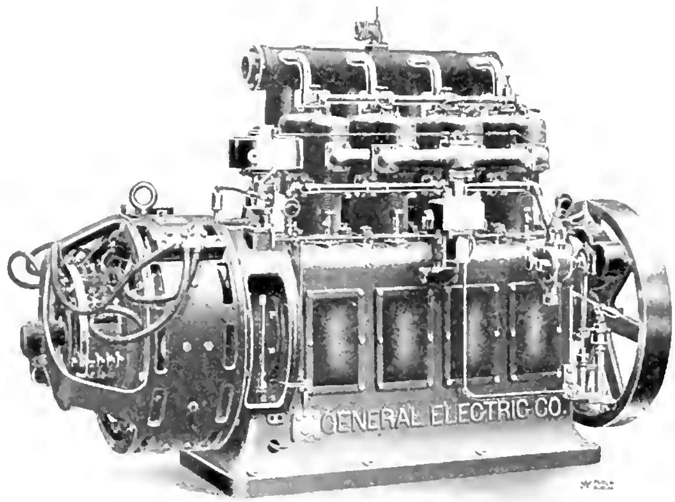
The Government specifications did not require that these gasolene engines should conform to the requirements of the National Board of Fire Underwriters, which Board is the final court of appeal on questions of insurable property in this country; but in order to produce consistently the very best that could be conceived of in this type of apparatus, these sets were made to conform absolutely to those requirements, thereby assuring a purchaser the validity of the fire insurance on his property.

It is not by any means claimed that these sets are the only ones fit to use in all cases, and the fact is recognized that in many instances a less expensive non-insurable and less compact equipment will fully meet the particular requirements of the case; but just as there is a demand in the automobile business for the strictly high class, high priced touring car as well as for the little single-cylinder runabout, there is also a demand for the strictly high class direct connected gasolene engine-driven electric generating set, which demand cannot be filled by any other type of apparatus. This is no more a reflection on the single cylinder, "hit-and-miss" governed, air-cooled, drip-lubricated, gravity-feed, belted type engine than are the claims of the high grade touring car a reflection on the inexpensive runabout, it being a recognized fact that each has its particular field of usefulness.

It is claimed, however, that for those installations which require close speed regulation with variations of load, steady voltage at any load from zero to maximum load, a safe margin of capacity to assure continuity of service even though an overload condition arises, independence of storage battery equipment, a minimum amount of attention and a maximum of endurance, together with safety from fire and explosions, there is no similar apparatus on the market at the present time to which these sets have to take second place. No steam-driven outfit in the large central stations can claim any more than this; and consequently when one is so situated that he cannot leave the responsibility and expense of generating his electric energy to others organized for that purpose, and still demands the very best of electric service, he may be assured that in these gasolene sets he will find the goods that he demands. The same refinements of design and operation of prime movers that made possible the alternating current generating station in large units, are now available in these gasolene engines for the new central station in a small town, and the two larger sizes of this line (25 kw. and 10 kw.) are available in 60 cycle, 3-phase units of any standard voltage. These alternating current gasolene engine-driven sets have been operated in parallel with each other in the manufacturer's testing department. One of these 25 kw., 60 cycle, 3-phase, 2300 volt sets is the entire equipment of the central station in the village of Lewis, Iowa, where, located in a concrete building only 16 ft. by 16 ft., it has been lighting the streets of the village, and a large number of the residence and business places, since the plant was first started, the 6th of last January.

This plant is operated by a man who is general electrician, looks after wiring and new installations, reads the meters, makes out the bills, and in fact does everything that the superintendent of a small plant usually does. There is one station attendant who was formerly a house-mover and he stays at the station during the evening run.

The possibilities of utilizing this apparatus



Twenty-five Kilowatt Set; Direct Current Generator

as an auxiliary to a steam power central station, both to carry the day load that would be but an inefficient fraction of the normal load of the station generator, and also help out the steam-driven generator at peak load, are attracting considerable attention among central station operators. The manager of one large central station in the east proposes to secure two or three of these 25 kw. alternating current sets, and set them out as "missionaries" in small communities just outside his present zone of service, with a view of running lines out from the central station as soon as the "missionary" has secured enough "converts" to warrant the investment, feeling confident of the result and realizing the easy possibility of transplanting the gasolene set to some other similar districts, in the event of either the success or failure of the original extension venture.

In other words, realizing that the gasolene engine is at last a wholly successful prime mover for a small lighting plant, this manager proposes to utilize that knowledge to the ultimate advantage of the larger city central station, rather than wait until the residents of these outlying communities have heard of, and copied, the example of Lewis, Iowa.

SOME POINTS IN THE CONSTRUCTION OF GASOLENE ENGINES

By B. H. Arnold

At present nearly every large town and its suburbs within a radius of several miles is lighted by a central station; but beyond the limits reached by the most extended feeders of these stations are the ranches of progressive farmers, and the summer estates of wealthy people from the cities. The first of these two classes look upon electricity with its attendant convenience and flexibility as a business proposition, and, once convinced of its value, are satisfied with a fairly steady light. On the other hand the man from the city, who has used electric light and power

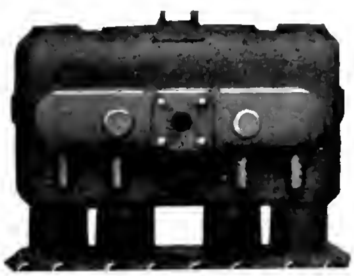


Fig. 1. Four Cylinders Cast En Bloc

daily, regards it as a necessity; and as he is accustomed to the excellent service of a large central station with turbine driven units, expects, and must receive, a light equally steady and serviceable from his own residential plant.

For small units the superiority of the internal combustion engine over the steam engine with its boilers, has been clearly proved. The automobile has familiarized the country at large with the gasolene motor, and mainly for this reason it has become the first choice as a prime mover for generators in installations of this kind.

These small power plants are installed beyond the limits of the central station territory, and hence beyond the reach of machine shops and expert attendance. It is therefore a matter of primary importance that materials possessing the best of wearing qualities be employed in their construction, and that a simplicity of design be attained that will facilitate rapid repairs.

Of the foregoing essentials, the hardest to realize is ease of repair. Other qualities depend to a large extent upon design and choice of materials; but to insure quick and accurate renewal of parts, with no other aid than that of a wrench and screw driver, requires not only accurate design and standardization, but the best of machine work and unceasing vigilance in the inspection of each individual piece. As absolute accuracy is practically impossible, actual trials, even though extremely costly, must be made to determine the permissible limits of error. These have been found to vary from 0.0005 to 0.002 inches. By far the greater number are between 0.0005 and 0.001 inches, larger limits being allowed only on rough work. Owing to differences in the coefficient of thermal expansion, special care must be devoted to work which involves the use of two or more metals.

For a better understanding of the processes by which the necessary qualities are obtained, some of the more prominent construction processes of a high grade gasolene engine, used for lighting purposes, are here described.

The cylinders are cast *en bloc* for the small sizes and singly for large machines, and are made of a special grade of iron which flows readily into the mould, and possesses peculiar strength and heat-resisting qualities. The casting, with its water jackets and gas passages, presents a very difficult casting problem, especially when the cylinders are made *en bloc;* indeed, the highest type of founders' art is then called for. Fig. 1 shows a casting of the most complex type; not only are the four cylinders with water jackets and valve chambers in one piece, but the throttle chamber intake pipe and exhaust header are included as well.

The water jackets of the cylinders must withstand a water pressure of one hundred pounds for 5 minutes, and the cylinder walls a pressure of 400 pounds for a similar time. The test is made on the casting before and after machining. The water jackets are also given a steam bath to rid them of all particles of moulding sand, which might cause serious trouble to the water circulating pump.

All machine work of the cylinders must be done on expensive and carefully designed jigs, to insure an exact duplication of all work. The machining of the bore itself is done in four operations, between each of which the iron is allowed to cool, to prevent any of its parts from being thrown out of shape. The final finish is obtained by grinding, or "lapping."

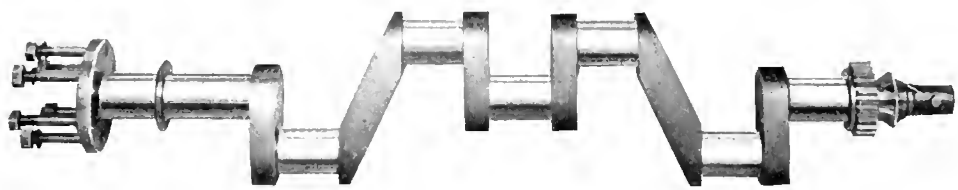


Fig. 2. Three-Bearing Crank Shaft

The pistons and rings are cast of the same special iron as the cylinders, and are machined and ground to their proper dimensions with equal care and precision.

Both the crank shaft and connecting rod are drop-forged from selected steel, heat-treated, the crank shaft material containing in general a small percentage of chromium or nickel. As these parts are subjected to the heaviest stresses, care must be taken to see that all material is sufficiently strong. Upon completion a piece is cut from at least one in every ten of the crank shaft forgings. This "coupon" is subjected to a strength test, in which the elastic limit must equal 60,000 lb. per square inch, and the tensile strength 90,000 lb. per square inch.

In order to pass inspection, all bearing surfaces of the shaft must be accurately ground to size, the variation permitted being only 0.0005 inch. Fig. 2 shows a three bearing crank shaft completely machined and ready for assembly.

The cam shafts are made by pinning drop-forged cams onto a steel shaft. The cams are hardened and are ground to the proper shape on a specially designed cam-grinding machine. In certain cases, however, it may be advisable to machine the shaft, cams and bearings all from one solid piece of steel, sufficient material being left from the early operations to permit hardening and grinding of the cams and bearings. Fig. 3 shows two of the "built up" shafts.

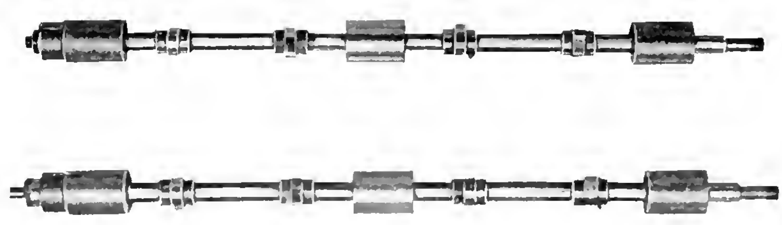


Fig. 3. Two Built Up Cam Shafts

All gears are cut from drop-forged steel blanks. The cutting must be done accurately, for $\frac{1}{1000}$ inch too deep or too shallow will cause noise and excessive wear. In order to eliminate as much noise as possible, the gear teeth are cut at an angle, or, if the power transmitted is slight, gears of special compositions are used.

Linings for the crank shaft bearings must be of a special babbitt or of Parsons' white brass, to secure the degree of toughness required to withstand the sudden pressure to which they are subjected. In small sets these parts are preferably die-cast to effect interchangeability. The cam shaft linings may be made of ordinary babbitt or bronze, as they are not put to such severe service.

In spite of the exercise of all possible care and forethought in design and manufacture, certain flaws will inevitably creep in. As a last check, therefore, the completed machine is sent to the testing department and made to operate under actual service conditions. The test is as follows:—The machine is driven three to five days by belt, a plentiful supply of oil being provided; one day at no load under its own power; and three days during which the load is increased to full and a trial made at overload. During this period time may be taken to correct small troubles; but the last day on test is occupied by a ten hour full load run, followed immediately by a two hour run at from ten to twenty-five per cent. overload. The consumption of fuel and lubricating oil is recorded, together with the temperature of various parts.

A report of every engine, covering its behavior during the entire time of test, must be written. The test as outlined is the shortest made; frequently several additional days are needed to satisfy the testing department that an engine is fully satisfactory.

The foregoing gives but the barest idea of gas engine construction, for nothing can be written that will adequately describe the long and expensive tests that are made to determine the proper kind and quality of material, or the correct shape and dimensions of the various parts, such as cams and carburetors. In the continual striving for simplicity, every time an alteration is attempted much time and energy must be expended to ascertain not only the direct results effected, but the consequent changes made necessary in all dependent parts. Another important problem, though seldom mentioned, is that of the constant warfare of competition. The tendency to reduce the cost, rather than to establish a high grade production worthy of its price, must constantly be striven against.

In the design and construction of high grade gasolene engines for lighting service, the best automobile engine must be equalled, if not surpassed. As this statement may appear extreme, the following brief contrast of service requirements is offered:

The lighting engine, in order to deserve the name, must operate evenly and smoothly at all loads, for any variation in speed, however slight, will immediately be shown by flickering of the lights. Tired eyes or even a headache will quickly ensue; if a light of this nature is used constantly the eyesight will be permanently affected. Variations in speed that cannot be noticed on a speed indicator will appear prominently on lamps. But few automobile engines operate at constant speed under light loads, even as judged by the eye or ear. A governor is, of course, necessary, but even the best will not be good enough unless carburetion and distribution are most carefully designed.

The most striking contrast to the casual observer is the small size of the automobile engine, when compared with a stationary engine of the same rated horse-power. It should be borne in mind, however, that very few automobile engines will deliver their rated output at any reasonable speed for one hour, to say nothing of the ten or fifteen hours run required of the lighting engines. Again, when an automobile passes by, the quietness at which it operates seems remarkable; but the machine is out of doors, mounted on a spring-supported chassis, and covered with the hood. The lighting engine runs uncovered—frequently in a small room —firmly fastened to an inelastic foundation of iron and concrete, which is generally integral with the engine room floor, if not with the whole building.

As the lighting engine is not under a hood and has no drip pan beneath, it must operate cleanly. All oil must be kept inside—a feature not easy to attain, as the expansion of the metal from the heat may open slightly the finest of machined joints, through which the heat-thinned oil will quickly work. The uncovered lighting engine must also have its various parts finished; the brass must be buffed, the iron filled, sandblasted and aluminum painted, etc., as the lighting plant on many summer estates is one of the interesting features exhibited by the owner to his guests, and must, therefore, show no flaw as far as its outside appearance is concerned.

GASOLENE-ELECTRIC EQUIPMENT AT LEWIS, IA.

By John Hay Kuhns

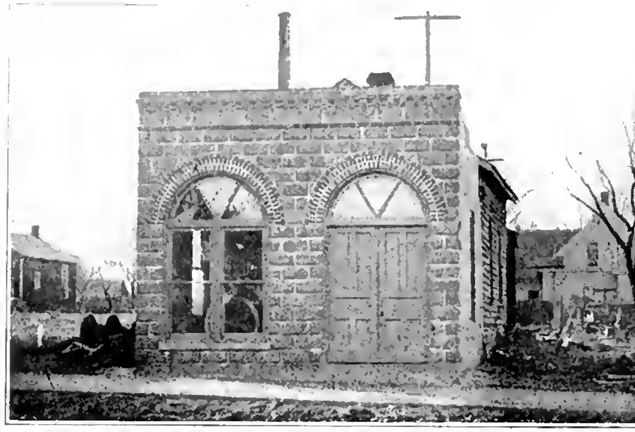
Supplying Energy to a Town of 650 Inhabitants

The problem of electric lighting and power service for villages and small towns seems to be finding satisfactory solution in the gasolene-electric generating sets designed originally for the United States government for the long-continued and rigorous duty in seacoast fortifications. The successful use of these sets in a number of the forts has suggested their broader commercial utility. On Jan. 6 the Lewis Electric Light and Power Company started to operate at Lewis, Ia., what is believed to be the first central-station plant exemplifying the applicability of these gasolene-electric sets for street and general commercial lighting and motor service. Already there are connected to the circuits eighty customers, twenty-five of whom are new users of electric energy. Over 800 lamps, or an average of over ten lamps per customer and nearly one and one-quarter per individual member of the town's population, are connected, with still a large reserve of undeveloped business to draw upon to build up a profitable station load.

Lewis is a small town of 650 population in a rich and fertile section of the best farming country in Iowa. Farm lands are valued here at about an average of $150 an acre; much seed corn is raised and shipped from this center, while one of the most prominent horse and cattle ranches, handling high-grade stock, is located close by. As a town Lewis has had a varied history, dating back over sixty years.

Lewis was at one time the county seat of Cass County, but was outrivaled for that honor by the more populous thriving little city of Atlantic, which has the good fortune to be situated on the main line of the Rock Island Railroad. With the building of the Atlantic and Griswold branch of the Chicago, Rock Island and Pacific Railroad a few years ago, now a connecting link between Atlantic and Red Oak, an important town on the main line of the Burlington route, Lewis spread out to the west, doubling its area and extending to meet the railway which crosses from north to south the extreme west end of the town. The railway station is at the foot of Main Street, a block west of the electric light plant. This newer portion comprises the principal business and newer residence part of the Lewis of to-day.

Five or six years ago there was installed an electric light plant in connection with a mill operated by waterpower and later by steam. It met with but indifferent success in the hands of various parties. An un-



Exterior of the Central Station at Lewis, Ia.

successful effort was made to dispose of the old plant and system to the town at a considerable loss, after which it was entirely dismantled and removed, a portion of the machinery being transferred to another town.

For the erection of a new plant upon more modern and progressive lines a group of business men organized the Lewis Electric Light and Power Company with the following officers and board of directors: Prof. S. W. Rowley, president; Mr. David Hickman, vice-president; Mr. William B. Davis, secretary; Mr. Ivan H. Beardsley, manager and engineer, and Messrs. Daniel Stevens, Bert Hardenberg, W. W. Albright, V. M. Elstin and M. H. Elliot, directors. The company is capitalized for $5,000, all stock being common and issued at a par value of $10 per share. No bonds have been issued. The primary purpose has been to install a thoroughly good plant and equipment, and to this end the actual cost has exceeded the capitalization, which is permissible by Iowa State law, the whole costing in round numbers $6,000. In addition, $500 to $1,000 worth of supplies is carried for the convenience of consumers. The company is operating by agreement under a franchise granted other parties some years ago, as did its predecessors, no transfer of franchise rights ever having been made. After three years the town may acquire the plant, if desired, upon payment of a valuation determined by a committee of three appraisers, one appointed by the town and one by the company, these two to select the third.

Rear of the Central Station

The central station is located on Main Street, which is the principal thoroughfare, and is installed in a low one-story building for which a mere nominal rental charge is paid, the company having the option to buy the property later at the value of the land plus the cost of the improvements and simple interest on the same. To the front of an old frame building about 16 ft. by 28 ft. has been built a neat, well-lighted concrete blockroom, about 16 ft. by 16 ft., carrying the building to the lot line and affording ample space for the generating set and switchboards, and such desk room as is needed for the ordinary office business of the company. In this room, which is finished in natural pine with plastered walls, has been installed a standard General Electric 25 kw. gasolene-electric generating set consisting of a four-cylinder, four stroke cycle, vertical water-cooled, 43/54 h.p. gasolene engine, direct-connected to a three-phase, 2300-volt, 600-r.p.m. alternator with a 125-volt exciter mounted on the same shaft and in the same frame. The whole is so constructed as to insure permanent alignment and prevent objectionable vibration.

The carburetor is of the constant-level type, and the gasolene is delivered by a pump connected to the engine. This pump draws its supply through pipes direct from a 120-gallon tank set in the ground back of the station at a safe distance from the surrounding buildings. Ignition is furnished by high-tension magneto with starting battery. Lubrication is effected by means of forced circulation through a pump connected with the engine.

With the generating set is a slate switchboard panel mounted on iron frames, the panel being equipped with three ammeters, one voltmeter, an instrument plug switch for voltage indication, one single-pole carbon-break switch, one automatic oil circuit-breaker line switch and rheostats. Instrument transformers are mounted above and back of the board.

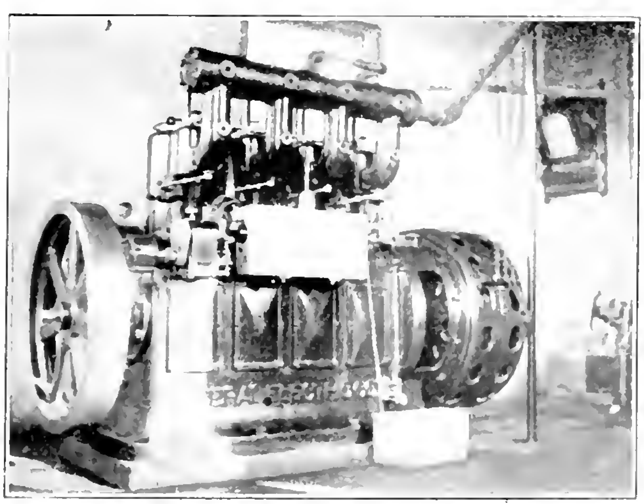
For street-lighting service a 4 kw. constant-current transformer has been installed, and with it a gray marble switchboard panel mounted on iron frames and carrying an ammeter and a four-point plug switch. On a board near the generator set are mounted in convenient reach suitable wrenches, spanners and repair parts and tools.

Business Section of Main Street, Lewis, Ia.

To cool the engine cylinders a battery of five galvanized cylindrical steel tanks, 6 ft. in diameter and 8 ft. high, have been installed in the old part of the building adjoining the generating room and slightly above the level of the latter. By means of a pump connected with the engine the water with which these tanks are filled is kept in constant circulation during operation, thus dissipating the heat from the engine jackets. It was at first attempted to effect this water cooling by using a single small tank and pumping cold water direct from a well at the rear of the building. This proved inadequate because of difficulty with the pump and frequent need of pump repairs. Hence the well and pump method was abandoned, and the tank system substituted. The rest of the space in the old part of the building is utilized as a stockroom for wire and supplies.

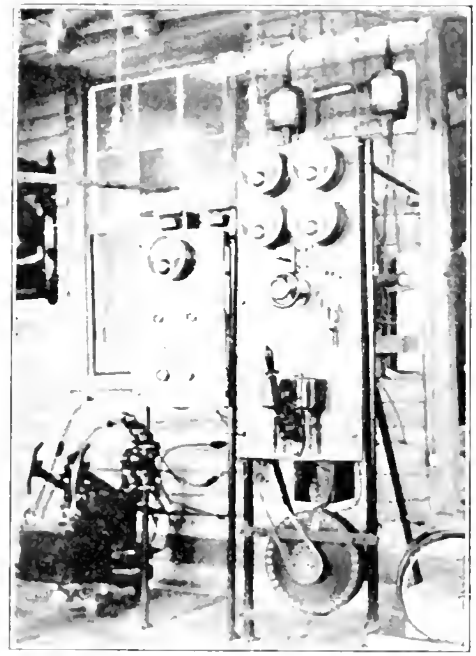
Insufficient data have as yet been taken to ascertain the amount and cost of fuel per unit of energy. However, for a period of fifty-three days, from Jan. 21st to March 15th, there has been an average daily consumption of 21 gallons of gasolene at 11.7 cents per gallon.

Evening lighting service is furnished from dark until 11 o'clock daily except Saturday, when service is extended until 12 midnight; and morning service from 5:45 A. M. until daylight. Thirty-two 6.6-amp., 32 c-p. series-tungsten lamps at street crossings are lighted during



Gasolene-Electric Generating Set

the regular operating hours, modified by a moonlight schedule. For this service the town pays $1 per lamp per month. A few additional street lamps in the residence portion will be added soon. For commercial light-



Switchboard Panels

ing a combination schedule of flat rate and meter rate has been arranged. For a small number of lamps the charge for energy per month is 75 cents for a 16 c-p. lamp, $1 for two, $1.50 for three. When there are more than three lamps the circuit is metered. Consumers may own their meters, or the company will furnish them on a rental charge of 25 cents per month. The company now has $260 in rented meters in service and about as many more are owned by consumers. The meter rate is 15 cents per kw-hr. up to 20 kw-hr., and 10 cents per kw-hr. for all energy in excess of that amount.

Consumers furnish their own wiring, fixtures and lamps, the company furnishing service connection to the house entrance. The company has adopted the policy of wiring houses at an advance of 10 per cent. on the cost of materials, with a charge of 30 cents an hour for labor. Lamps are sold at 25 cents for a 16 c-p. carbon, 80 cents for a 40-watt and $1.10 for a 60-watt tungsten lamp.

Probably the best lighted house is a very pretty modern cottage at the corner of Main and Washington Streets where twenty-three 40-watt tungsten lamps are used. The attractiveness of this well-lighted house sets a commendable example for others there and elsewhere. Liberal use of light goes a long way toward solving the problem of lighting villages and small towns, and promotes a spirit of progress that soon puts the town out of the rural village class, increases business and enhances property values.

Negotiations are under way for operating the town pumping plant by means of a three-phase motor. The town has already bought and installed a 5-h.p. Fairbanks three-phase, 60-cycle, 220-volt motor belted to a countershaft, and the company has run a special set of primary feed wires from the station to the pumping plant on Market Square to provide for this service. The water is lifted by a Deming pump from a 65-ft. well to a water tower on the Public Square, six blocks distant on higher ground in the old part of the town. A 6-h.p. gasolene engine is now used for pumping, but it is estimated that not over 3 h.p. is required.

It is thought that by slight additional running time, or by operating a few hours in the day once or twice a week, the pumping can be done at a saving to the town and a profit to the company. The gasolene engine at the pumping station will be retained for auxiliary or emergency pumping service, and will probably be operated by the company for the town at about actual cost of fuel and labor. A two months' trial will be given before closing negotiations.

There seems little demand in a place of this size for a day load. A possibility spoken of by the management is that, in case of doing the water-works pumping, it may be arranged to run the electric service on Tuesdays to care for washing machines and laundry irons, that being a convenient time for most housewives.

An electrical exhibit, perhaps with some of the practical domestic apparatus for heating and cooking, is contemplated in connection with the annual school exhibit about commencement time. It would be strange indeed if the intelligent demonstration by these bright young people of the utility, simplicity and convenience of such appliances, did not influence their parents and friends to put some of these appliances into their homes.

Leaving the generating room all primary mains and feeders are carried from the back of the station to the pole line in the alley at the rear. The station equipment and circuits are protected by lightning arresters inserted where the lines leave the building. Additional lightning arresters will be placed upon the lines.

All primary and street-lighting circuits are of No. 10 weatherproof copper wire and the secondaries are of No. 6. The pole line exemplifies good regular engineering practice, though heavier poles would be an advantage. Much credit is due to the company's electrician, Mr. Ivan H. Beardsley, for his skilful construction. White cedar poles of 25-ft., 30-ft. and 35-ft. lengths, supplied by local dealers, are set from 110 ft. to 125 ft. apart.

The entire equipment was supplied by the General Electric Company and installed under the supervision of an engineer from its Chicago offices. The service is said to be unsurpassed by that of any other town of similar size.

Modern Cottage at Lewis, Ia.

GASOLENE-ELECTRIC GENERATING PLANT, HOTEL INDIAN RIVER, ROCKLEDGE, FLA.

By M. E. Bonyun

An excellent illustration of the peculiar suitability of the gasolene-electric system for isolated plant service is provided by the installation at the Hotel Indian River, Rockledge, Florida. The design of the equipment here and the manner of its installation possess certain features of originality. The system is so representative of what the General Electric Company promulgates, and so closely approximates to the ideal system for this class of service, as to warrant the following brief description of the installation.

Rockledge is situated on the west bank of the famous Indian River about 175 miles directly south of Jacksonville, Florida. It is peculiar in that it is essentially a residential community, every house, small or large, constituting a winter home. The banks and stores are located in the town of Cocoa, which lies about 1½ miles north of Rockledge, connected to it by an excellent shell road. It would seem that Rockledge possesses all the attributes essential for a health and holiday resort; and during the winter season, say from the beginning of December to the beginning of April, the village blossoms forth into a gay and festive resort.

The Hotel Indian River has lately been reconstructed and extensive improvements have been carried out, the chief of which relates to the installation of the gasolene electric generating plant. This equipment consists of two 4-cylinder 4-stroke cycle gasolene engines direct connected to two electric generators each delivering 25 kw. at 125 volts direct current; with auxiliary equipment including generator and feeder switch panels, gasolene storage tank, hot water storage tank and cooling tanks. These two generating sets displace a twin cylinder 2-stroke cycle engine of the "hit-or-miss" governing type, connected to a bipolar generator, which unit had throughout its life given but very indifferent service. During the season previous to the installation of the new electrical equipment, the hotel was several times placed in utter darkness, due to failure of the engine, while finally the electric service had to be abandoned and resort made to the use of kerosene lamps.

The new machinery is installed in new foundations in the old power house which is quite close to, but separate from, the main building. (See Fig. 2.)

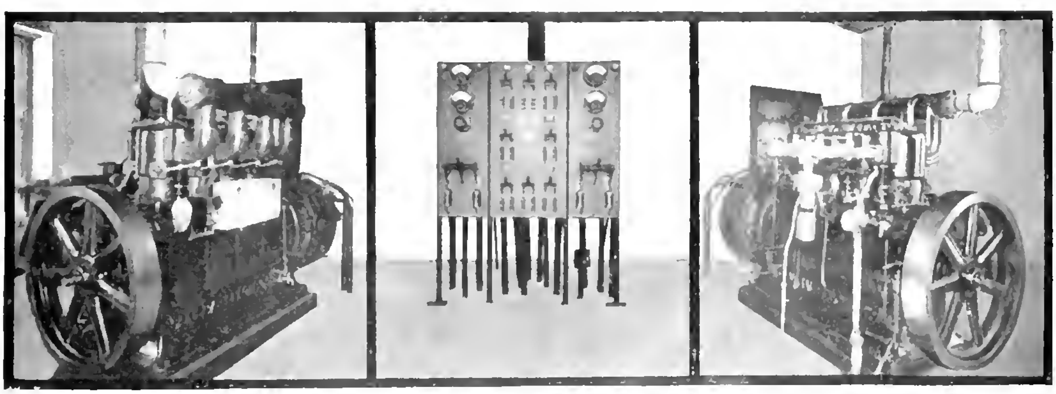


Fig. 1. Power Plant of the Hotel Indian River

The electric distribution system embraces the lighting of the entire hotel, tungsten lamps being used in the lobby, ball-room, dining-room, reading-room, billiard-room and halls. The lighting installation represents about six hundred 16 c-p. equivalents, including grounds and dock. An up-to-date steam laundry has been built and is operated by a 10 h.p. 115 volt G.E. motor, while energy is also supplied to the elevator motor. The hotel is provided with a refrigerating plant, in which a 10 h.p. motor is used to drive the compressor.

In addition there are several small motors employed operating a vacuum cleaner, dish-washer machines, fan motors, etc., while a number of heating appliances are used in the rooms of the hotel and laundry. The wiring of the power house is in conduit, while the distribution to the lighting standards in the grounds and dock is also of the underground construction.

Fig. 2. Power House

Aside from the electric load which the generators carry, the method which has been adopted for supplying hot water for domestic purposes in the hotel is of considerable interest. It was proposed to use the jacket water of the engine cylinders for domestic purposes in the hotel, and hence it became necessary to design a special system of circulating tanks, including a special hot water storage tank. Ordinarily 340 gallons of water per hour at 68 deg. F. is sufficient to cool one 25 kw. engine, running at full load continuously. This jacket water leaves the engine at 185 deg. F. Frequently where abundant water is obtainable for this purpose it is allowed to run to waste; but where water is scarce, it has been substantiated by experience that 2700 gallons contained in five 4 ft. by 6 ft. open tanks connected in series, will radiate sufficiently between the first and last tanks to allow the same water to be used again and again.

Since it was proposed to use the hot water from the engines in the hotel, as above stated, and since the top hot water in the hotel is 30 ft. above the engine foundations, it was evident that the storage and cooling tanks would have to be designed for a closed pressure system. Further, in order to protect the engines against an excess of hot water, which might accumulate in the system of tanks at periods during the day when little or no hot water would be used, it was considered advisable to interpose six 4 ft. by 6 ft. closed tanks between the storage tank and the engine (Fig. 3), the storage tank being covered thickly with asbestos lagging, and thus permitting but very slow radiation at this point.

The cooling and storage tanks are located on the north side of the power house, between it and the hotel where little sun strikes them. By reference to Fig. 3, it is seen that the six cooling tanks are each provided with a three-way by-pass valve, which allows any or all of these tanks to be cut in or out of the circulating system. This provides for periods when hot water is being used rapidly in the hotel, and can be supplied as rapidly.

Rockledge is not supplied with a general water system. Drinking water, which is pure and excellent, but somewhat hard, is obtained from artesian wells. The hotel company in order to supply itself with soft water, has constructed a reservoir about 500 yards in the rear of the hotel, having a storage capacity of 75,000 gallons. Water is pumped from a large surface well located on the far side of the reservoir, being seepage from the St. Johns River. Having percolated through many miles of sandy soil this water is quite clear and soft.

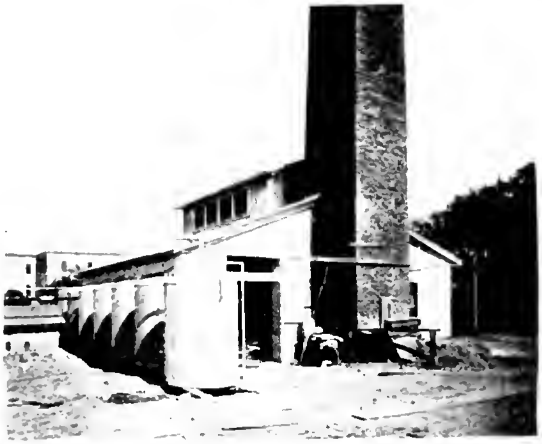


Fig. 3. Tanks for Reducing Temperature of Cooling Water

From levels taken by the writer it was ascertained that the bottom of the reservoir was about 8 ft. above top water in the hotel. The reservoir being 10 ft. deep a good average head was always available at the highest discharge in the hotel. Such conditions made a gravity system for hot water circulation very easy of achievement; for in order to keep the system full, it was only necessary to tap the main from the reservoir at the engine level for connection to the tanks, and to construct a vent pipe above the storage tank to a height slightly above maximum high water in the reservoir. This vent pipe constitutes a relief against surges in the hot water system, and provides a constant and ready escape for any steam which might collect in the storage tank and cause trouble.

It is safe to say that this method of supplying hot water in the hotel has saved the proprietors practically the entire cost of a separately fired boiler and its installation, together with the entire cost of fuel which such a boiler would consume; since it will be understood that to maintain this supply of hot water from the engine cylinders requires no additional expenditure of gasolene.

To the most critical this plant in its class should appeal as a model of excellence in design and application; and at this date we are able to report that the entire system has given excellent results.

THE DIARY OF A TEST MAN

[CONTRIBUTED]

We are glad to be able to publish this month the first instalment of a series of contributions which we propose to publish regularly under the title of "The Diary of a Test Man." Earlier in the year full particulars with regard to this matter were circulated throughout all the General Electric testing shops. The first set of contributions which appear below give but a small idea of the scope which may be embraced by the series. It is our intention to make this a regular feature of the paper; and, with the assistance of men engaged on the test, we hope to publish in this manner a serial story which will be of considerable service to college men, young engineers and central station operators.

Ex-testers are invited to send us short accounts of their test experiences, which we may use in this section of the paper; while we would also mention that we are anxious to secure contributions from outside construction men with regard to their experiences on construction work.

No. 1. Pumping Back Tests

My first impression of the test was one of a jumble of wires and whirling machinery. I very soon learned to respect the "white tape" and to regard the "red tape." In those days all wiring and connections to machines were worked out by the boys, and there were no plug receptacles or snap switches, so conveniently arranged for the present day test man. I remember the first machine to which I was assigned was a 5 h.p. induction motor, and I was as proud of running that machine then as later when larger machines came to my lot. I was fortunate enough to get an early transfer to the larger test; and my feelings when introduced to the machines in this building as compared with the earlier ones were very much the same as a villager's on his first visit to New York when beholding the skyscrapers.

It was in this test that my best experience was gained; and I particularly recall the difficulty in those times of testing large quarter-phase machines. In one instance we received for test on the same day one 750 kw. quarter-phase synchronous motor-generator set, a.c.-d.c., two 500 kw. induction motor-generator sets, and one 700 kw. engine-driven quarter-phase generator. The direct current machine on the synchronous motor set was 550 volts and the direct current machines of the induction motor sets were 150 volts each, while the voltage of the 700 kw. engine-driven generator was 220 alternating current, that of the synchronous motor 2300, and the induction motors 5400.

It was necessary, therefore, on account of the size of the machines, to use 12 transformers in multiple with auto-transformer connection, stepping up from 220 volts to 2300 and 5400, respectively. The direct current generator being slow speed had to be direct connected to a fairly slow speed motor, and this motor so arranged as to obtain the heaviest field current possible, in order to reduce the speed to that of the generator. As the production on the machines was in the greatest kind of hurry it was necessary to proceed with the test in the method outlined, which did not afford sufficient capacity to enable the machines to be started from the alternating current sides at the same time.

The direct current sides of the machines were arranged in the following manner in order to pump back. The two 150 volt machines in series, were connected through a water box with the direct current end of the synchronous motor set. The complete arrangements were, therefore, somewhat complicated, and the method of testing was as follows: Two induction motor sets were started, one after the other, then disconnected hurriedly and the synchronous motor set started. As soon as this set obtained sufficient speed, its field was closed and the switches on the induction motors were again connected to the line. The synchronous motor field at this time was increased sufficiently to cause enough leading current to flow to counteract somewhat the heavy lagging current taken by the induction motors. After several attempts all the sets were started and we proceeded to load the direct current end in the following way: the fields of all direct current machines were excited and by means of the water box were equalized sufficiently to parallel the direct current ends. It then became a question of adjusting the water box and fields of the direct current machines, so as to obtain full load by pumping back.

Many incidents occurred during this test. On account of the number of machines involved and the many adjustments required, it was necessary to use twelve men during the heat run, and I can safely say that all drew a long breath of relief when the test was completed.

No. 2. Core Loss and Copper Loss of Transformers

Transformer testing is probably as interesting as any other form of testing, and a man will be able to take better advantage of his time on other sections of alternating current apparatus, if he has first gone thoroughly into the behavior of transformers. I cite the following case as it shows a method of taking a heat run on a number of similar transformers slightly off the beaten track, and which may be of some interest to others engaged in transformer testing work.

The job on hand was to test six 30 kw single-phase transformers having a ratio of 100 to 6000 volts. The usual way would be to take the heat run with the transformers arranged in two groups, each group being delta connected; but as we were placed at the time we found it more convenient to test all the six at the same time. For supplying the core loss and copper loss current of the six transformers, two alternators were available. We connected the six low tension sides in parallel across the first alternator; and the high tension sides we divided up into three pairs, connecting the windings in each pair so as to buck one another, and thus giving zero voltage across each pair of high tension windings connected in parallel in this manner. These three pairs we then took and placed in parallel across the second alternator.

As far as the actual readings were concerned, the low tension voltage was set at 400 volts on the first alternator, and the second alternator was adjusted to give normal full load current of 5 amperes in each pair of high tension windings. The total current taken from this alternator was, therefore, 15 amperes; and the passage of this current in each high tension winding, of course, induced normal full load current in the corresponding low tension winding. This condition was therefore obtained without placing any heavy load on the first generator used to supply normal voltage for core loss.

One batch of transformers was tested in this manner; but on the following day when six similar transformers were on hand, it was obvious as soon as the low tension core loss voltage was applied that something was wrong. We had great difficulty in getting the volts up on the first alternator, and after some hunting around, we found that a mistake had been made with regard to the polarity of one of the high tension windings. The result was that in this particular pair the two high tension windings were connected so as to add their voltages instead of bucking; and since this pair was connected in parallel with two other pairs, the resultant added voltage was virtually shorted on the two other parallel circuits. The fault was noted in time and the connection remade; but it is obvious that if the first alternator had been of sufficient capacity to carry the overload and the excitation had been suddenly applied, the heavy resultant voltage induced by the faulty connection in the high tension windings, would have set up a heavy current, sufficient to burn out the transformers in this particular pair.

In taking core loss and copper loss tests on transformers, there is always plenty of room for faulty connections and the results are very frequently disastrous.

No. 3. A Lesson in Significant Figures

I have been working with the Company for a year and until the other day I thought

I was getting along very well. To be sure, I had made a few short circuits as the result of wrong connections, and in other ways received a moderate amount of calling down; but I had satisfied myself that I was doing as well as, and perhaps a little better than, the next man. This feeling of satisfaction was probably increased by being delegated a couple of weeks ago to special test work.

Why should I have forgotten today the work in college and the almost numberless times our old professor repeated to us that a long string of figures after a decimal point is meaningless, and as a matter of fact, worse than useless, unless the instruments or data on which the decimal figures are based, are all as accurate as the final answer would indicate?

Word came down from the office that one of the engineers wished a hurry-up test on some special connections of transformers, to ascertain, or more probably to verify, some effects of both direct and alternating currents in the same transformer windings at the same time.

From the data given us for making the test, it should also have been obvious that quick results showing the general nature of the combination desired, rather than any close values of current, voltage, etc., were wanted, as the transformers brought together for the test were not of the same class as those to be used on the job for which the information was wanted. However, since the engineer from the office had only time to look over the apparatus and read one or two of the instruments, it was left that I should complete the test and make a report to him. I can now see that my zeal to make a good showing was the cause of all the trouble.

To make a long story short, one of the ammeters that we were using in the test was tagged with the correction factor 1.0167. I had a column of about twenty readings from this instrument. Picking up my slide rule, I soon realized I could not do justice to the figures in that way, so began multiplying out the readings by the correction factor. When I had about a dozen of these multiplications done, word came that the engineer was leaving town within half an hour, and wished to see the figures.

After some delay, I hurried to the office. Apparently the column of figures was the first thing that caught the engineer's eye. He asked me what sort of ammeter I was using that would show a change in current of only one part in something like one million. I saw immediately that I had queered myself on this particular job; but there was still the correction tag on the instrument. However, the only comfort received from bringing forward this tag was that a new man in the standardizing laboratory received perhaps an even more definite setback than I had experienced.

The end of this episode was that the engineer said a lot of things about using yard sticks to measure the diameter of a steel shaft within a thousandth of an inch, and various other things which, to repeat, would be merely going over again what I knew perfectly well we had received at college. The only difference seemed to be that while we were getting it in the lecture-room, we thought it advisable to remember long enough to pass an examination; while today I realize that failure to remember has cost the company money, and temporarily checked my half formed notions to ask for a transfer from the test to the office engineering force.

No. 4. A Compass as Slip Meter for Induction Motors

The slip of an induction motor with wound rotor and slip rings can be measured by connecting an aperiodical ammeter between two of the rings, or, after the slip rings have been short circuited, by connecting the leads of a galvanometer to two slip rings. The galvanometer or the ammeter, provided the latter is polarized, will then make a number of complete oscillations, depending on the frequency of the secondary current.

We were one day making this test when we found that the galvanometer, which was standing quite near to the motor, started to swing with a regular oscillation before the leads had been connected up to the slip rings. Keeping the load on the motor constant, we further discovered that the number of oscillations of the galvanometer did not change, no matter whether the leads were connected to the slip rings or not. These oscillations we found to be caused by the leakage field of the rotor current, the magnetic path of which lies partly through the air, partly through the end shield bearing and shaft; and the indications on the ammeter which we obtained showed that the field leakage extends further into the air than one would usually suppose. From these readings, given the frequency of the secondary current, it is therefore possible to calculate the slip of the motor.

We afterwards tested a squirrel cage motor in a similar way, and found this method extremely accurate, provided the number of oscillations was not too high to be easily read. It becomes, of course, a difficult matter to count these oscillations if the needle is swinging very rapidly; with a 25 cycle motor, the slip can be more easily determined by this method than is the case with a 60 cycle machine. For instance, with 5 per cent. slip, the needle will make 75 oscillations per minute with a 25 cycle motor, against 180 oscillations per minute with a 60 cycle motor.

It is not necessary to employ a galvanometer for measuring these oscillations, as a pocket compass will answer the purpose admirably. In applying this method we usually laid a small compass on the bearing housing of the motor.

If O = the number of oscillations of the magnet needle during t seconds, f_2 = frequency of the rotor current, f_1 = frequency of the line current, and s = slip of the motor, then

$$f_2 = \frac{O}{t}$$

and

$$s = \frac{f_1 - f_2}{f_1} \times 100$$

It is not claimed that the method described above gives a more accurate measurement of slip than the standard method employed in testing shops, in which a slip meter is used; but in cases of outside testing, where one of these meters is not at hand, or where the necessary gears for motors of different number of poles are not available, the method is of very considerable service.

A. I. E. E. CONVENTION 1911

We have space only for a short notice of the 1911 convention of the A.I.E.E. which was held at the Hotel Sherman, Chicago, from June 26th to 30th inclusive. The attendance at Chicago, which finally was in excess of 900, far surpassed the numbers recorded at any previous convention of the Institute.

Mr. Ralph W. Pope during the convention tendered his resignation of the position of Secretary of the Institute, a position which he has occupied for 26 years. Perhaps the best testimony to the efficiency of his long years of service is to be found in the healthy condition of the Society at the present stage of its development.

An attractive list of visits to places of electrical interest in the neighborhood was arranged, and included excursions to the Hawthorn works of the Western Electric Company, the generating stations of the Commonwealth Edison Company, and the plant of the Indiana Steel Company at Gary, Indiana. Owing to the unwieldy size of the party, it was found impossible in the case of the visit to Gary to conduct all the delegates over the interior of the various buildings; and the inspection was therefore confined to a comprehensive circular tour of the whole works layout, including the coke oven plant, power houses, blast furnaces, open hearths, and mills. An invitation was courteously extended by the management to members of the Institute to visit the plant in smaller parties, with a view to a detailed inspection of the interior of the various buildings.

The business of the various meetings followed broadly the lines indicated in the advance program, and nearly all of the 35 papers presented were of exceptional interest and ability. Lists of papers are sometimes deceptive, and the value of a session often depends on the nature of the discussion which follows the reading of the paper. Judged from this standpoint, the convention will probably rank as the most successful in the history of the Institute, since at those sessions devoted to the deliberation of questions of really paramount importance at the present date, vigorous, thorough and pertinent discussions of the subject in hand were evoked, which will provide very valuable data in the pages of the Transactions.

Some thirty of the General Electric Company's engineers were present at the convention, many of whom made useful contributions to the various discussions which took place. In addition to this, the following papers were among those presented:

The Development of the Modern Central Station, by Dr. C. P. Steinmetz.

Tests of Oil Circuit Breakers, by E. B. Merriam.

Induction Machines for Heavy Single-Phase Motor Service, by E. F. W. Alexanderson.

The Law of Corona and the Dielectric Strength of Air, by F. W. Peek, Jr.

The Application of Current Transformers in Three-Phase Circuits, by J. R. Craighead.

Lightning Protection, by Prof. E. E. F. Creighton.

GENERAL ELECTRIC REVIEW

VOL. XIV, No. 9 SEPTEMBER, 1911

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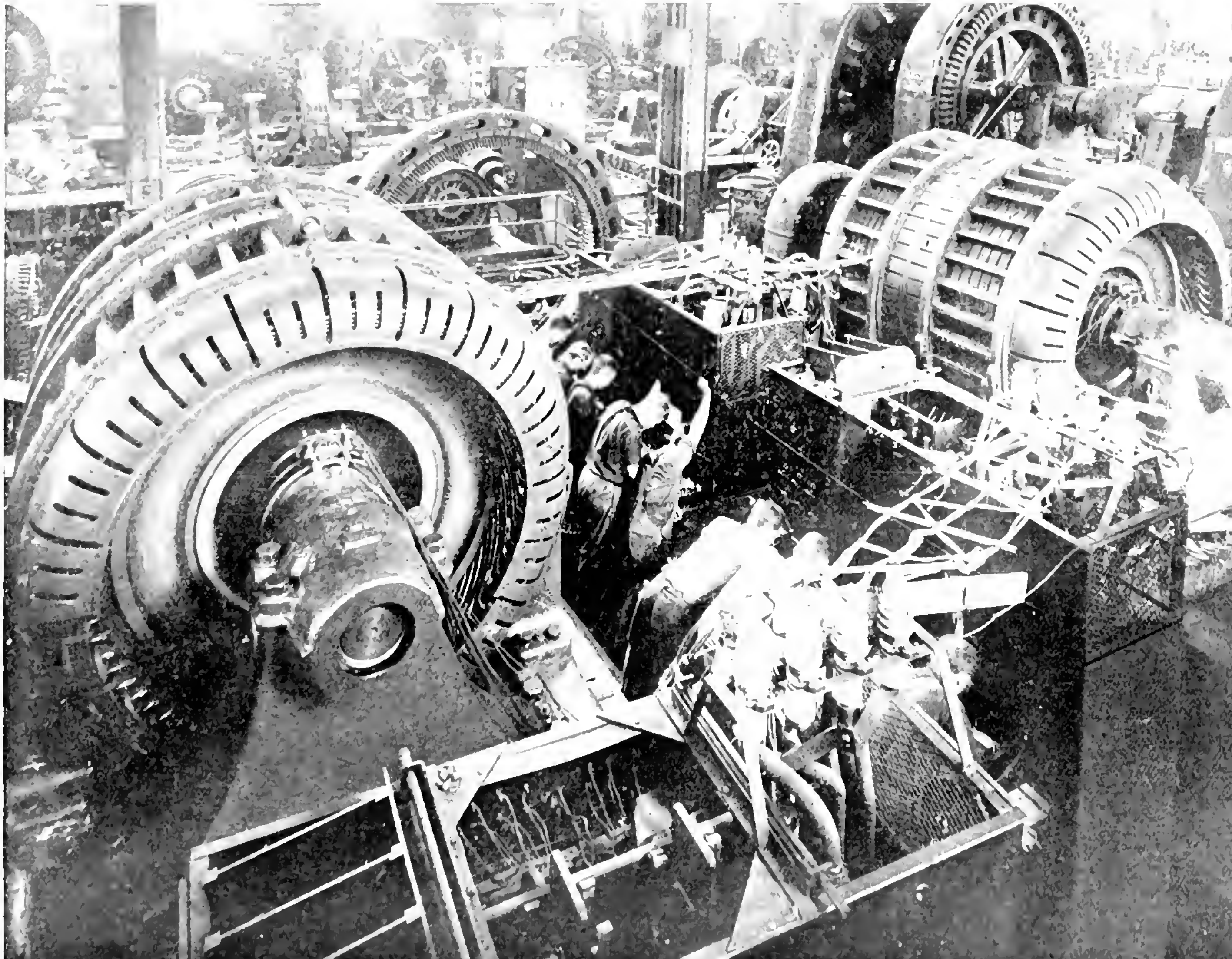


"Pump Back" Test on Two Frequency-Changer Sets

Diary of a Test Man—page 441

GENERAL ELECTRIC REVIEW

CENTRAL STATION DEVELOPMENT

It is interesting to speculate as to what the electric power supply system of the future is going to be like, but it is not everyone who is competent to do so, with any prospect of giving a forecast even approximately correct. An intimate knowledge of the various steps in the evolution of the modern central station is required, which cannot be obtained from a cursory perusal of the history of its development. The evolution has not been by a succession of easy stages a natural evolution; but is made up of a number of distinct steps, each one marking some difficulty of a definite nature, encountered, studied and finally overcome. The men who, in the past, have played a prominent part in overcoming these obstacles, and have thus largely assisted in nursing the art along through its developmental stage, are in a position to judge of the nature of the problems which are to-day waiting for solution, and hence can form a fairly accurate conjecture as to the main lines along which future progress will be made.

In the paper which he presented before the A.I.E.E. at its 1911 Convention at Chicago, Dr. C. P. Steinmetz discussed the development of the modern central station. He concluded with a statement as to the future, as to the direction in which all modern central station development is tending, and the two problems of prime importance which have to be successfully solved. This conclusion reads as follows:

"We must realize that in the direct line of the modern central station development is an extension of the power supply to that of an entire state or a number of states, from a few huge main stations near the centers of power demand, and numerous smaller outlying stations, with the entire system operating in synchronism through feeders and tie-lines, in which the power flow fluctuates in amount and in direction, and of which very few are sufficient to pull stations together into synchronism, but just sufficient to keep them in synchronism, if the speed regulation of their prime movers is independently maintained very closely the same.

"These then are the two problems before the modern central station: The localization of any disturbance by power limiting reactances, and the synchronous operation over lines of limited power, by speed control of the prime movers."

In order fully to appreciate the value of these concluding paragraphs, the whole paper should be carefully studied. The above extract gives a clear and authoritative summing-up of the situation as regards future development.

We are publishing this month two articles which bear directly upon this question; the first is a further contribution to the subject by Dr. Steinmetz, prepared specially for this paper, on power limiting reactances, in which he describes their functions in greater detail, and specifies, by means of a connection diagram, the positions in which the reactances should be located in a typical supply system in order to provide the maximum of protection. While the matter has been under discussion for some years, and the necessity for such reactances has, indeed, long been recognized, it is only recently that they have been installed as a practical device for limiting the amount of power which can flow into a fault. The reasons for the delay are clearly set out. Their design has presented the engineer with some of the severest obstacles which he is ever called upon to face.

The second article to which we have referred above, is concerned with the remaining problem which is involved in all further development of electric supply on a large scale, viz., the parallel operation of alternating current generators, or systems. This article is by Mr. B. P. Coulson, Jr., and constitutes one part of the series of papers we are publishing on operating troubles of alternating current machinery. While the purpose of the article is primarily to indicate how troubles in parallel operation may be avoided and remedied, it considers at the same time the conditions which must be met in order that satisfactory operation may be ensured; and considerable attention is given to the question of the linking-up of individual central stations for supplying vast areas with electric service.

With the aid of a few simple diagrams, Mr. Coulson illustrates the necessity for a considerable amount of reactance to increase the synchronizing power of two alternators; and proceeds from this to the conditions which are met when two power houses are connected together through tie-lines of comparatively low reactance. Here several factors must have close consideration, one of the principal being the size of tie-line which should be allowed. Since the synchronizing current, or cross current, which the tie-lines have to carry is additional to their normal current, it must, for economical operation, be kept within as small limits as possible, and hence the solution to the problem must be found in synchronous governing of the prime-movers.

When employing external reactances, in the above manner, for counter acting the effect of high resistance tie-lines, it should be borne in mind that there is a limit to the amount of reactance which should be inserted. While the percentage of the cross-current which is synchronizing current increases with reactance, the absolute value of the resultant cross-current, and hence that of the synchronizing component of this resultant, decreases.

ELECTRICITY IN THE COAL MINING AND THE STEEL INDUSTRIES

With this issue we are commencing two series of papers dealing with the application of electricity in the coal mining industry and the steel industry.

On page 397 Mr. John Liston commences an exhaustive paper covering electricity in coal mines. Included in the scope of this paper will be electric mine locomotives, hoists, pumps, ventilating fans, air-compressors, rock- and coal-crushers, coal-cutters, breaker and tipple drive, including conveyors, picking-tables, etc., with descriptions of typical installations in both anthracite and bituminous mines. This series will extend over approximately four issues.

The series on electricity in the steel industry will cover the use of electricity in ore unloading and ore handling; coal-conveyors, coal-crushers and coke-ovens; the blast in Bessemer and open-hearth furnaces, with particular reference to the centrifugal compressor; electric motors and automatic control equipment for the operation of various types of rolling-mill. Besides descriptions of actual installations illustrating the use of electricity in these various departments of the steel industry, considerable space will be devoted, in the rolling mill articles, to a theoretical consideration of the subject.

The first paper in the series, published this month, is by Mr. Edward J. Cheney, and treats of the use of flywheels in rolling-mill motors. The consideration of the flywheel problem for a particular motor must commence with a study of the load-curve. Next must be determined what effect a flywheel of practical size will have on smoothing out the load, and the effect of such alteration of the load-curve on the motor and on the supply system. From these considerations it can be determined whether the use of a flywheel is warranted or not, and also what size of flywheel will result in maximum economy and advantage. Typical load-curves are shown in the article to illustrate the method of studying the problem, while a number of illustrations are also given, showing flywheel motors as installed for actual operation.

THE DIARY OF A TEST MAN

The first set of contributions to this series gave some idea of the kind of matter that we desire to secure. The second instalment, appearing in this issue, shows a considerable improvement; and to men on the test and others who, while perfectly willing to send in descriptions of tests and other experiences, are a little uncertain as to the class of contributions which we are looking for, we can give no better advice than to refer them to the detailed description of the pump-back test on two frequency-changer sets, by Mr. H. B. Broderson, on page 443. This description, studied in conjunction with the cut illustrating the test, and the wiring diagram of the machines and testing tables, presents a very complete and interesting record of a somewhat complicated test, of a kind which cannot be found in any text book on the subject.

We also desire to take the opportunity of stating that this section of the paper is thrown open to all, whether testers, ex-testers or not; as our purpose, in conducting this series, is to furnish practical information which shall be of service, as well as interest, to men engaged in any department of practical electrical work.

ELECTRICITY IN COAL MINES

By John Liston

The magnitude of the coal mining industry in the United States is indicated by the fact that during the year 1910 the total production of coal was approximately 500,000,000 net tons, of which amount more than 74,000,000 gross tons was anthracite, while the output for the bituminous mines exceeded 415,000,000 net tons.

In view of these figures it is evident that the power requirements of this industry represent an annual outlay of such proportions as to justify the most careful scrutiny of all factors entering into the cost of producing and applying the energy required for the numerous mechanical aids which have become indispensable to the modern working of coal mines.

It was unavoidable in the early days of the industry that the low cost of fuel and general familiarity of operators with the uses of steam power should tend toward a very widespread use of engines of various types for hoisting, pumping, ventilation, surface haulage, and the driving of conveyors, breakers, tipples, etc. The use of steam in the mines has, however, always been both difficult and costly, and in even the most limited application underground it serves to diminish the factor of safety in an industry in which potential danger to workmen must always be a matter of primary importance.

No. 4. Tipple of the United States Coal & Coke Co., Gary, W. Va., showing Arrangement of Motor Driven Steel Belt Conveyors

Compressed air for underground work met some of the objections to the use of steam, and as a result was extensively used for this class of work until the advent of electrical service, which at once rendered possible the application of a single form of power to all classes of machinery, both on the surface and in the mine itself.

The use of electricity in coal mining is not new, as it has been employed to a limited extent for many years, but the rapid extension which has recently characterized its application is due to several causes, the more important of which can be briefly outlined as follows:

First, the improved efficiencies of modern electrical machinery in general, and the increasing use of alternating current with its greater flexibility in transmission over distances that are beyond the economical limit of direct current distribution.

Second, the specialization of the electrical manufacturing companies' engineers on the power requirements peculiar to coal mine operation.

Third, the growing appreciation by the engineers of the mining companies of the advantages of electrical power and their active co-operation in the solution of the problems entailed by special conditions.

Fourth, the notable operating economies which have resulted in numerous installations utilizing electric power, even under the severest service conditions, and the attainment in practically every case of an increased output for a given power consumption.

Fifth, the necessity for the development of coal fields in which the geological conditions were such that the mines could not be economically operated by the older methods; and the continually increasing distances between the working faces and delivery points in mines already in operation which tended to render electric haulage practically imperative.

That the above causes are all given the practical consideration which their effect on operating costs so fully merits, is clearly demonstrated by the fact that in all recent coal mining developments of appreciable size electricity has been adopted as a source of applied power either wholly or in part.

Electric Locomotive. Consolidated Coal Company of St. Louis, Mo.

In many of the older workings it has been found that true economy would sanction the scrapping of a large percentage of the steam power equipment and its replacement by a centrally located generating station.

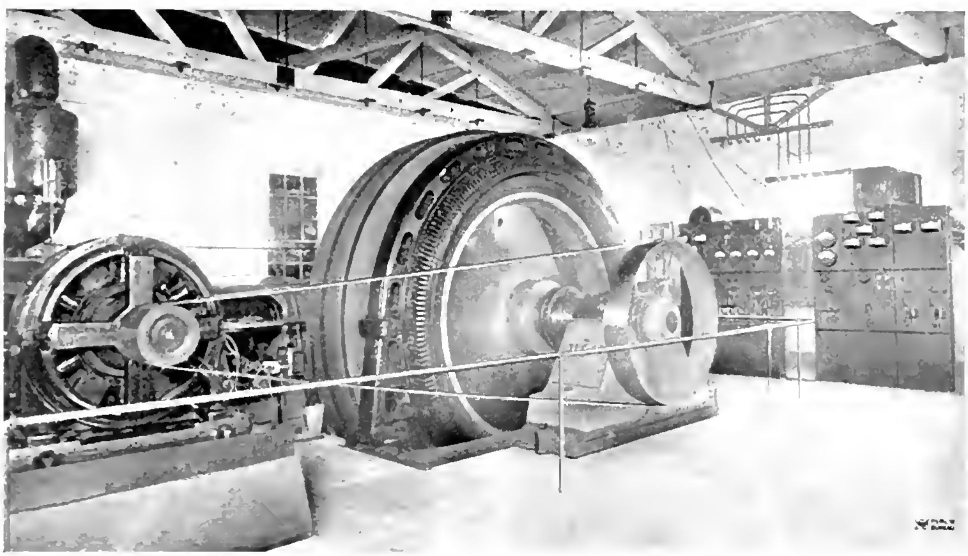
In some cases, however, the engineers of the mining companies are not fully aware of the inherent economy of electric service and its practically universal applicability, and are, therefore, disinclined to supersede older equipment which, while not so economical in operation, has still proven of practical use.

As a logical demonstration of the value of electricity in coal mining, this article will contain:

First, a general statement covering the advantages of electric drive for all classes of coal mining machinery.

Second, typical examples of the application of motors; the use of both alternating and direct current generators, motor-generator sets, rotary converters, etc., and an analysis of the conditions affecting alternating and direct current transmission.

Third, descriptions of installations illustrating the extent to which various coal mine operators in both the anthracite and bituminous fields have electrified their plants.



400 Kw. 2300 Volt Three-Phase 60 Cycle Engine-Driven Alternator with Belted Exciter and Switchboard in Power House. Bear Valley Colliery, Shamokin, Pa., Philadelphia and Reading Coal and Iron Company

Advantages of Electric Power

In an electrically-operated mine or group of mines all the machinery may be served from a single power plant, thereby obtaining economies inherent in central station practice by the use of large and highly efficient prime movers and generating units. The cost of supervision and maintenance is thereby reduced and continuity of service insured by being able to carry temporary overloads on a portion of the generating equipment in the event of injury or failure to any unit, or by providing a reasonable capacity in generators normally held in reserve for the same purpose.

The central station may be located and constructed solely with a view to the most economical generation of power, the supply of boiler or condensing water, the handling of fuel and disposal of waste, etc., practically regardless of the relative location of the various points at which the power is to be applied.

The use of electricity eliminates the necessity for long lines of steam or air piping, which are expensive to install and maintain, and with which the danger of breakdown and the difficulty of obtaining the necessary working pressures increase with every extension of the service. For these conditions electricity substitutes a simple and thoroughly flexible system of transmitting power by means of conductors which can be easily run and rapidly extended to meet changes involved in the progress of development, and which are not affected by temperature variation and are not liable to mechanical injury nor to breakage due to floods or shifting ground. They can be safely used in places where steam lines would introduce an element of danger, and finally, they can in many instances be run in shafts or bore holes already in use for other purposes without occupying room that could be otherwise utilized.

Notwithstanding the remarkable efficiencies which have been obtained by the engineers of some mining companies in the operation of carefully constructed steam lines, the investment and operating expense of this method has been so heavy that resort to the alternative of separate boiler plants even in comparatively closely grouped developments has been found necessary.

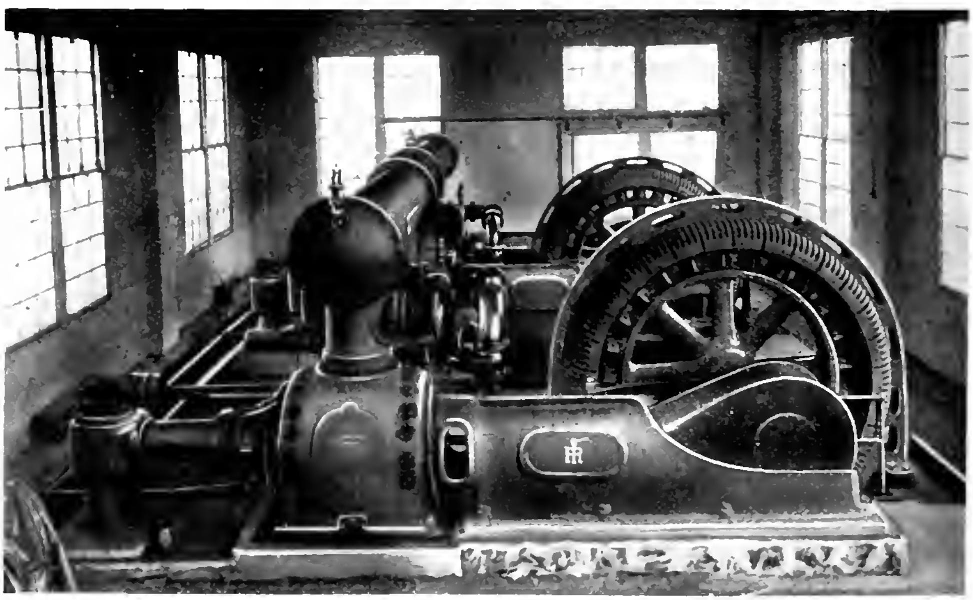
With electrically equipped mines this problem does not exist, and many coal mining companies are at present economically distributing current from central stations over transmission lines of more than 10 miles in length, and in some of the larger systems for distances approximately twice as great.

In the application of electric motors to the various machines the characteristics of modern types of both alternating and direct current motors are such that in a large majority of cases they can be direct connected or direct geared to the driving shaft, thereby eliminating a large percentage of the friction losses and repair charges, as well as the first cost of the belting and countershafts.

It is also possible to further reduce the power losses by substituting individual drive in the sections of long conveyor or scraper lines, and for the different units in breakers and tipples, thereby effecting a considerable saving in power over that required by the older method of group operation by means of engines. In the case of motor-driven breakers, the saving effected in belting alone is a very considerable item; but due to the design of some of the breakers and tipples, the mechanical retention of some belts and countershafts is still necessary. For the driving of rock and coal crushers the interposition of belting is not usually considered in modern equipments, as the motors are capable of carrying heavy overloads for the short periods during which they are liable to occur in this particular service.

Inasmuch as the power required by individual motors can be readily measured by instruments temporarily connected into the circuit, it is possible to maintain the machinery in the best operating condition, as any excess power requirement can be readily detected and any defect in the machinery promptly corrected. The motor applications may be so subdivided that individual sections of the mine or the colliery equipment may be operated with a minimum demand on the power station, and if the generating equipment is divided in two or more units the few sections of the machinery which must necessarily be maintained in operation during a shutdown—as for instance, the ventilating fans or pumping sets—can be run with only a fraction of the power plant in service.

The flexibility of motor drive renders possible the use of portable machinery, and additions to or changes in the location

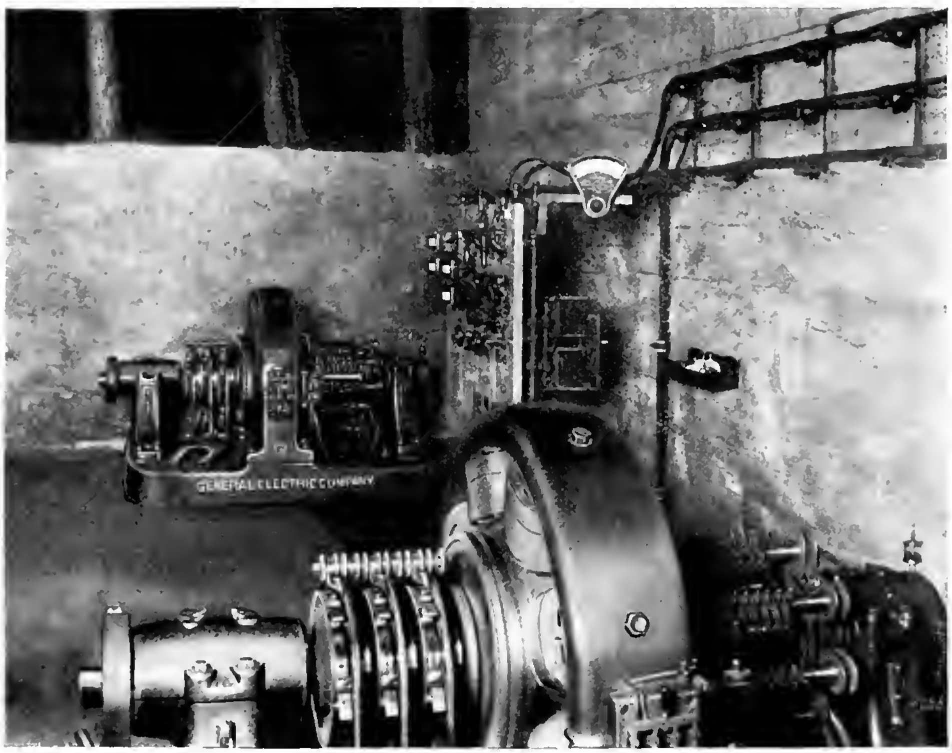


Air Compressors—Capacity 2650 cu. ft. at 100 lb. in Lucerne Substation No. 2, each Direct Driven by an ATI 450 Kv-a. 6000 Volt 125 R.P.M. Synchronous Motor.
Rochester and Pittsburg Coal and Iron Company

of existing machines can easily be arranged for without interfering in any way with the operation of the remainder of the equipment.

The benefits of electric lighting, both in the mine and for night operations on the surface and for signalling, are universally acknowledged, and electric current is used for these purposes even in mines which have not as yet adopted electric power service.

The accompanying illustrations show various applications of alternating and direct current motors to mining machinery as at present used in both the anthracite and bituminous coal fields, and it will be noted that there is a notable tendency toward the standardization of the electrical equipment and the use of polyphase induction and synchronous motors for all surface operations with the exception of locomotive haulage.



Rotary Converters in Substation in Woodward Mine, D.L. & W.R.R. Company, Mining Department

Mine Locomotives

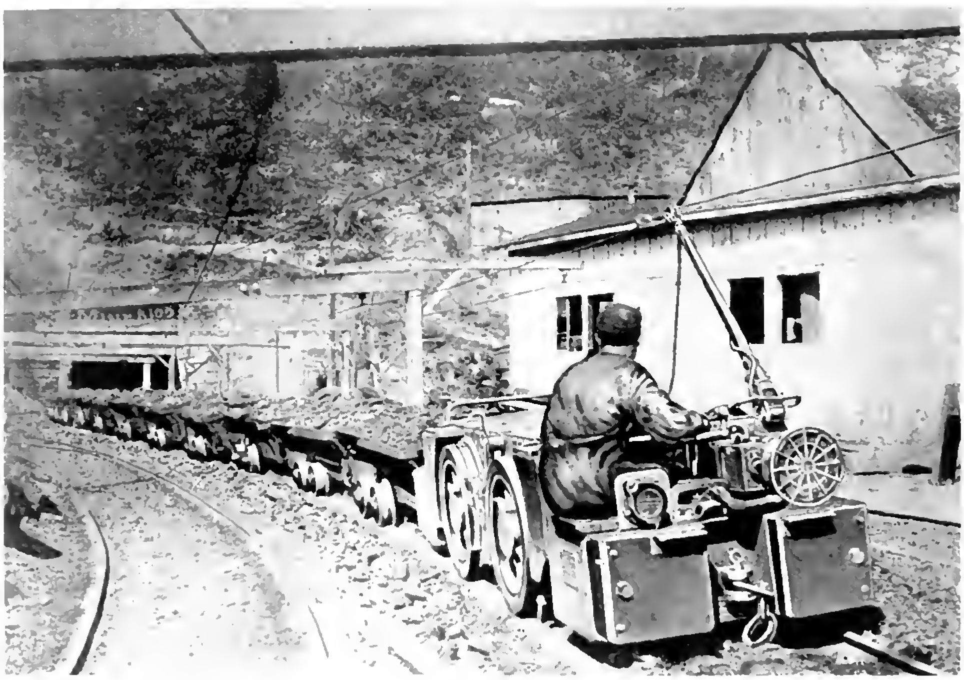
The superiority of the electric locomotive for mine haulage is generally conceded and is largely due to the fact that in addition to its high efficiency, mc hanical strength, dependability and simplicity of control, it is the most compact form of tractor available. This last characteristic is of the utmost importance in underground operations where the available head room is usually limited and where the cost of increasing height along a roadway—either by brushing the roof or taking up the bottom, would materially increase the cost of mining. Except in special cases it is obvious that steam locomotives cannot safely be used in the mines, and the compressed air type also has numerous limiting features. It can only develop an average efficiency of from 25 to 30 per cent. is more cumbersome than the electric type for a given capacity, and the necessary frequent re-charging of the storage tanks involves delays which diminish its serviceability. The distance which it can travel on one charge is limited, and as its first cost is higher and its mechanical strength inferior to that of the trolley type, it is seldom used in new installations and has been very generally superseded even in mines using air service for other purposes.

In the development of the electric mine locomotive there has been a constant improve-men in the structural details, as the arduous service conditions which are normally encountered in coal mine operation have become more fully understood by the designing engineers. Due to the compact and heavy structure necessitated by the tractive requirements and limited head room in which it must ordinarily be operated, the electric mine locomotive has from the first been unusually strong mechanically, and the earliest locomotive of this type built by the General Electric Company is still in daily use after a constant service of 22 years. Three general forms are now commonly used; i.e., the straight haulage, the cable reel or gathering, and the combination or crab type. The standard weights range from 3 to 25 tons and for low vein mines the total height of the smaller sizes does not exceed 27 inches. The economy obtained in the use of the straight haulage type for delivering trips to the shaft, slope, entry, tipple or breaker in mines having reasonably long haulage is generally acknowledged, and units of this type are used in practically all mines where electric service is available.

For the main haulage in mines the mule or horse has been almost universally discarded where electric service could be obtained, inasmuch as a single locomotive can effectively displace a considerable number of animals, can travel faster, requires less head room, and can operate 24 hours a day if required. For gathering, however, animals are still used to some extent, as the question of their replacement in this service by gathering locomotives is governed by such a diversity of operating conditions that each installation must in effect be considered as a separate problem.

In some of the larger mines the question of comparative operating costs for each group of workings has been ignored, and cable reel locomotives used throughout for gathering, simply on account of their greater capacity, reliability and general convenience, and the resulting increased output has in every case fully justified the expenditure involved in the complete abolition of animal haulage.

The type of gathering locomotive developed by the General Electric Company consists of a reel of large diameter driven through double reduction gearing by a small vertical series wound motor, the reel being supported by the motor frame and rotating on ball bearings. Friction is further reduced by



Six Ton Steel Frame Mine Locomotive. Secondary Half of Twelve Ton Two-Unit Locomotive Operating as a Single Unit. The Brushy Mountain Coal Mines, Petros, Tenn.

also providing the armature shaft with ball bearings. This motor is connected directly across the line and is equipped with a permanent series resistance which protects it from a heavy rush of current when the locomotive is standing still.

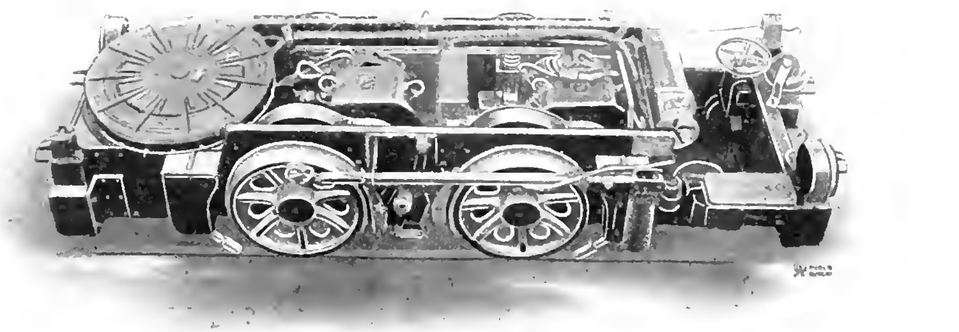
A combined switch and fuse is also inserted in the circuit for protection against short circuits and for convenience in opening the circuit if desired, but is not involved in any way with the ordinary operation of the reel. The motor is so designed that it is of sufficient capacity to permit of its being stalled for any length of time without overheating.

After the cable is attached to the trolley wire and the locomotive moves forward the unwinding of the cable causes the motor to act as a series generator, and the counter-torque thus developed produces sufficient tension on the cable to cause it to pay out evenly and drop along the roadbed without producing kinks. This counter-torque produces enough braking effect to instantly stop the reel when the forward movement of the locomotive ceases, and as soon as the locomotive starts back the motor action comes into play and the reel is rewound at a tension sufficient to obviate any possibility of the locomotive overrunning the cable. As the operation of the reel is entirely automatic, the motorman is free to devote his entire attention to the handling of the locomotive.

For haulage in gangways in which the grading for the roadbed is such as to prohibit the use of cable reel locomotives, the combination or crab type, equipped with a hoisting drum and steel cable in addition to the cable reel, is generally used, as it can be blocked in the entries of successive gangways and by means of the hoist can draw the loaded cars up the slopes and then deliver the trips to the main haulage tracks. On short slopes it does the work as rapidly and effectively as a permanent rope haul or hoist, with the added advantage of portability; and, as it can also perform the duties of both the straight haulage and cable reel types, it is often considered indispensable in mines where a limited number of locomotives can handle the entire output. Its "general utility" features have caused its adoption for all underground work in some of the largest mines in the anthracite fields where the irregular grades in numerous gangways render it especially valuable.

In some types of cable reel locomotives the reel is operated by means of coiled springs or driven through a chain and sprocket by one of the locomotive motors. These methods have proved ineffective due to the frequent breaking of springs or driving chains and became practically obsolescent after the independently motor-driven reel originated by the General Electric Company had been developed. In like manner the first combination locomotives were arranged for driving the hoisting drums by means of the locomotive motor through gearing controlled by clutches, but in the newer types the hoisting drum is driven by an independent motor, which, while it adds a fourth motor to the standard equipment gives improved efficiency by eliminating the clutches and axle gearing, and at the same time insures a positive and more simple control of the hoisting speed.

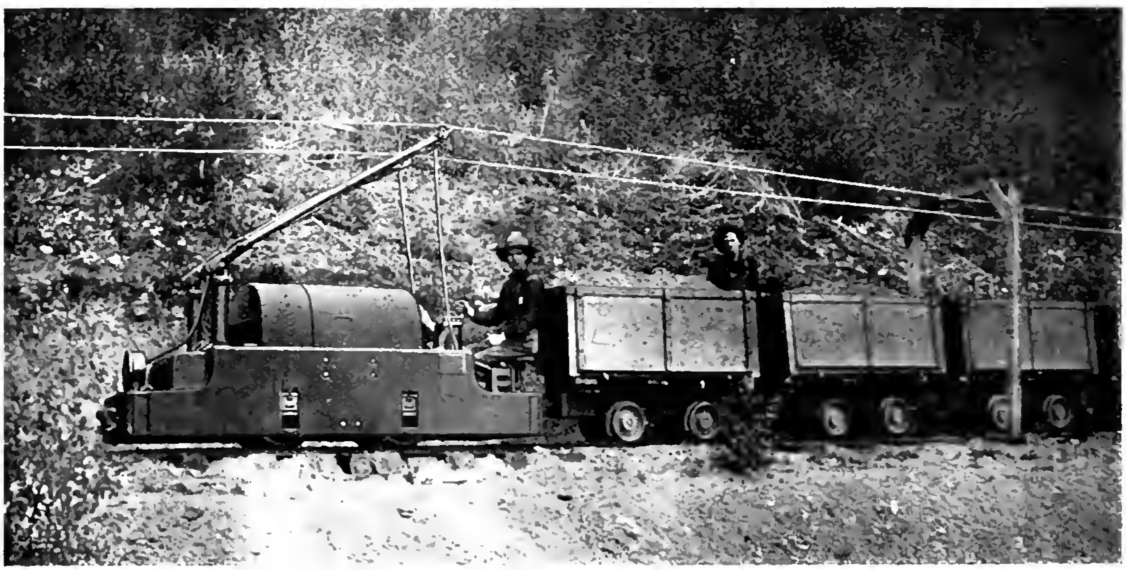
In collieries and mines where the breaker or tipple is located at a considerable distance from the entries or shafts, separate locomo-



Internal Arrangement of Seven-Ton Gathering Locomotive Designed for Low Vein Work tives can be advantageously used for surface haulage, and as they are practically unrestricted in the matter of size, excepting in regard to the capacity of the breaker or tipple for handling the coal received, heavy locomotives—ranging from 10 to 25 tons, capable of delivering a large number of cars per trip—are commonly used. The retention of steam locomotives for this work involves interruptions due to the necessary coaling and renewal of the boiler water, and render impossible that continuity of service which is essential in order to obtain the most economical operation of the coal handling plant. Furthermore, they usually require skilled and, therefore, expensive operators, and they do not compare favorably in general efficiency and economy of maintenance and operation with the electrical type; the result being that in electrified mining properties they have been very generally discarded or relegated to other duties.

The standard modern mine locomotive motor equipment consists of two direct current units connected to the driving axles through a single reduction gear, although three motors are sometimes used with three pairs of driving wheels, in which case the center pair are flangeless in order to permit the turning of curves of short radius. There are also a limited number of single motor locomotives still in use although they are being very generally superseded by the two motor type.

In exceptional cases where the generating and auxiliary motor equipment of a mine is all alternating current and a limited number of direct current locomotives would involve a disproportionately heavy investment for rotary converters or motor-generator sets to supply a direct current haulage system, locomotives utilizing polyphase induction motors can be adopted with entire success, the necessary speed control being secured by a variable external resistance connected in the rotor circuit.



Four-Ton Three-Phase Alternating Current Locomotive, Wellington Mines Company, Breckenridge, Colo.

Owing to the high speeds characteristic of this type of motor it is necessary to interpose double reduction gearing in order to obtain the running speeds which experience has shown are safe for mining service; and two overhead conductors and trolleys or a double trolley are also required.

Bonded rails may be used for the third wire, but it has been found advisable in some of the installations of this nature to utilize a cable laid along one of the rails and connected to each section, as by this means better conductivity is insured.

(To be Continued)

POWER LIMITING REACTANCES

By Dr. C. P. Steinmetz

In the appreciation of the effect of reactance in alternating current circuits, three periods can be distinguished: in the early days of alternating current circuits, reactance was an evil which handicapped the alternating current system, by impairing the regulation, that is, causing the voltage in lines, generators and transformers to drop off under load, more than corresponds to the resistance, that is, more than it would in direct current circuits. In the lines, this difficulty was overcome, or at least mitigated, by limiting the size of conductors, using several circuits in multiple. In the generators, the reactance was reduced by distributing the winding in a number of slots per pole, and using as low armature reaction as economically feasible; in the transformers, the regulation was secured by subdividing and intermixing primary and secondary coils.

With the introduction of synchronous apparatus, as synchronous motors and converters, reactance becomes useful as a means of automatically controlling the voltage by varying the phase of the current, by the excitation of the synchronous machines. This method of "phase control" affords a voltage regulation under changes of load, far superior than is feasible in direct current systems, and instead of carefully avoiding reactance as an enemy to regulation, reactances are now built and installed in synchronous machine circuits, for voltage regulation. In the standard system of operation of interurban and long distance electric railways from a high voltage transmission line, supplying power to the trolley circuit by converter substations, reactances of 15 per cent.* are installed between the step-down transformer and the converter, and the converter field is compound wound so as to be under-excited at light load, over-excited at full load: at light load, the under-excitation causes the current to lag, and with a lagging current, the reactance consumes voltage and thereby keeps the voltage down. At normal load and overload, the over-excitation causes the current to lead, and with a leading current, the reactance adds its voltage to the supply voltage, and thereby keeps up the converter voltage. The cause is, that the reactance voltage is 90° behind the current, and if the current lags behind the supply voltage, the reactance voltage thus is more than 90° behind the supply voltage, thus in opposition or subtractive; if the current leads the supply voltage, the reactance voltage is less than 90° behind the supply voltage, thus partly in phase with it, or additive.

Finally, in the last years, in the huge electric generating systems, of 100,000 kw. capacity and more, which were made possible by the development of the steam turbine generator, reactances had to be called upon as protective devices to guard the system against the tendency of self-destruction, which resulted from the enormous power available in the system. In these high power systems, supplied from generators with almost unlimited momentary over-load capacity, an accident, which allowed the concentration of the full momentary power of the system, such as a short-circuit at or near the bus-bars, is liable to produce wide-spread destruction, electrically by the enormous momentary currents, mechanically by the forces exerted by the magnetic fields of these currents.

The high frequency transformers of the early days of alternating current distribution had an internal reactance as high as 15 to 20 per cent. Their voltage regulation therefore was poor at lighting load, and practically none existing at motor load. Since that time, the design of transformers has been continuously improved, until now the modern lighting transformer has a reactance of 1½ to 2 per cent. and thereby almost perfect regulation not only on lighting load, but also on motor load. Unfortunately, the same low reactance has also been insisted upon in large power transformers, where it is unnecessary, often undesirable, and always dangerous. 2 per cent. reactance means that at full load current, 2 per cent. or 1/50 of the supply voltage is consumed by the reactance; at short-circuit the total voltage has to be consumed by the transformer reactance, and the short-circuit current of the transformer at full supply voltage then is 50 times full load current. Mechanical forces are exerted by the magnetic fields of the current in the transformer coils. These forces are negligible at full load current. They vary, however, with the square of the

*Reactances are frequently expressed by the percentage of the circuit voltage, which is induced in the reactance with full load current passing through it. Thus a 15 per cent. reactance is one in which full load current of the circuit produces a terminal voltage equal to 15 per cent. of the voltage of the circuit for which it is designed.

current, and at a short-circuit current equal to 50 times full load current, these mechanical forces are $50^2 = 2500$ times as large, and in large transformers of several thousand kilowatt, they amount to many hundreds of tons, and thus are far beyond the mechanical strength which can be given to the structure. That is, the transformer is torn to pieces by a short-circuit at full supply voltage. Hence the only thing, which saves most of the large low reactance transformers from self-destruction at an accidental short-circuit, is, that there are very few generating systems in existence which can give 50 times the current of a large transformer, without dropping their voltage, and in small transformers, as lighting transformers, the mechanical forces are correspondingly less, and even there the impedance of line, etc., usually causes a material drop of the supply voltage on short-circuit, and with it a relief of the transformer stresses. However, there are now a number of steam turbine stations in existence, which can momentarily give a quarter of a million kilowatts without material voltage drop, and on these systems, a short-circuit on a large low reactance transformer is almost certain destruction. Thus safety requires to limit the possible short-circuit current of large transformers by reactances. Such reactance may be internal in the transformer, or consist of separate reactances inserted into the transformer leads. The former is preferable by its simplicity, but may not always be feasible, since it is easier to design a large low frequency transformer efficiently for low reactance, than for a reactance of 6 to 8 per cent. Safety thus requires that large transformers in high power systems should have an appreciable reactance, preferably 6 to 8 per cent., and certainly not less than 4 per cent.

Still more serious is the case with the generators. The short-circuit current of an alternator is limited by armature self-induction and armature reaction. Both are usually combined in the expression "synchronous reactance." 25 per cent. synchronous reactance thus means that at full load current 25 per cent. or $^1/_4$ of the induced voltage, is consumed by the synchronous reactance, and the short-circuit current thus is 4 times full load current. This is about the case with the modern large turbo-alternators. An essential difference, however, exists in the action of armature self-induction and armature reaction, in that the former is instantaneous, while the latter requires an appreciable time, often several seconds; and thus in the first moment of short-circuit, only the armature self-induction comes into play in limiting the current, and the momentary short-circuit current thus is larger than the final short-circuit current. How much larger depends on the proportion of the effects of armature self-induction and armature reaction.

Armature self-induction gives a true reactance: the current in the armature produces a magnetic field in the armature iron, and this induces a voltage in the armature conductors. As the magnetic field of a current is coincident with the current, the voltage consumed by the armature self-induction thus is coincident with the armature current, and no time lag exists in the action of the armature self-induction—it is instantaneous. The component of the synchronous reactance, however, which is due to armature reaction, is not a true reactance, consumes no voltage, but is a magnetic effect: the current in the armature—which is lagging at short-circuit—acts demagnetizing on the field poles, and so reduces the field magnetic flux, and with it the voltage induced in the armature. However, the magnetic field of the machine poles represents stored energy, which cannot instantly be destroyed; and thus the demagnetization of the machine field requires some time. The armature reaction thus is not instantaneous, but has a time lag, and thereby does not limit the current at the first moment of short-circuit, and the momentary short-circuit current is larger, and gradually, with the appearance of the armature reaction, decreases to its permanent value.*

In the high frequency alternators, the armature reaction was small compared with the self-induction, and the momentary short-circuit current thus little larger than the permanent current. When designing the 60 cycle belt-driven and engine-driven machines, due to the halving of the frequency, twice the pitch per pole on the armature surface was available, and this allowed doubling the armature reaction, while the self-induction was reduced by subdividing the conductors in a number of slots per pole, and in these machines armature reaction and self-induction thus are about equal, and

This time lag of armature reaction is of importance also in other phenomena, as in hunting, and in parallel operation in general: in the synchronous operation of alternators, the reactance, which gives the synchronizing power, as discussed in the article by Mr. B. P. Coulson, Jr. (see p. 418), is essentially only the armature self-inductive reactance, and not, or only to a small extent, the equivalent reactance of armature reaction: but the latter by its time lag, under certain conditions gives the energy which produces cumulative hunting the momentary short-circuit current rarely rises beyond twice the permanent value. The frequency of 25 cycles again doubled the pitch per pole and with it the armature reaction, and the introduction of the steam turbine as high speed prime mover led to an increase of peripheral speeds to about twice the previous values, thus still further doubling the pitch per pole and with it the permissible armature reaction, while the self-induction remained the same. However, with the very large armature reaction and correspondingly large field excitation of these machines, deeper armature slots and higher densities became permissible and necessary for economical design. The former still further increased the armature reaction, while the latter decreased the self-induction, so that in these turbo-alternators the self-induction has decreased to about one-tenth the armature reaction, and the momentary short-circuit current may be 10 times the permanent value, and reaches values as high as 30 to 50 times full load current.

In a 150,000 kw. 9,000 volt station, a momentary short-circuit current of 40 times full load current is 400,000 amperes, sufficient to bend and twist heavy copper bars, to tear cables from their supports, etc. No switch can be designed within reasonably moderate size and cost to safely open such currents. It is true that at dead short-circuit the current represents no power, just as at open-circuit the voltage represents no power. However, in opening the circuit, while the current passes from 400,000 amperes to zero, the voltage at the switch passes from 0 to 9000, and the power, as the product of both, therefore passes from zero at short-circuit, over a maximum to zero at open-circuit. This maximum power, assuming the opening arc as non-inductive, is half the product of the maximum current and maximum voltage, or

$$\frac{400{,}000 \times 9000 \times \sqrt{3}}{2} = 3.12 \times 10^6, \text{ i.e., over}$$

3 million kilowatts, hence comparable with the power of Niagara. It is obvious that this is beyond the safe limit of any economically feasible switch, and it is equally obvious, that it is economically impracticable to subdivide the system into so many separately operated sections, as to bring the maximum power of each section within safe limits. Thus it becomes necessary for the safety of these huge systems, to limit the power which may be developed at any place in case of accident.

Experience has shown that modern oil circuit-breakers can safely, and with ample margin of safety, handle a quarter to a third of a million kilowatts.

Assuming then, that each generator is given a reactance of 8 per cent., thus limiting its momentary short-circuit current to 12 times full load current, and that the system is subdivided into sections not exceeding 50,000 kw. each; then the maximum momentary short-circuit current is reduced to 40,000 amperes, the maximum power at the switch to about 300,000 kw., that is, a reasonably safe value.

Under the assumptions made above, a reactance of 8 per cent. thus appears sufficient to give safety of operation to the system. It also safeguards the generator to a considerable extent against self-destruction With 40 times full load current at short-circuit, or $2\frac{1}{2}$ per cent. reactance, the effective resistance of the armature circuit (including ohmic resistance and effective resistance due to magnetic stray fields, etc.) may be assumed as 1 per cent. This gives a power-factor of the short-circuit current of about 40 per cent., and thus a power consumption in the generator of 40 per cent. of 40 times full load, or 16 times full load. That is, a momentary short-circuit puts a sudden mechanical strain on the turbo-alternator, equal to about 16 times the full load torque: sufficient to seriously endanger the alternator and the turbine. With the reactance increased to 8 per cent., a short-circuit current of 12 times full load current, the effective resistance of the armature circuit obviously is also lowered, and is more nearly the ohmic resistance. Assuming, however, still 1 per cent. effective resistance, we get a power-factor of $\frac{1}{8}$, and a mechanical force equal to $\frac{1}{8} \times 12$, or $1\frac{1}{2}$ times full load torque, that is, well within safe limits. Experimental evidence is in agreement herewith, by showing that a short-circuit with 8 per cent. reactance does not appreciably slow down the turbine.

The simplest arrangement of providing the required reactance would be to design the generator with an internal self-inductive reactance of about 8 per cent. One of the objections hereto is, that in this case a short-circuit in the generator is a short-circuit on

*The increase in the economy of design can best be realized by considering the active armature surface required per kva output (that is, armature surface at the air-gap, or the value: $\frac{2\pi dl}{p}$, where d = diameter, l = length of iron of the armature at the air-gap, in inches, p = output, in kva.) This was about 20 sq. in. in the 60 cycle high speed belt-driven alternators, rising to 30 sq. in. and more in slow speed engine-driven machines, while large high speed turbo-alternators of today give values as low as 2 or 3 sq. in. per kva. output.

the bus-bars, into which all generators feed, while with an external reactance interposed between generator and bus-bars, the bus-bars, and with them the system, are guarded against excessive currents in case of an accident to a generator. The latter arrangement thus is the safer one for the system. The second objection against locating the entire reactance in the generator can be appreciated from the designing consideration given above: the low armature self-induction of the turbo-alternator is not abnormal, but is the value given by economical design. Quadrupling this reactance would lead to an abnormal design, resulting in a sacrifice of efficiency and of mechanical strength. It thus appears preferable to design the alternator with as high internal reactance as can be given to it without material sacrifice of efficiency and mechanical strength, and insert the rest of the required reactance external to the alternator.

The question then arises, whether this additional reactance should be inserted in the phase leads, that is, between alternator terminals and bus-bars, or in the neutral of the alternator. The latter arrangement appears preferable on first sight, especially with grounded neutral, as it brings the reactance close to ground potential. This, however, is a fallacy: assuming 2 per cent. internal reactance and 6 per cent. external reactance, then with the reactance in the phase leads, the reactive coils are always at full Y potential against ground. With the reactance in the neutral, their maximum potential difference under normal operation is only 6 per cent. of the Y potential. However, under short-circuit, the full generator voltage distributes between the 2 per cent. internal and the 6 per cent. external reactance, and the latter thus takes $^3/_4$ of the total generated voltage, and the voltage between the generator terminal of the neutral reactance and the ground thus under short-circuit rises to 75 per cent. of full generator potential. It obviously is safer to have an apparatus continuously exposed to full voltage, than to have it normally at no voltage, and have it exposed to $^3/_4$ voltage just under emergency condition, where its reliability is most essential. Adding hereto, that reactances in the neutral do not protect the bus-bars against a short-circuit in the generator, it appears preferable to locate the reactances in the phase leads, and not in the neutral.

However, even with the momentary short-circuit current limited to 12 times full load, at 50,000 to 60,000 kw. generator capacity a value is reached where it is not advisable to further increase it, without using larger and more expensive circuit-breakers, and even then finally some limit must be reached. However, in the huge generating systems of today, the 200,000 kw. mark has already been passed, and probably in not many years the half-million mark will be reached. Operating the system in a number of separate sections is economically undesirable, and becomes impracticable if the number of sections is large. Thus there appears little doubt that parallel operation of all the generating units, and all the stations of the entire system, is essential for economy and reliability of operation. To enable parallel operation of the entire system, no matter how large, and still limit the momentary power which may appear at any place in case of accident, requires dividing the bus-bars by reactances.

These bus-bar reactances must be sufficiently high, so that in case of a short-circuit on one bus-bar section, the voltage of adjoining sections is not seriously disturbed by the current flowing from them over the bus-bar reactances into the short-circuited section. At the same time, these reactances must be low enough to permit the interchange of current between the bus-bar sections, required to take care of changes in the distribution of the load on the different bus-bar sections. Such a transfer of current between bus-bar sections over reactances obviously does not occur by a drop of voltage between the sections, but by a phase displacement between the voltages of the bus-bar sections. Probably a bus-bar reactance allowing a transfer of power equal to 20 to 25 per cent. of the generator capacity of each section will be sufficient.

The arrangement of the generator reactances and bus-bar reactances required to safeguard the operation, while permitting parallel operation of the entire system of unlimited extension, is shown diagrammatically in Figure 1 (the figure shows one phase). G represents the generators, B the bus-bars, x_1 the generator power limiting reactances, x_2 the bus-bar dividing reactances; T may be tie feeders connecting different generating stations together into the ring bus, which includes the entire system.

While the employment of power limiting reactances in the high power steam turbine stations has been discussed for a number of years, and progressive operating engineers have realized the necessity of their use for years, it is only recently that the first of these reactances are being installed. The reason is to be found in the difficulty of design of these reactances, which has required years of theoretical and experimental work to arrive at a design which appears satisfactory. Indeed, the design of these reactances constitutes one of the most difficult problems of electrical engineering. It does not appear so on first sight. Consider for instance the 6 per cent. power limiting reactances installed in the leads between the bus-bars and a 12,000 kw. 9000 volt three-phase 25 cycle turbo-alternator. These reactances have a full load capacity of 770 amperes by 312 volts, or 240 kv-a. Reactances of similar current, voltage and power have been built and operated for many years, for phase control of converter substations. However, the design of these converter substation reactances is entirely and hopelessly unsuitable as power limiting reactances, and these reactances, even if insulated for the voltage, would be an absolute failure in protecting the system.

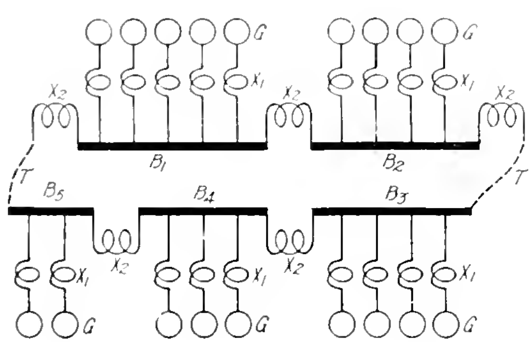


Fig. 1

Consider thus the requirements which such a 6 per cent. power limiting reactance between bus-bars and 12,000 kw. turbo-alternator has to fulfil. Normally, at full load, it consumes 6 per cent. of the generator voltage, or 312 volts. If a short-circuit should occur at the generator terminals, the full Y voltage of the bus-bars, or

$$\frac{9000}{\sqrt{3}} = 5200 \text{ volts,}$$

that is 16 times the normal voltage, comes on the reactance. It is then, that the reactance is relied upon to limit the power. Thus, at 16 times normal voltage the reactance must be there, that is, its magnetic circuit must not saturate. If the short-circuit comes on at the zero point of the voltage wave,—and this is always approximately the case in one of the three phases—during the first half cycle the magnetic density rises to double value, that is, 32 times the full load density. Thus, if iron is used in the power limiting reactance of this kind, it has to be operated at such low density as not to saturate at 32 times normal density. Hence, the permissible magnetic density is limited to B=500 lines of magnetic force per cm². This low density makes the use of iron uneconomical in the power limiting reactances, even if its use were electrically permissible, since an iron magnetic circuit would be larger than an air circuit, and very much heavier.

Thus the power limiting reactances, to fulfil their purpose, must be ironless reactances.

The magneto-motive forces of machine fields, as motors, generators, etc., usually range between 1000 and 8000 ampere-turns, and the highest magneto-motive forces heretofore met are those in the huge fields of the high power low frequency turbo-alternators, and in the enormous fields of bipolar locomotive motors, as that of the New York Central locomotive. They reach values of 30,000 to 40,000 ampere-turns. The magnetomotive force of the 6 per cent. power limiting reactance of a 12,000 kw. alternator is at full load 40 turns times 770 amperes, or over 30,000 ampere-turns, that is, as high as the highest magneto-motive forces ever employed, while at short-circuit with 16 times full load current it rises to half a million ampere turns.

This is by far the highest magneto-motive force ever produced by man.

Fortunately, this gigantic alternating magnetic field does not reach to any considerable distance; but within the field, all solid conducting material and especially magnetic material has to be kept away. Oscillatory mechanical forces are produced by this enormous field, amounting to hundreds of tons, and against these the structure has to be held rigid.

Electrically, the reactance must continuously stand the full circuit voltage, temporarily double circuit voltage, and also must stand unlimited transient voltage.

Besides this, the position of the power limiting reactance in the system is peculiar: it is not, as in other apparatus, an economic question between the cost of more perfect insulation and the damage resulting from its failure, but the reactance is supposed never to fail, even if everything else fails, as on it depends the safety of the system: the

Fig. 2. Concrete Core of Power Limiting Reactance Coil

localization of the effect of any failure of a part of the system.

Permanently, it is at a potential difference from ground, equal to the Y voltage of the circuit, or 5200 volts. At short-circuit, this full voltage comes across the terminals of the reactance, and in the first moment of short-circuit, by recoil twice this voltage may appear across the coil terminals.

The insulation against a dynamic voltage equal to twice the circuit voltage, while difficult with a structure of such large bulk, limited in the use of structural materials to non-conductors, is not the most formidable problem, but more difficult is the protection against the unlimited voltages of transient impulses. The position of the reactance in the electrical system, between the generator as the source of power, and a cable system of hundreds of miles extent, is analogous to that of a break-water between the land and the ocean. A large cable system, just as the ocean, is never at rest, but waves continuously traverse it, from small ripples, high frequency traveling waves and impulses, to occasional big surges, long high power waves. What happens can be watched on an ocean wave: even a small wave of moderate height, harmless in the open ocean—the cable system—when it approaches the break-water, rises in height until it finally breaks, throwing the spray up to heights many times greater than the height of the free wave. The cause is this: the wave contains a certain amount of energy. In the propagation in the open water, this energy is carried onwards with the wave, but where the wave is stopped by the break-water its energy is dissipated, discharged in raising the water to abnormal height. Thus the electric energy of any impulse or wave in the cable system, when it reaches the reactance, is discharged into space, as a transient of unlimited voltage but limited energy. While harmless in itself, such a transient is dangerous if it can discharge to ground or otherwise close the circuit and thereby permit a dynamic current to follow. These reactances thus require insulation against definite voltages of unlimited power, and also against unlimited voltages of limited power.

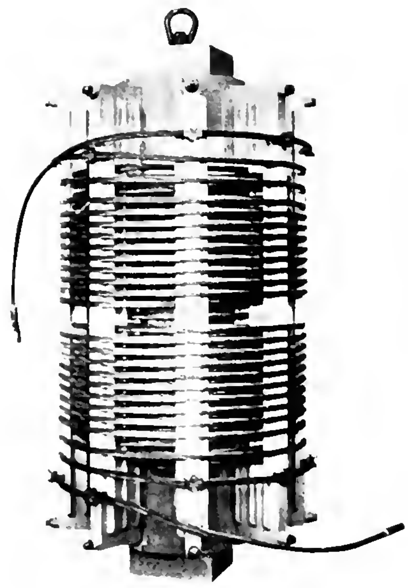


Fig. 3. Power Limiting Reactance Coil

The problem of design of these power limiting reactances thus is a very difficult one: enormous mechanical strength, and constancy of the reactance up to 32 times the full load value; control of enormous magneto-motive forces; elimination of iron as magnetic material; exclusion of all grounded metal near the conductor, and also of all metal or other conductors except isolated pieces of such small size as to have negligible static capacity.

It is believed that the design finally adopted, and represented in the present power limiting reactances, has solved this problem. These reactances consist of stranded conductors, wound on concrete cores, with the exclusion of all metal except small supporting pieces. Fig. 2 shows the concrete core, while Fig. 3 shows a complete coil.

FLYWHEELS FOR MOTOR-DRIVEN ROLLING MILLS

By Edward J. Cheney

The application of electric motors to the driving of main roll trains in steel mills was a radical step and involved the solution of many new problems. Some of these problems arise from the extremely irregular load curves, characteristic of such installations. Railway loads were formerly considered the most fluctuating ones which electrical apparatus had to deal with, but they must now yield this distinction to the steel mills; the load factor, or ratio of average to maximum load, is probably lower in steel mill service, and in suddenness and violence of fluctuations there is hardly any comparison. The railway load may sometimes mount from a low to a high value very suddenly, but it does not do so as a regular performance, and it is not likely to drop again to nearly zero in the next second or so, as the mill load will do.

Rolling mill loads are fundamentally irregular because the process of rolling steel is inherently an intermittent one. Neglecting the comparatively few "continuous" mills, all steel is rolled down from a bloom or ingot to its final form in a succession of passes. As regards any particular ingot, the load consists of periods of heavy load during passes, varying in duration as the metal lengthens out, interspersed with periods of friction load. The first passes will occupy merely a fraction of a second, and the last pass will not be longer than a very few seconds. The time intervals between passes will probably exceed the rolling time during actual rolling, and there is apt to be an additional idle interval between the completion of one ingot and the beginning of another.

The load on the motor will depend upon the class of work and the general arrangement of the mill. The most int rmittent service will be where the motor drives only one "two-high" roll stand and where the metal is being "bloomed" down from a large ingot, and the passes are consequently short and heavy. By "two-high" is meant a mill with only two rolls. The ingot must be taken back over the top of the mill after a pass before it can again be put through the rolls, and the interval will probably be longer than where a "three-high" mill is used. A "three-high" mill is one with three rolls, in which the top and bottom rolls revolve in one direction, and the middle one in the opposite direction, so that the metal is passed through the mill between the bottom and the middle rolls and comes back between the middle and top rolls.

If the mill consists of several stands, driven by one motor, a very common arrangement, two or more ingots may be in the mill at once, and the load curve will depend upon whether they all go through the mill simultaneously, alternately or in some mixed relation. The more stands there are in the mill, the more nearly constant the load is apt to be by reason of the diversity factor of the different stands and passes. The load curve approaches a straight horizontal line at infinity, but in actual practice we are usually very far short of infinity and the curve is more apt to be composed largely of vertical lines.

With a given mill the load will be varied with different classes of work, and with the same class of work it will be affected by differences in temperature, individual characteristics of operators and a multitude of minor things. Probably no two mills ever had the same load curve and the same mill never exactly repeats a curve except by rare chance, but nevertheless, certain curves may be picked out which are broadly typical of different classes.

Fig. 1 shows the load on a "two-high," one-stand mill. On "three-high," one-stand mills, there will be no difference except a possible shortening of intervals between passes. This curve is typical of blooming mills, roughing mills, plate mills, etc., which give the lowest load factor.

Fig. 2 is representative of a large and mixed class which have a medium load factor, and includes small merchant mills, bar mills, sheet mills, etc.

Fig. 3 is a curve of such high load factor that it can hardly be approximated by anything except merchant mills with a large number of stands and a large crew which works the mill to full capacity.

It must be borne in mind that in every mill where more than one piece may be in the rolls at one time, the entire contour of the curve may be changed by varying the time relations between different passes and different ingots, and that in practice, unless the load, what result it will have on the motor and supply system, whether a flywheel is warranted and what size flywheel will result in maximum economy. The problem is not simple in any instance and no general solution can be given, because there is no general case. Within the scope of a short article, it will only be possible to outline the problem sufficiently to show the principal factors which must be considered. Since most mills, particularly those which need flywheels, are driven by induction motors, the discussion will consider induction motors only, although the problem is very similar where direct current motors are used.

In the beginning it must be considered that the mechanical proposition of putting a flywheel on the mill has many limitations. Contrary to widely entertained opinion, the gross weight of a flywheel does not determine its usefulness. The true measure of a flywheel is its kinetic energy, and this, by the $\frac{1}{2} MV^2$ law, depends upon the first power of the weight and upon the square of the velocity of the center of gyration. In order properly to compare different wheels, the actual weight of each must be multiplied by the square of its radius of gyration and by the square of its angular velocity or r.p.m. If we have two identical flywheels, one rotating at 50 r.p.m. and one at 100 r.p.m., the higher speed wheel will have four times as much kinetic or stored energy, and will be four times as effective as a flywheel. Also, if we have two wheels of the same weight and speed, but one of twice the diameter of the other, the larger wheel will have four times the stored energy, provided, of course, that the radii of gyration are proportional to the diameters.

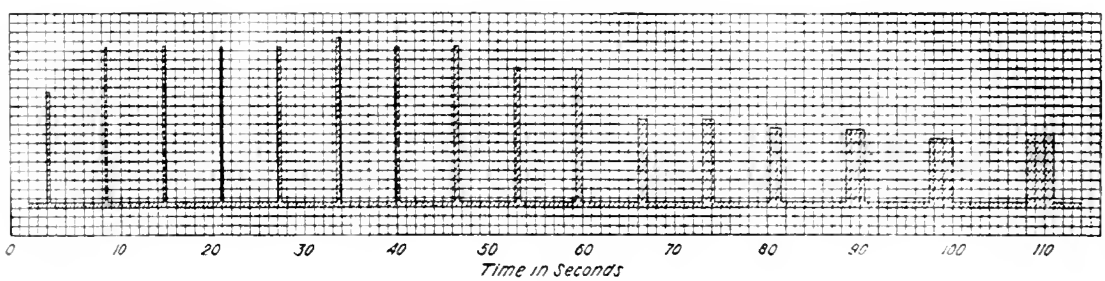


Fig. 1

unusual precautions are taken, the contour will vary back and forth through more or less irregular cycles. Evidently the first consideration in solving a flywheel problem will be to determine the most irregular (highest peaks) load curve which may be encountered, as well as the average load curve.

In steam engine practice it was necessary to have a flywheel on account of the varying torque of the engine. With motors this factor is eliminated and, indeed, that is one of the strongest points in favor of electric drive. A motor has no dead points, pulls smoothly and evenly, and is always ready with any required torque, up to its maximum capacity, in any position and at any speed. There are other reasons, however, which make flywheels desirable, the chief ones being the reduction in peak loads and the mitigation of shocks on the system.

The general problem is to determine what effect a flywheel will have on smoothing out

Now it must be considered that rolling mills are all of comparatively low speed. Even when motors are geared or connected by rope drive, the motor speed is usually comparatively low; and where a speed reduction is employed, it is better, mechanically, to put the flywheel on the mill shaft, in order that the driving system may be relieved of the loads and shocks which are taken by the flywheel, and the wheel should not be located on the motor shaft where it is feasible to avoid it.

Another factor which limits the usefulness of a flywheel is the allowable variation in speed. The flywheel is only of service on account of the energy which it gives up, and this is proportional to the difference between the squares of the initial and final speeds, or $V_1^2 - V_2^2$. If the speed drops 10 per cent., the flywheel will deliver 19 per cent. of its kinetic energy in the form of mechanical work, and a speed drop of 20 per cent. will convert 36 per cent. of the energy. A drop in speed will decrease the production and may affect the product. Depending upon these factors, the maximum speed reduction permissible will usually be 10 to 15 per cent., so that we can actually use only 20 to 30 per cent. of the energy stored in the flywheel.

In considering the effect of a flywheel, it must also be remembered that it is not an inexhaustible source of energy. It cannot supply a certain number of horse power for an indefinite time, but can, with a given drop in speed, supply only a given number of horse power seconds. A certain flywheel may very easily clip off a peak amounting

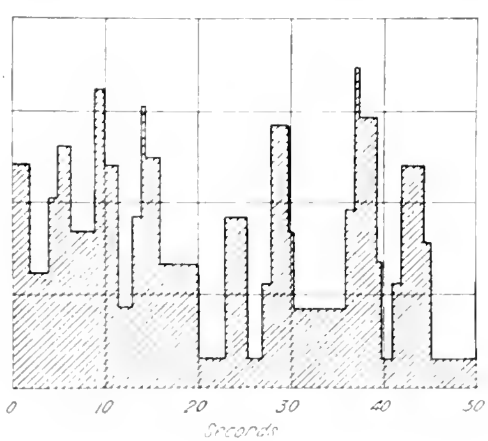


Fig. 2

to 100 per cent. overload for one second, but be entirely inadequate to handle a 50 per cent. overload which lasts five seconds. If it were just able to handle the first condition, it would have exhausted its available energy and dropped the entire load back on the motor, before it was half way through the five second peak.

On account of the low speed and good speed regulation necessary, we may very

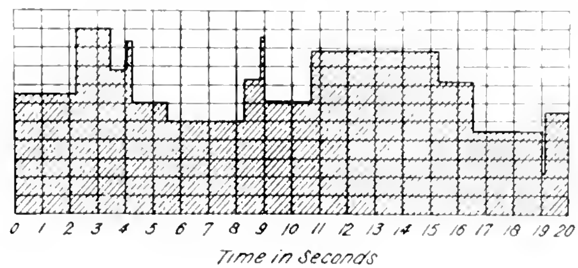


Fig. 3

soon run into prohibitive sizes and find it impossible to put on as large a flywheel as we might otherwise desire. In practice we must usually be content with a flywheel which will materially reduce the short, high peaks, and which will only be of service on the long peaks by causing the load to go on and off the motor gradually, and so ease off the sudden jolts, which would otherwise be demanded from the power supply.

The actual effect of a given flywheel, used with a given resistance, upon any load diagram may readily be calculated from the formula,

$$*T = T_1 - \frac{T_1 - T'}{\epsilon^{\left(\frac{308\, T_s\, t}{W N S_s}\right)}}$$

Where T = motor torque at any time t,
T_1 = total torque of the load,
T' = initial torque of the motor at zero time,
ϵ = base hyperbolic log. = 2.718,
T_s = motor torque at slip S_s,
W = flywheel effect in pounds at one foot radius,
and N = synchronous speed in r.p.m.

All torques are expressed in pounds at one foot radius; time is expressed in seconds and measured from the same instant at which T' is taken; slip is expressed as a fractional part of synchronous speed.

This formula is based on the assumption that the relation between slip and torque is constant and expressed by $\frac{T_s}{S_s}$, where S_s is

*The mathematical solution of this problem has been very completely treated by Mr. F. G. Gasche. See Transactions A. I. E. E., June 1910.

any slip and T, is the torque developed by the motor at that slip. While this assumption is not strictly true, it is sufficiently so, within the ordinary working range, for all practical purposes. It will be observed that all the factors in the exponent of ϵ are constant except t, the time, and the formula may be written,

$$T = T_1 - \frac{T_1 - T}{\epsilon^{At}},$$

Where $A = \frac{308\ T}{WNS}$.

The shape of the motor output curve depends upon the constant A, which depends upon the speed, the flywheel effect and the ratio of torque to slip. The ratio of the torque to the slip depends upon the amount of secondary resistance. We can, therefore, change the motor curve by changing either the flywheel effect or the resistance, and doubling the resistance will have exactly the same effect as doubling the flywheel effect. By doubling the resistance, however, we double both the resistance loss and the slip.

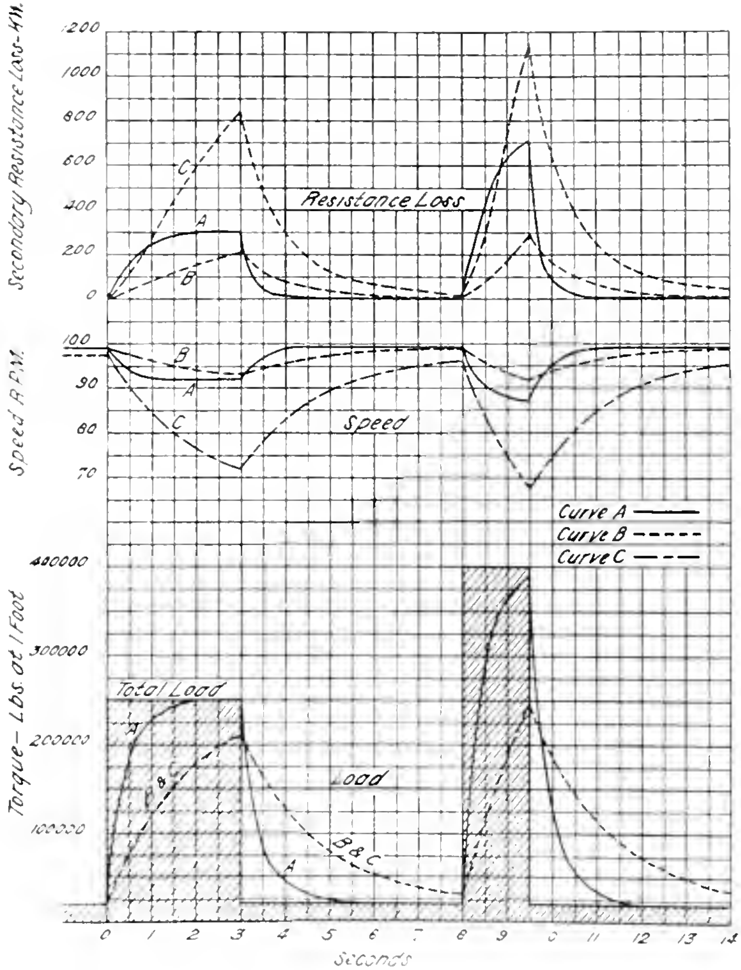


Fig. 4

Fig. 4 illustrates the application of the formula and indicates the general effect of changing flywheel effect and resistance. Curves of motor load, speed and secondary resistance loss are shown for the same duty cycle with three sets of values.

Curve A.
- Flywheel effect = 4,000,000 pounds at 1 foot radius.
- Speed = 100 r.p.m.
- Slip at 150,000 pounds torque = 5 per cent. = 0.05.

Curve B.
- Flywheel effect = 16,000,000 pounds at 1 foot radius.
- Speed = 100 r.p.m.
- Slip at 150,000 pounds torque = 5 per cent. = 0.05.

Curve C.
- Flywheel effect = 4,000,000 pounds at 1 foot radius.
- Speed = 100 r.p.m.
- Slip at 150,000 pounds torque = 20 per cent. = 0.20.

In comparison with curve A, it will be observed that in curve B the flywheel effect has been increased four times, and the resistance left unchanged, while in curve C the flywheel effect has been left unchanged, but the resistance has been increased four times. This results in the motor load being identical for B and C, and the peak loads being much lower than for A; but the speed regulation is worse and the resistance loss higher for C than for B. It should be noted that no correction has been made for variations in length of passes due to drop in speed; this will be quite a percentage in curve C, but can ordinarily be neglected or roughly approximated.

A word of warning must be given against drawing general conclusions from the particular case shown here, as other conditions will give very different results; no definite conclusion can be reached without investigating each specific problem.

Having determined what effect a flywheel will have upon the motor load, we can proceed to see what general results are accomplished by it and whether they warrant its use. Let us first consider the question with respect to the motor.

From the standpoint of efficiency there is usually not much in favor of a flywheel, as it entails additional mechanical losses. On very irregular loads there may be some gain, however, on account of the reduction in C^2R losses resulting from the lower peaks. It should be said, also, that if a flywheel is used, a large one may be more efficient than a small one, since the same results may be accomplished with the larger one with smaller resistance loss.

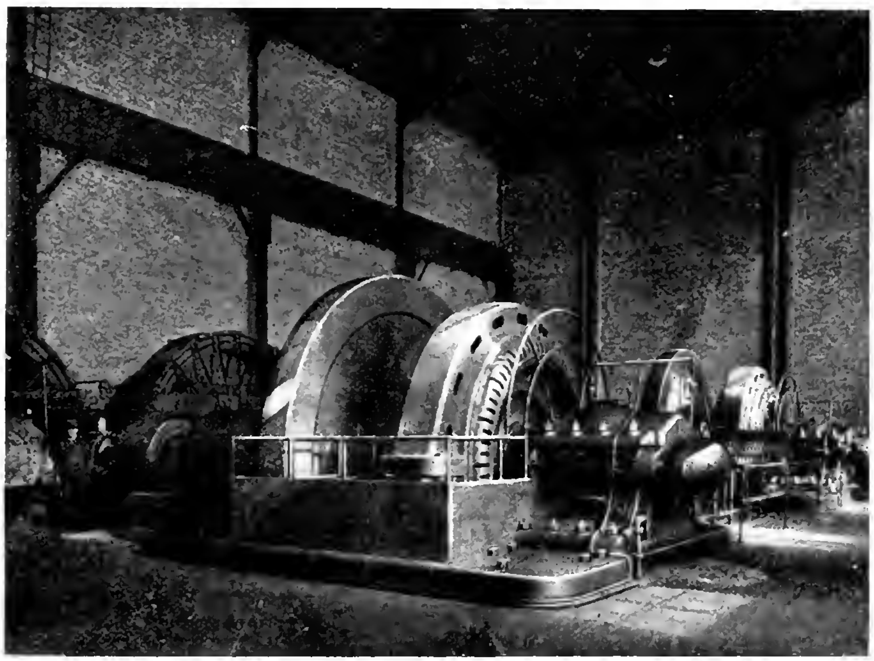


Fig. 5. 2000 H.P., 214 R.P.M. Induction Motors with 100,000 Lb. Laminated Steel Flywheels Flywheel Effect of Each, including Rotors, 4,000,000 Lb. at One Foot Radius

The question of first cost depends mostly upon the maximum load. With curves similar to Fig. 3, where the load is fairly steady, any motor capable of handling the average work will have sufficient brief overload capacity to handle any part of the cycle unassisted. It will, therefore, require exactly the same motor in any case and a flywheel will be of no use.

If, however, we have su 'i a load as that shown in Fig. 1, and no flywheel is used, it is likely that the motor size will be determined by the highest peak, and that a flywheel which will materially reduce the maximum load will permit a smaller motor to be used. It seldom happens that much gain in total first cost can be made, except on the very worst loads, as the additional cost of the flywheel will usually offset the saving in the motor.

In power-factor, considerable improvement may be made on account of the possibility of designing the motor for lower maximum load. This improvement will be most marked at low loads, the wattless, or magnetizing, current taken at friction load being practically in proportion to the maximum capacity of the motor. Since all mills are apt to run a considerable portion of their time with no steel in the rolls, this gain in power-factor may be important.

The question of power-factor naturally leads to a consideration of the supply system, and it is in the supply system that the most important results of flywheels are to be found. While the problem still deals with the question of flywheels on the individual motors, it is now concerned with their effect upon the total load. While the fluctuations on one motor may be great, its effect upon the power station will be negligible if it is only a small percentage of the total. The fluctuations of one motor become important, however, when it is relatively large compared with the system, or where a large part of the load is composed of similar motors and there is a possibility of the various peaks coinciding. In general practice the motors are large, few in number and comprise a large share of the load.

In order properly to study the problem it is necessary to make up diagrams of the total load by combining the individual portions. Different flywheels may be assumed for the various mills and the resulting power curves combined in the various possible relations. In doing this the diversity factor and the laws of chance must be properly considered in addition to all the facts peculiar to the particular installation. If there are a large number of motors, it is reasonably certain that all of them will never be working on their worst cycles simultaneously and with coincident peaks; but if there are only three or four motors, it is equally certain that they will, at times, arrange themselves in the worst possible relation. It can be depended upon, however, that not more than two or three will ever remain in such relation with each other for any length of time.

Having plotted out our load curves for various conditions, we shall find that there are three factors influenced by the flywheel sizes which affect the supply system. These are, first, peak load; second, suddenness of fluctuations; and third, power-factor.

Where power is purchased from an outside company it is only necessary to determine how the changes which we can make in the above factors will affect the power bill. But ordinarily current is generated by the company which uses it, and a detailed study is required to find how the cost of producing power will vary. The relative importance of each factor depends upon the general type of the system and particularly upon the generating equipment.

High peaks will generally mean an increase in first cost and a decrease in generator efficiency, but these effects will be more marked with gas engine generators than with

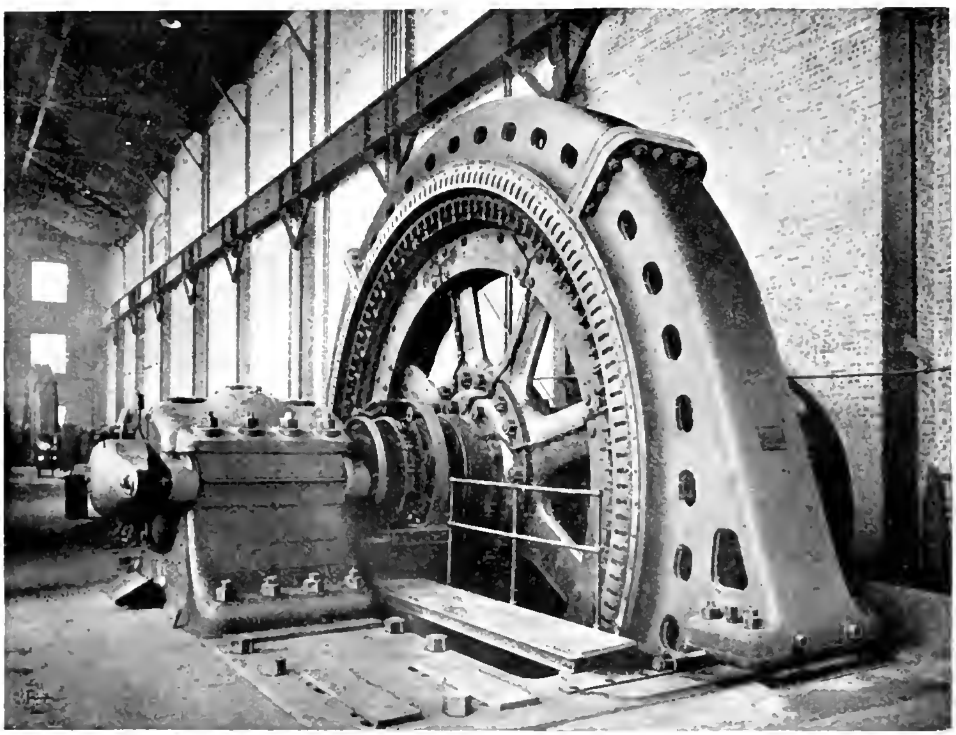


Fig. 6. 6000 H.P., 83 R.P.M. Induction Motor. The Steel Side Plates are Bolted to the Rotor Arms to Increase the Inertia. Flywheel Effect 14,000,000 Lb. at One Foot Radius

turbines, since the latter have higher overload capacity and flatter efficiency curves. The effect of peaks upon station capacity depends also upon their frequency. When a certain maximum load can only occur at rare intervals, due to a particularly unfortunate combination of loads, much less margin may reasonably be allowed than if this maximum is expected to recur frequently.

Violent fluctuations disturb voltage and frequency and may affect parallel operation. In general, a higher peak can be carried when the load comes on gradually. In some cases it may be absolutely necessary to equip the motors with flywheels in order to obtain satisfactory operation of the generators, and in others the use of flywheels may permit of considerable reduction in generating capacity, due solely to their steadying effect. Here again turbine generators have the advantage over gas engines, due to their better governing characteristics on swinging loads.

As regards peak loads and rapidity of variation, there is less need for flywheels where there are several motors or a large percentage of steady load, than where there are only a few motors and no other load. Where each motor is a small portion of the whole, its individual variations become less important. In considering power-factor, however, the gain which may be made becomes less important with a smaller number of motors. This arises from the fact that where there are few motors, the generating equipment is largely decided by the peak loads, and little or no gain in power-factor can be made at the peaks; but the increased power-factor at light loads becomes more important on a large system, where there will always be some motors running without load.

The above discussion is based on motors being wound for generator voltage and located near the station. Where there is a high voltage transmission, the peak loads may fix the size of line on account of voltage regulation but will probably not affect the transformers. Rapidity of fluctuations will have no influence on either line or transformers, but power-factor will affect both.

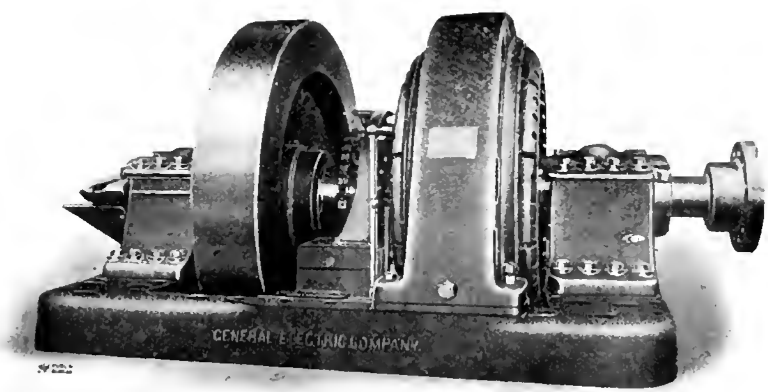


Fig. 7. 500 H.P., 214 R.P.M. Induction Motor with 30,000 Lb. Cast Iron Flywheel. Flywheel Effect, Including Rotor, 470,000 Lb. at One Foot Radius

To sum up the matter, we can say that first the load curves on each individual motor must be determined, particularly the most irregular loads. It must then be determined what alterations can be made in these curves by flywheels of practical size, and how these alterations will affect cost and operating characteristics. The effect of different flywheels must be considered on the individual motors and then on the supply system. A careful study made upon these lines will indicate whether it is advisable to install flywheels or not and, if so, what their sizes should be. It should be needless to say that good judgment and a complete practical knowledge of the working conditions are essential aids to the mathematical treatment.

ALTERNATING CURRENT APPARATUS TROUBLES

Part IV

By B. P. Coulson, Jr.

A PRACTICAL CONSIDERATION OF PARALLEL OPERATION OF ALTERNATING CURRENT GENERATORS AND OTHER SYNCHRONOUS MACHINERY

In considering the subject of parallel operation of alternating current generators, it is hardly feasible to undertake an analysis of the difficulties which may arise, on the basis of cause, symptom and remedy; but it is the purpose of the present article to consider broadly the conditions which must be met to obtain satisfactory parallel operation, and to proceed from this to an examination of the various characteristics of the machines themselves which affect their ability to meet these conditions. The latter part of the article gives some hints as to methods which may be tried out on sets which are not running satisfactorily in parallel. It should, however, be pointed out that as a rule it is a very difficult matter to cure machines of this trouble without making some radical change, and the loss thus involved is likely to be considerable.

Perhaps this subject is not of so great importance in this country as in Europe where the slow speed prime mover, both of the steam and internal combustion type, is much in vogue. There are, however, signs that the explosion engine is becoming more used in America than formerly, as, for instance, in central station work to overcome the peak loads. The subject has of late been studied extensively in connection with synchronous units situated in different power houses perhaps miles apart, further reference to this matter being made below. During the last few years the question of parallel operation of alternators has been deeply studied by a few German writers, and our present knowledge of the subject is due in a large measure to their works. It may, however, be pointed out that this subject was first considered some 40 years ago.

To enable two or more alternators to run satisfactorily in parallel, they must essentially run at the same frequency, while it is also necessary that they be connected so as to allow flexibility, or phase adjustment. If two alternators have a rigid mechanical connection, i.e., if they are on the same shaft, there can be no flexibility, and a difference in field excitation would cause large cross currents between the machines. If, however, two alternators running at constant speed, but having different field excitations, were on separate shafts but connected together electrically, there would take place a phase adjustment, and the alternator with the higher excitation would strengthen the field of the alternator with the lower excitation; thus there would be an equable adjustment and no energy loss through cross currents, the only loss occurring being I^2R loss. In other words, the alternator with the stronger field would be demagnetized by a lagging current, and the alternator with the weaker field would be magnetized with a leading current.

Natural Period of Oscillation of Alternators

When two or more alternators are running together in parallel, they have a natural period of oscillation about one another. This oscillation may be started by one alternator slowing down a little; the immediate result would be for a current to flow from the alternator of the higher speed. This would tend to speed up the slower alternator above the speed of the other, and so a current would flow back again. In the absence of any other disturbing element, these alternators would oscillate about one another until the pulsations would gradually die out, due to eddy currents, friction, or other causes

The frequency of these oscillations will depend upon the synchronizing forces between the machines and the weight of the revolving parts. The heavier the flywheel, the slower will be the oscillation; while on the other hand, the stronger the synchronizing power, the quicker will be the periodicity of oscillation. An analogous condition to these phenomena is the swinging of a clock pendulum. These pulsations can readily be observed by paralleling an alternator slightly out of phase with a system of large capacity, and noting the beats while the machine is getting into phase.

Impressed Oscillations of Crank Mechanism

Furthermore, all prime movers of the reciprocating class are subject to impressed oscillations due to the crank mechanism, to a greater or less degree, depending on their type and construction. For instance, if two alternators are being driven by two separate single cylinder engines whose cranks happen to be crossed, one engine will be working while the other is near the dead center, and conversely. Thus one alternator will tend to speed up while the other slows down, and then the second will speed up while the first retards. If, therefore, there is not sufficient flywheel effect to smooth out these irregularities, there will be cross currents flowing from one alternator to the other, and thus a considerable loss of energy, as in this case the cross currents will be energy currents. If these pulsations (or a multiple of them) approach or coincide with the natural oscillations of the alternators, there would immediately be set up a *resonance*, or cumulative effect, which tends not only to maintain the initial displacement, but, in some cases, depending primarily on the closeness of the coincidence, will increase this initial displacement to such an extent as to throw the machines out of step.

To an observer looking across the spokes of two rotors which happen to be placed side by side, this resonance effect becomes plainly apparent whenever the alternators are running badly in parallel.

Conditions Determining Satisfactory Parallel Operation

From the foregoing it will be seen that the smooth running of the prime movers is no criterion whereby good parallel operation may be ensured. To ensure satisfactory parallel operation, it is necessary to keep the variable displacement within comparatively small limits; to obtain this condition the inherent irregularity of the prime movers must be small, while further, any resonance effect which would tend to increase this initial irregularity must be avoided.

We are now in a position to consider in greater detail the various factors which will determine the ability of a generator set to meet these conditions; and for the purpose of this analysis, we may first consider factors relating to the prime mover, such as flywheel effect and torque diagram, thus preparing the way for a more detailed discussion of the electrical characteristics of synchronous machinery in general bearing upon their capacity for successful parallel operation.

Consideration of Flywheel Effect

In laying out a generating set, it is of prime importance to have such a flywheel effect in the revolving parts as will prevent the inherent irregularity of the engine from being excessive. The permissible displacement in practice is generally set at about $1\frac{1}{2}$ to 4 electrical degrees (to convert this into mechanical degrees, divide by number of pairs of poles in alternator) either side of the position which the flywheel assumes during uniform rotation.

From this it will be noted that the mechanical angular variation allowable on slow speed machines having a large number of poles is less than on high speed machines. The smaller figure indicated as the permissible displacement would apply to close voltage regulating machines, and the larger figure to poor regulating machines. This permissible displacement must also be considered very closely when machines are to be connected by means of tie lines of comparatively low current-carrying capacity, as is often the case when machines are placed at a considerable distance apart. We will, however, consider this question later.

Any resonance effect which tends to increase this initial irregularity must be avoided. The flywheel effect necessary to take care of this latter complication can readily be determined when the electrical characteristics of the alternators, together with the type of engine used, are taken into consideration. This amount of energy is the minimum which should be supplied in the set.

Torque Diagram of Prime Movers

When dealing entirely with prime movers having even turning efforts, such as steam and water turbines, no trouble from hunting of alternators may be expected, provided satisfactory governors are employed and the auxiliaries do not cause resonance, such as may happen when, for instance, a single-acting air-pump is used. Turbo-alternators having a low reactance will be considered later. On the other hand, when engines of the reciprocating class are chosen, it is necessary to know the characteristics of the torque diagram. The turning efforts of a steam or gas engine can be represented by a series of irregularly formed waves which will be found nearly to repeat themselves after one or two revolutions. For our purpose, these waves can be analyzed and represented by simple sine waves of different periodocity in such a manner that the super-position of these sine waves represents, or nearly so, the irregular waves indicating the actual turning efforts of the engine crank.

In a single crank steam engine which admits steam on both sides of the piston, the wave of the second harmonic has the largest amplitude, the fundamental wave being taken as extending over one revolution of the crank shaft, as in this type of engine the torque diagram practically repeats itself after each revolution.

For a double-crank engine having the cranks set at 90 mechanical degrees in relation to one another, and admitting steam on both sides of the pistons, the wave of the fourth harmonic (for a three crank engine the sixth harmonic) has the largest amplitude. There may also be other harmonies of a higher order which need not be considered.

In the above cases the fundamental harmonic may be taken as extending over one revolution. If, however, steam engines are well balanced, that is, if the mechanical parts are all well designed and the impulses given by the steam on both sides of all pistons are equal, this fundamental wave will be very small. In practice, it is impossible to obtain this ideal condition at all loads, and we must therefore be prepared to meet the case where the fundamental wave does occur.

In the case of an explosion engine working on the 4-stroke principle, the fundamental wave must be taken as extending over two complete revolutions, even when the engine has two or more cylinders, the reason for this being that it is a practical impossibility to design an engine whose cylinders will divide the work equally under all conditions of load. When considering the single crank explosion engine, the wave of the largest amplitude is the one extending over two revolutions. In the two-crank engine the wave of the largest amplitude extends over one revolution, and so on.

In dealing with this subject from an electrical standpoint, it is not necessary to closely analyze the torque diagram of an engine. All we are concerned with at the moment is the fact that such harmonics do exist, and, knowing this, we can so design the sets as to prevent the natural swing of the alternator from coinciding with these harmonics.

Explosion engines whose governors work on the hit-and-miss principle should not be used when parallel operation is necessary, as, with this type of governor, the torque diagram of the engine may be very eccentric.

Methods Which Have Been Adopted for Smoothing Out Torque Diagram

When dealing with generating sets of different sizes running in parallel, each machine should be considered relatively to its own impulses, and also to the impulses of the other sets with which it is running. It is sometimes found in practice that impressed oscillations are caused by the governors of the prime mover. This difficulty, however, can, as a rule be easily remedied by the use of dashpots. When alternators are being driven by ropes or belts from engines or electric motors, oscillations are sometimes set up by the swing of the ropes or belt, and these may be found to have a natural period of their own which causes resonance. By altering the tension of the ropes, or using a longer or shorter drive, this natural period of oscillation may be either shortened or lengthened and so the difficulty overcome.

When rope-driven alternators are considered, this question may become very complex, and when the prime movers are of the slow speed reciprocating class, it is safest to consider the case as though the alternators were direct-connected to the engines and were directly subjected to the crank impulses. The author, however, knows of cases where engines of medium speeds were used and the ropes were relied upon to smooth out the torque of the cranks, and perfect operation was obtained. This condition is probably more the rule than the exception, provided the frequency of the alternating current is below, say, 60 cycles per second. Flexible couplings are sometimes used and found to smooth out the engine impulses; the condition in this case would be somewhat similar to using rope and belt drives, but in some instances is of more harm than good.

In designing slow speed gas engine sets, it is sometimes found that the minimum flywheel effect specified by the dynamo makers to give a period of oscillation well within the fundamental harmonic of the engine is more than sufficient to smooth out the torque diagram. In these cases the use of a smaller flywheel will quicken the alternator oscillations. Care must, however, be taken to prevent a coincidence with the higher harmonics of the engine.

It is common practice on the continent of Europe, when dealing with large slow speed gas engines, to mount the poles of the alternator on the inside of the flywheel and outside the armature, thus obtaining economically a much larger flywheel effect. This method also has the advantage of eliminating the engine flywheel.

Consideration of Engine Torque

We will now consider the engine torque, and its effect, a little more closely. For example, we will take an engine whose fundamental wave extends over one or more revolutions and whose generator has a constant load. The engine torque can therefore be represented by a constant torque on which is super-imposed an oscillating torque as represented in Fig. 1. This variable torque impressed upon the alternator will cause its revolving element to accelerate or retard. This acceleration will, of course, be in phase with the torque. Now if the acceleration varies as a sine wave, as shown in Fig. 1, it will tend to displace the alternator rotor. The speed of this displacement will not, however, be in phase with the torque and acceleration. While the acceleration is positive, the rotor will speed up and attain its highest velocity when the acceleration is at zero, or just changing from positive to negative. When the acceleration becomes negative, the rotor speed will decrease, and the minimum value will be reached, when the acceleration again passes through zero.

Thus the rotor speed lags a quarter of a complete period behind the super-imposed torque. In a similar way, while the speed is positive, the displacement will increase, and the maximum and minimum displacement will be attained when the speed is passing from positive to negative, and from negative to positive, respectively. The displacement therefore will be 180° behind the acceleration.

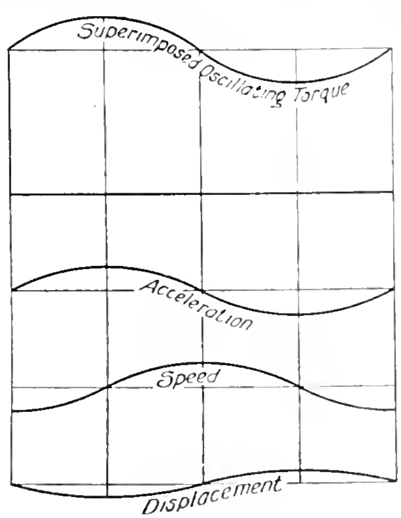


Fig. 1

Alternator Characteristics

Having now dealt with those factors concerned immediately with the prime mover which affect satisfactory parallel operation, we will next consider the characteristics of the alternators which influence parallel operation, not considering for the moment the question of three-phase machines having their neutrals connected.

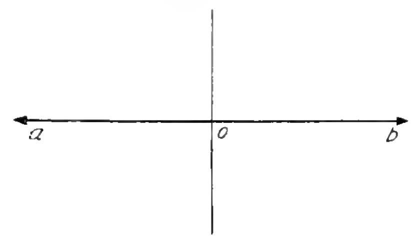


Fig. 2

Supposing we have two alternators connected in parallel, and each machine is running at constant angular velocity; then in the circuit consisting of the two alternators their E.M.F.'s will be in opposition, and may be represented by vectors *oa* and *ob* as shown in Fig. 2. These vectors will represent the E.M.F. of both machines in magnitude and phase relation. Supposing these two machines have a normal oscillation about one another, as explained above, then at a given time the instantaneous voltages of both machines may be represented in magnitude and phase relation by the two vectors *oa* and *ob*, Fig. 3, and the voltage tending to circulate current between the two machines will be represented by *oc*, the resultant difference between *oa* and *ob*. This voltage will practically be in quadrature with the terminal voltages *oa* and *ob*, as the angle of displacement $\frac{\alpha}{2}$ is, of course, very small.

The cross current flowing between the two machines will lag behind the E.M.F. producing it by an angle β,

where $\tan \beta = \frac{x}{r}$,

x = reactance of the two machines,
and r = armature resistance of the two machines.

Let *oi* represent the cross current flowing when *od* and *di* are directly proportional to the resistance and reactance of the two alternators, respectively. Then *od* will represent the energy component of the cross current, being in phase with the voltage *oc*, but in quadrature with the voltage *oa* and *ob*.

This current therefore transfers no power between the two machines. The synchronizing power is derived from the reactive component *di* which, being in quadrature with *oc*, is practically in phase with the terminal voltage *oa*, and in opposition with the terminal voltage *ob*, thus accelerating the lagging machine and retarding the leading machine. This transfer of energy tends to keep the machines in step.

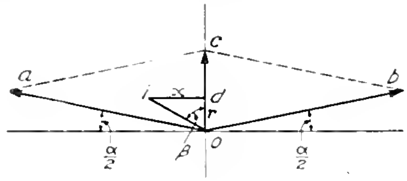


Fig. 3

Effect of Reactance on Synchronizing Power

It will be realized from a study of Fig. 3 that if the resistance of the machines is high in comparison with the reactance, then the current flowing between the two machines will be practically in quadrature with the terminal voltages, and thus there would be very little synchronizing force exerted tending to keep the alternators in step. On the other hand, if the reactance is high in comparison with the resistance, the current flowing between the two machines will be in phase with the terminal voltage of one machine, and in opposition to the other. The synchronizing force in this case will be large. It will thus be seen that alternators should be designed with a fair amount of reactance, so as to give a reasonable synchronizing power. Machines of high reactance have inherently a poor voltage regulation, and conversely, machines of low reactance have a good voltage regulation.

Thus alternators having a good voltage regulation may have a tendency towards bad parallel operation, and conversely, poor regulating machines may have a tendency towards good parallel operation. Bad parallel operation may often be improved by placing reactance between the machines. In practice, therefore, alternators which are to run in parallel are either designed with a fair amount of reactance, or reactance is placed in the external circuit; otherwise, the synchronizing power will be too small. There is obviously a limit to the amount of reactance to be employed. While the percentage of the cross current which is synchronizing current increases with reactance, the resultant value of the current, and that of the synchronizing current, decreases.

If the two voltages of the two machines are in phase with one another, that is, supposing the alternators are not oscillating, but the field of one alternator is stronger than that of the other, then the instantaneous voltages could be represented in magnitude and phase relation by the vectors *oa* and *ob*, Fig. 4. The voltage tending to circulate current between the two machines will be represented by *ac*, the resultant difference between the terminal voltages *oa* and *ob*. This voltage will be in phase with the terminal voltage *oa* and in opposition to the voltage *ob*. As in the above case, the cross current flowing between the two machines will lag behind the E.M.F. producing it.

In all modern alternators, the armature resistance is very small compared with the reactance. Since this is the case, the cross current flowing when the machines are displaced is nearly in quadrature with the voltage producing it, that is, the synchronizing component is large. In the other case, where the machines are not displaced, the magnetizing current predominates.

These conditions must be carefully studied when it is desired to connect two or more power houses at some distance apart. For instance, it may be desired to connect a small power house with a large main station so as to help out the small station and, at the same time, to form a stand-by. The synchronous machinery in the station may be designed with a small reactance, and by placing the lines between the two stations, the total resistance may be increased considerably, whereas, the total reactance may be left the same, as there is very little reactance in tie lines.

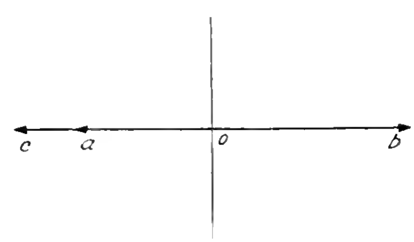


Fig. 4

We should, therefore, get a condition where the total percentage resistance is high when compared with the total percentage reactance. This would mean that the synchronizing power between the machines, tending to keep them in step, would be small. The insertion, however, of external reactance may overcome this condition. Difficulty may also be experienced when connecting two power houses together through the total impedance being too large. This condition prevents sufficient synchronizing current from flowing to keep the machinery in step, as explained above.

When designing the tie lines, it may be considered economical to have them of such a size as to be just sufficiently large to carry the desired current for normal duty, in which case they may not be large enough to carry in addition the desired synchronizing current. In this case, it will be necessary for the initial displacement of the prime movers to be small, so that only a small additional current will be required to keep the machinery in step. This point should be considered when giving the engine makers the permissible displacement of the rotors.

Amortisseur Windings

In practice, it is sometimes considered advisable to place amortisseur windings in the pole-faces of alternators, rotary converters and synchronous motors. These windings consist of copper bars short-circuited on one another similar to a squirrel cage induction motor. Care, however, must be exercised in designing these, otherwise excessive heating and large losses may occur. These bars must be of low resistance and should be placed as near the periphery of the rotor as possible so as to obtain the maximum effect. These amortisseur windings exert a torque opposing the displacement of the rotors from their normal position. When this type of winding is used, it is preferable to have the magnetic reluctance around the rotor as even as possible, otherwise short circuit currents are produced, due to more magnetic lines being cut by the bars in the denser flux than in the weaker flux. Another point of salient importance to be considered when employing amortisseur windings is whether at any time it will be desired to run the alternators on single-phase, or with uneven loads on the phases. Alternators when run under these conditions have inherently a pulsating flux tending to penetrate the poles; this flux is formed by the armature reaction being uneven at different parts of the stator; and induces currents in the short circuited bars which must be calculated. The bars should then be made with sufficient cross section to carry this current in addition to fulfilling their other duties.

Synchronizing of Alternators

A few remarks regarding the synchronizing of alternators will not be out of place. Before two or more alternators are connected in parallel, the phase relations between the machines should be tested out. This can easily be accomplished by driving a motor from each machine separately and observing the direction of rotation. If alternators are thrown together having incorrect phase relation, the machines are in danger of being destroyed, the risk of which depends upon the value of their respective short circuit currents and strength of their structure. Before the machines are thrown together, they should be brought up to approximately the same frequency and voltage. The voltage of each machine should be kept constant, and, at the same time, the phase relations should be observed by means of phase-lamps or some other device.

When paralleling machines which have a fairly high reactance (that is, poor voltage regulating machines) a small difference in voltage or frequency would have no detrimental effect, for the same reason as stated above in connection with keeping alternators in step. On the other hand, more care must be exercised in synchronizing alternators having a low reactance (that is, good voltage regulating machines), otherwise the machines are likely to be ruptured.

Parallel Operation of Y Wound Alternators with Neutrals Connected

We will now consider difficulties which may be expected when the neutrals of two or more three-phase Y connected alternators are joined, unless due precautions are taken to forestall them.

Slow speed alternators having a large number of poles as a rule have inherently a wave shape which does not exactly coincide with a sine wave. The fundamental wave is often distorted by the existence of a third harmonic wave. The existence of this third harmonic, which will be explained later, may cause difficulties when alternators are connected as stated above and are running badly in parallel. A displacement of one of the alternator rotors (causing say an electrical displacement of 3 degrees) from the normal position which it would have, when running with an even angular velocity, may not cause any appreciable flow of energy current between the terminals of the machines. If, however, there is existing a third harmonic, and the neutrals of the alternators are connected, there may be a considerable flow of current between the neutrals caused by swinging of the alternators, due to this higher harmonic.

This trouble may be eliminated if it is found feasible to disconnect the neutrals of the alternators, or by leaving only one alternator with its neutral connected.

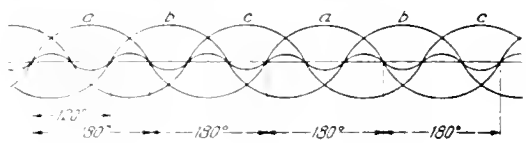


Fig. 5

When selecting the type and speed of prime movers, and also when designing the alternators, this question should be carefully considered if it is desired to transmit three-phase current on the four-wire principle.

Effect of Wave Shape on the Neutral Current

In designing the alternator, the question of wave shape is of salient importance, and as large a number of slots per pole per phase should be selected as will be commensurate with the other characteristics of the design. A wave shape formed by the vectorial addition of several instantaneous values of voltage or current, from a number of conductors cutting a flux wave of approximate sine distribution at different points, will approach nearer to the true sine wave than would be the case if only one or two conductors were to cut the same flux wave at one or two points. For this reason, it is desirable to use an armature winding having a fractional pitch, that is, the span of the armature coils should be less or greater than the pitch of the field poles. In practice it is sometimes found desirable to wind some coils less, others greater than, the field pole pitch on the same machine. Another method used in practice to obtain a true sine wave is to have a distributed field winding or a field winding with poles of different pitch, in which case the armature coils must be connected in series.

It will be seen from the foregoing that trouble from bad parallel operation may, as a rule, be expected only on machines running at a small number of revolutions per minute, i.e., on machines having a large number of poles, assuming a normal frequency. It will not be found feasible in all cases to design this type of alternator as outlined above. This type of alternator is liable therefore to have in its wave shape a third harmonic which must be considered when specifying to the engine builders as to the minimum amount of flywheel effect to be supplied.

When considering the fundamental frequency only, a minimum electrical displacement of $1\frac{1}{2}$ to 4 electrical degrees is specified, as stated above. This would, of course, mean $4\frac{1}{2}$ to 12 electrical degrees when considering the third harmonic. This, however, would cause a considerable amount of neutral current, and it is therefore advisable somewhat to reduce this displacement.

It may be pointed out that a current of considerable magnitude may flow between the neutrals of alternators without doing any great amount of harm. This may be seen from reference to Fig. 5. The sine waves *a*, *b*, *c*, represent the fundamental waves of the three phases of a three-phase alternator, displaced 120° from one another. We will assume that the actual wave shape of the machine is distorted from the sine wave by the super-position of a third harmonic. Referring to Fig. 5, it will be seen that this third harmonic is displaced zero degrees from the fundamental, also that the third harmonic of phase *a* is in phase with those of phases *b* and *c*. The resultant therefore may be represented by Fig. 6. This curve shows a triple frequency equal in amplitude to three times that of the triple frequency in each phase. The current therefore flowing between the neutrals of the two machines due to the triple harmonic is three times the current per phase due to this higher frequency. For example, let us assume a machine having 100 amperes full load current and say the current flowing between neutrals is measured as 90 amperes; then the current per phase due to the triple

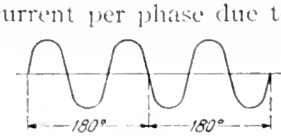


Fig. 6

frequency wave is 30 amperes and the total armature heating due to both currents per phase:

$$= (100^2+30^2)\times R$$
$$= (10000+900)\times R$$
$$= 10900\times R \text{ ohms}$$

where R = resistance of armature per phase.

The heating due to load current only per phase $= 10{,}000\times R$ ohms.

It will therefore be noted that we get an increase of only 9 per cent. in the heating of the alternator stator coils when we have a neutral current flowing 90 per cent. of the full load current of the machine.

Other Causes Responsible for the Neutral Current

While dealing with the subject, it is perhaps advisable to point out that neutral currents may flow through other causes. Two alternators may be running perfectly in parallel, but if they have different wave shapes, a neutral current will probably be observed. A similar phenomenon may be observed if the phases of the alternator are unevenly loaded.

If a three-phase alternator be connected in delta, and a triple frequency voltage exists, there will flow in the delta a triple frequency current. This current can be measured by placing an ammeter in one corner of the delta. If, however, a voltmeter be placed across one corner of the open circuited delta, the voltage observed will be the sum of the three voltages generated in the three phases, due to this triple frequency. The current observed by means of the ammeter is, of course, equal to the triple frequency voltage divided by the generator impedance.

generator impedance $= \sqrt{x^2 + r^2}$

where x = total reactance of the 3 phases at triple frequency.

and r = total resistance of the 3 phases.

From this it will be seen that it is desirable to design alternators having a fairly high impedance, so as to reduce the current due to the triple frequency.

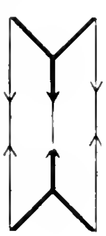


Fig. 7

From the foregoing it will be seen that in three-phase machines where a triple harmonic exists, these triple frequencies are in phase with one another. If, therefore, two of these alternators having Y connections were connected with their neutrals open, the triple harmonics would neutralize one another (see Fig. 7). It will thus be realized that when it is desirable to connect the neutrals of systems to earth or to one another, the question should have the closest consideration, otherwise trouble may be encountered, not only as regards overheating of the electrical machinery, but also as regards disturbance to telephonic or telegraphic systems.

In practice resistances are sometimes inserted between the neutral of a machine and the earth, thus reducing the neutral current. The wave shape of the different machines which are to run together should be as nearly as possible perfect sine waves, particularly so if these machines have their neutrals connected. If, however, the machines are connected with their neutrals opened, the wave shapes are not quite so important, as the third and ninth harmonics, if they exist, neutralize one another. This is not true, however, of the fifth and seventh harmonics. The question, therefore, of wave shape is important if the neutrals of the machines are to be connected, but not so important if the neutrals are kept open.

SUMMARY

When selecting the type of prime mover to be used, the feasibility of good parallel operation must have consideration.

When machinery of low reactance is selected, such as turbo alternators, care must be taken to ensure sufficient synchronizing power between the sets when any disturbance occurs, especially so if the units are located in different power houses.

Machinery which is likely to set up dangerous oscillations and cause resonance should not be used, such as slow speed engines with light flywheels driving alternators by means of ropes or belt; flexible couplings, single acting air pumps, and the like, should also be avoided.

When considering the design of the combined set, a compromise should be arrived at between a heavy flywheel and a small short circuit current. The reactance of the machines must, however, be commensurate with other characteristics such as voltage regulation.

When specifying the permissible displacement of the alternator rotor, the characteristics of the machines must be considered, such as inherent voltage regulation, the location of the different units, and the character of the load. The wave shape of the units is of the utmost importance and must have the closest consideration when the neutrals are earthed, or when three-phase current is distributed by the four-wire system.

The most common cause of bad parallel operation is due to resonance.

Impressed oscillations become dangerous when their periods coincide, or nearly coincide, with the natural periods of swing of one or more of the alternators. To cure this trouble, it is necessary to alter the period of oscillation of the hunting alternator, or eliminate the impressed oscillations. If this is not possible, it is often feasible to decrease the amplitude of these oscillations considerably and sometimes to change their period; for example, when the generators are being driven by ropes which have a periodic swing of their own, resonance can sometimes be prevented by changing the length of drive.

The impressed oscillations can be eliminated, or their amplitudes reduced, in the following ways. If reciprocating steam engines are used, indicator diagrams should be taken showing the operation of the steam on both sides of all the pistons under the same load; if the load is not equally divided, as shown by the diagrams, the valves must be adjusted. This applies also to internal combustion engines.

By using a heavier flywheel the rotor displacement can be reduced. As most of the trouble is caused through resonance, it is often necessary to alter the natural period of swing of the alternator. This can be accomplished by increasing or reducing the reactance or by increasing or decreasing the flywheel effect.

Resonance is sometimes reduced by dividing up the load unevenly between the different units, as the torque diagrams of the engines are sometimes changed with a variable load. This, of course, can be done by governor adjustment. Furthermore, this difficulty is sometimes obviated by decreasing the voltage on one or more units. Units equipped with sensitive governors simply take up the load more quickly and lose it more slowly than units having poor regulating governors. Poor regulating governors are better for good parallel operation than close regulating ones.

Cross currents between the neutrals of machines can sometimes be reduced by improving the parallel operation or by improving the wave shape of the machines. This is sometimes accomplished by changing the shape of the pole face. Further tests may be taken by disconnecting one or more governors and noting the results. This will prove whether the governors are at fault.

In conclusion, it may be said that the predominating importance of reactance in a transmission system cannot be exaggerated. It is preferable to have some of the reactance inserted in the mains near the generators. This arrangement not only helps in parallel operation, but also preserves the first few coils of the alternator stators from excessive voltage strains which are likely to be set up when the main circuit is opened. Moreover, reactance placed in the external circuit acts as a current limiting device when a fault is developed in the mains.

HISTORY OF INCANDESCENT LAMP MANUFACTURE*

By Henry Schroeder

In 1879 the first commercial incandescent lamp, using a horse shoe shaped filament made from carbonized paper, was introduced. In its essential parts this lamp was the same as those made to-day, after thirty-two years of experience and improvement in the art of manufacture. In December, 1879, Thomas A. Edison, the inventor, made his first demonstration of incandescent lighting at Menlo Park. He had increased the efficiency of the dynamo from 40 to 90 per cent., an accomplishment which scientists had long considered an impossibility; he had subdivided the electric current, a result hitherto unattained; he had also developed a complete system of electric lighting with its concomitant parts, switches, fuses, sockets, feeders, regulators, etc., all of which are in use at the present day.

The main parts of an incandescent lamp are the glass bulb, filament, glass stem, leading-in wires and the base.

The first step in the manufacture of incandescent lamps is the preparation of the glass bulb, which was formerly blown by hand, or, as was technically known "free blown." A small hole is then melted through the bulb and a piece of glass tubing attached for the subsequent purpose of exhausting the air in the bulb. The filament is next mounted on its stem, which is then inserted and welded to the neck of the bulb. The air is then exhausted and the glass tubing melted off, leaving a tip on the lamp. The leading-in wires consist of short pieces of platinum welded to copper, the platinum pieces being partly embedded in the glass stem. The metal platinum is used because of its coefficient of expansion, which is practically identical with that of glass, so that when the lamp burns and the bulb becomes heated, any leakage of air through the leading-in orifices of the wires is prevented. Upon completion each lamp is tested on a photometer to determine its efficient voltage. The base is then attached and the lamp is ready for shipment. The general method of manufacture as here outlined is practically the same to-day as at the beginning of the art, but remarkable improvements have been developed in the life and

*A paper presented at the National Convention of Building Owners and Managers, Cleveland, O., July 10, 11 and 12, 1911.

efficiency of the lamp and in the uniformity of the product.

The first incandescent lamp equipped with a filament of carbonized paper displayed an efficiency of approximately seven watts per candle-power, or about nine lamps of sixteen candle-power per kilowatt, or $6\frac{1}{2}$ lamps per horse power. As compared with lamps made today the life was exceedingly short, averaging forty hours.

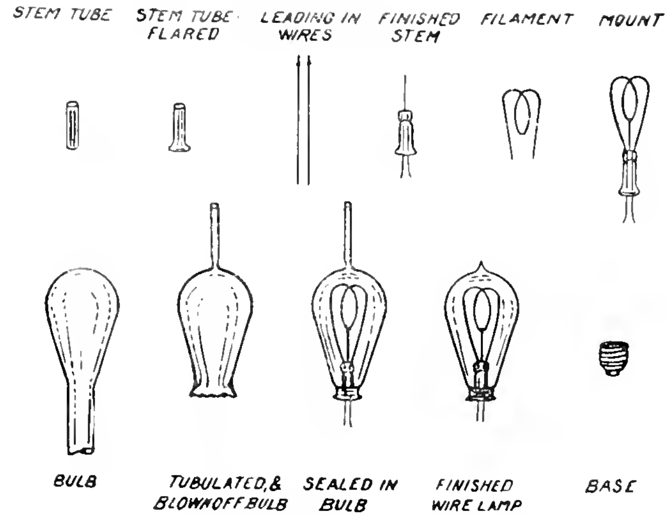
In the development of the filament many experiments were made with well-nigh every conceivable material, including platinum and other metals. At last carbonized strips of bamboo were adopted, by means of which the efficiency was increased to five watts per candle-power ($12\frac{1}{2}$ lamps per kilowatt, $9\frac{1}{3}$ per horse power), and the total life greatly prolonged. The decline in candle-power was, however, most noticeable, and it occurred very early in the life, falling off approximately 20 per cent. in the first hundred hours. The price of lamps at that time was $1.00 in standard barrel lots.

The filaments at this stage of development were shaped in single hairpin loops, instead of the oval form used at the present time, and were fastened to the leading-in wires, which latter, to give better contact, were copper plated. The parts of the base were set in a mould, the neck of the lamp was inserted, and plaster of paris poured into the mould to form the cementing medium between the base of the lamp and the other parts.

Originally the base consisted of a shell and an outside ring, but owing to the fact that a tension was produced when the lamp was screwed into a socket, often pulling the base and lamp apart, the outside ring was soon abandoned, and as is standard practice today, a center cap contact was substituted. The base was later made complete before being attached to the lamp, the cap and shell being held together by a piece of porcelain. At the present time glass is used, as it is water tight and rigidly holds the parts of the base together.

The first commercial installation, consisting of one hundred and fifteen lamps equipped with carbonized paper filaments, was made in 1880 on the steamship Columbia. Three 60-light dynamos were installed and run in a satisfactory manner for a period of fifteen years.

On land, the first installation was made in January, 1881, in the establishment of Hinds, Ketchum and Company, New York City. The first mill plant was installed in a woolen factory in Newburg, N. Y., and the first



Parts of Lamp During Manufacture

hotel plant in the Blue Mountain House in the Adirondacks, both being placed in operation in 1881. It was not until the following year (August, 1882) that the first central station plant was established, at Appleton, Wis. The second, the Pearl Street station in New York City, was established in September of the same year. In July, 1883, the first three-wire plant was put into operation at Sunbury, Pa.

During the year 1881 about thirty thousand lamps were made, the majority of which were of 16 c-p. In 1910, in the United States alone, the total manufacture of incandescent lamps reached the number of eighty millions, a figure probably representing one-half of the world's entire output. Twenty million of those manufactured in the United States were of the metal filament type. Thus, in about thirty years, the industry has increased over five hundred fold. An illustration of the extraordinary improvement made in the art may be deduced from the fact that the life of the present day carbon lamp, if operated at the efficiency of the lamps of 1881, would be about eight times as great as it is at present. In 1883 the price of lamps in barrel lots was reduced to 75 cents. Prior to 1886 it was necessary to shape the bamboo filaments at the ends for proper insertion in the clamps, which prevented any variation in length; but at this time the filaments were cemented to the leading-in wires by means of pasted clamps, an improvement which, by permitting a more careful adjustment of the lengths of the filaments, rendered greater accuracy in manufacture possible.

In 1891 various improvements were made, which resulted in an increase of efficiency of the product to 3.1 watts per candle-power (20 lamps per kilowatt or 15 per horse power), the filaments still being made of bamboo.

In 1893 the cost of the manufacture of filaments was greatly reduced owing to the adoption of the cellulose filament which permitted the more advantageous use of the "treating" process, so that still further improvements were also obtained in the quality of the lamps. In February of the same year the price in barrel lots was reduced to 52½ cents, a few months later to 42 cents, and again in December of the same year to 32½ cents.

The present form of filament—an oval with a short center anchor to support the loop—was adopted during the year 1894.

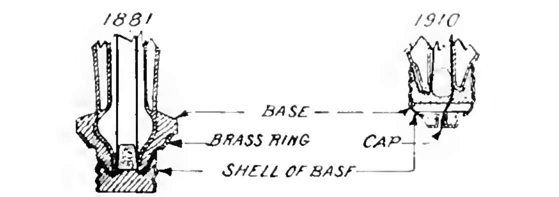
First Incandescent Lamp Factory, Menlo Park, N. J.

During the following year the process of "treating" was developed commercially. By this means a dense coating of graphitic carbon was deposited on the filament, insuring a uniform cross section throughout its length. The useful life of the lamps was also thereby increased, as the denser carbon filament decreased the blackening of the bulbs.

Prior to 1892, the bulbs were blown by hand, or, as was technically stated, "free blown," and as a consequence no two bulbs were of the same size. In this year began the manufacture of moulded bulbs which improved the appearance of the lamps, as they could be made in more uniform sizes. By its means the tip end candle-power was more than doubled, from which there resulted a more uniform distribution of light in all directions. A waterproof cement to fasten the base to the lamp bulb was also introduced. By its use lamps could be exposed to the weather—heretofore an impossibility, because the base was attached to the bulb by means of plaster of paris only. The most important of many improvements made from time to time during this period was the chemical process by which the final traces of air are removed from the bulb.

The price of lamps in barrel lots in 1895 was reduced to 20 cents; in 1900 in standard package quantities to 18 cents and in April of this year, 1911, to 17 cents—one-sixth of the price in 1881.

The Gem filament lamp was put on the market about six years ago. It consists of an ordinary carbon filament that has been subjected to the intense heat of an electric



SECTIONAL VIEW OF THE EDISON LAMP BASE IN 1881 AND 1910

furnace. This process increases the refractory quality of the carbon, and has resulted in raising the efficiency to $2\frac{1}{2}$ watts per candle (25 lamps of 16 c-p. per kilowatt) with the same life as that of a carbon lamp of 3.1 watts per candle. The useful life of the lamp was also increased to a considerable extent. The price of the Gem lamp has also been reduced to an average of about 5 per cent. more than that of the carbon lamp. It is made in units sufficiently small to replace all carbon lamps above 8 c-p.; and as a result the demand for carbon lamps is rapidly diminishing—the improved Gem being substituted therefor.

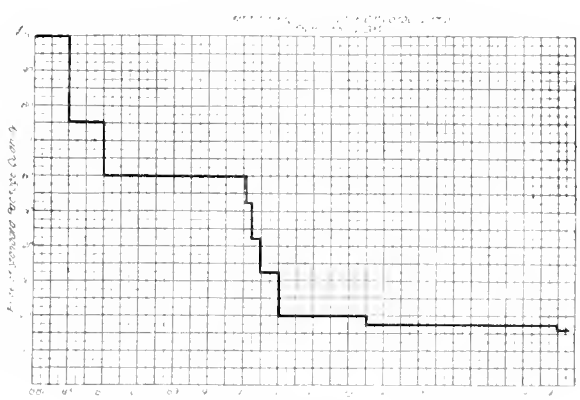
In 1906, the tantalum lamp with an efficiency of two watts per candle (equal to thirty-one 16 c-p. lamps per kilowatt) was first introduced in America. The life of this lamp was soon found to be much shorter on alternating than on direct current circuits, its life decreasing in a ratio with the increase of the frequency of the circuit alternations—characteristics which considerably retarded its general use. The tungsten filament lamp was then brought out and during the few years it has been on the market it has demonstrated not only its practical utility but its adaptability to improvement. The lamps are now made in the larger sizes at an efficiency of 1.13 watts per candle-power (equal to fifty-five 16 c-p. lamps per kilowatt as against 9 in 1880) a gain in efficiency of over 600 per cent.

As illustrating the rapidity of the development of the tungsten filament lamp, it is interesting to note that the present price of the 25 watt size is less than the price of the carbon lamp after the same number of years from its introduction. The price of the carbon lamp was reduced in the first three years from $1.00 to 75 cents; while the price of the 25 watt Mazda lamp has been reduced from $0.765 in 1908 to $0.585 in 1911.

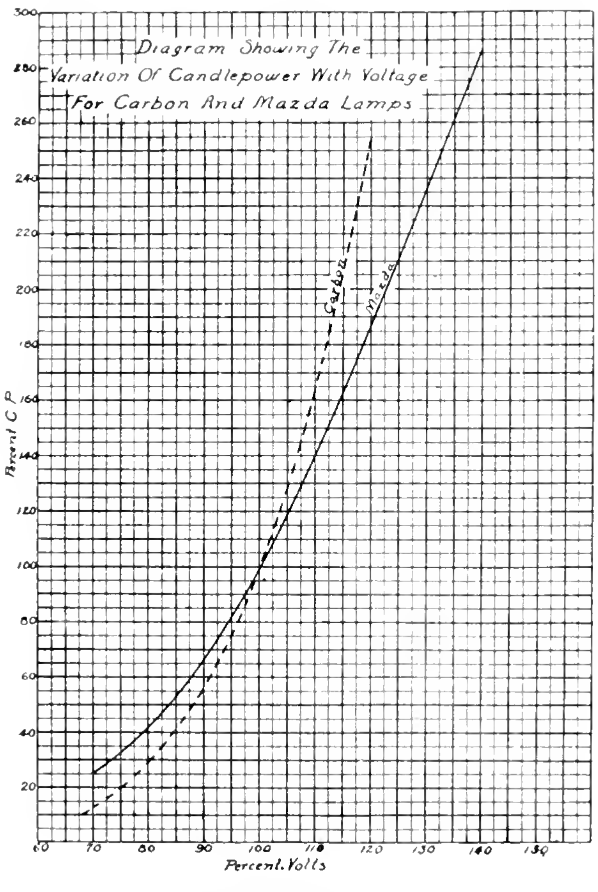
An important advantage of the Mazda lamp over the carbon and Gem is that on varying voltage its candle-power is not so liable to variation; complaints of poor service therefore usually cease upon the installation of Mazda lamps. Greater satisfaction is also afforded by their increased brilliancy and the improved color of the light.

The most economical life of a lamp is that at which the total cost of current and lamp renewals is a minimum. This life is subject to variations with changes of efficiency, an increase of either one being accomplished at the expense of the other. In order that lamps may be operated at different efficiencies, the sizes most frequently used are labelled with three different voltages—high, medium and low operating efficiency, varying by steps of two volts.

In most cases the greatest advantage can be obtained by operating lamps at a high voltage rating (high operating efficiency) as they then give the best quality of light. On an average a power plant must maintain a


Standard Package Prices of 16 C P. Carbon Lamp from 1881 to 1911

$12\frac{1}{2}$ per cent. greater station capacity to furnish an equal illumination when lamps are operated at their low instead of their high operating efficiency; that is, $12\frac{1}{2}$ per cent. more energy is required to produce the same light. If, however, the circuit is subject to large voltage variation, the lamps, when burning at high operating efficiency must at times burn at such a high voltage as to produce poor life results. In selecting a lamp for use on central station circuits its voltage should be chosen for that of the circuit at the outlet, and not that at the bus-bar as shown on the switchboard instru-



ment. It seldom happens that between the switchboard and the socket the drop is less than two volts. As the time also at which the lamps are in use usually corresponds with the period of heaviest load upon the central station, they are generally used at the moment of the greatest fall in voltage. To insure the most satisfactory results, therefore, frequent tests should be made of the socket voltage at the hours of burning.

The carbon lamps most generally in use are the 10, 20, 25, 30, 50 and 60 watt sizes—a range of from two to twenty candle-power; the most popular Gem lamps are the 40, 50, 60, 80 and 100 watt sizes, the first three mentioned frequently supplanting carbon lamps of 30, 50 and 60 watts. The demand for carbon lamps of 100 to 120 watts (giving approximately 32 c-p.) is slight and is diminishing, as the 80 and 100 watt Gem and the 40 and 60 watt Mazda lamps are found to meet the requirements in a more satisfactory manner. The tantalum lamp is also giving place to the Mazda. The former use of carbon lamps in clusters is now almost universally superseded by Mazda units; in fact, to replace an existing cluster of carbon lamps by a single Mazda, effects not only a saving in current but also in the installation cost of the lamps themselves, and results in an improvement in the quality of the light.

If Madza instead of carbon lamps are used on the circuit, the central lighting plant need only be of about one-third the capacity otherwise required, so that the fixed charges on the investment saved will more than repay the entire cost of lamp renewals. Approximately two-thirds of the maintenance charges of the plant—coal, oil, water, labor, etc.—will also be saved. If additions should be found necessary to an already fully loaded plant, a $1\frac{1}{2}$ kilowatt load of carbon lamps replaced by a $\frac{1}{2}$ kilowatt load of Mazda lamps releases 1 kilowatt for the additional requirements, giving an equal illumination (in fact, often a better illumination if the lamps are properly located) without necessitating the outlay of any sum whatsoever in addition to the existing plant. In this manner, if Mazda lamps are substituted for carbon lamps, a plant having a capacity of 150 kilowatts can do the service of a 250 kilowatt plant carrying a carbon lamp load. In the case of an underloaded plant, the substitution of Mazda for carbon lamps will often enable the central station to run only one generator fully loaded, thus effecting an economy in coal and water in addition to the many other maintenance charges. Such savings will more than pay for the Mazda lamps used.

ESSAYS ON SYNCHRONOUS MACHINERY

Part VII

By V. Karapetoff

OVERLOAD CAPACITY OF SYNCHRONOUS MOTOR

(Second Method)

The disadvantage of the preceding method for determining the overload capacity of a synchronous motor is that the maximum load has to be found by trials. Without sufficient experience, one may have to assume quite a large number of values of E_1 before values are found which are sufficiently near to that at which the output is a maximum. As is explained in the preceding article, the reason for which the problem has to be solved by successive approximations is that one of the relations between the unknown quantities, namely the saturation curve of the machine, cannot be put in the form of an algebraic equation, but must be treated graphically.

It is possible, however, to obtain a sufficiently accurate solution by replacing the saturation curve by a straight line $BCAF$ (Fig. 7). This straight line is selected so as to represent the working part AC of the saturation curve to a sufficient degree of accuracy. The equation of this straight line supplies the necessary additional relation between the variable quantities, so that the problem can be solved according to the general rule of maxima and minima, instead of by trials. The method outlined below is sufficiently simple only when the ohmic drop in the armature, compared with the reactive drop, can be neglected, as is usually the case; otherwise the first method will lead more directly to the result. The second method is particularly advantageous when the overload capacity is to be determined at a lower line voltage. In this case the machine works nearly on the straight part of the saturation curve, and OC can be assumed to be the straight line, which represents the saturation curve.

The immediate problem is to express analytically the equation of the straight line $BCAF$. We assume that this line passes through the point A at which the induced voltage at no load is equal to the rated line voltage. For instance, if the rated voltage of the motor is 6600 volts, then GA is 6600 volts, and the excitation $OG = M_e$ is such as to give this voltage when the machine is running as generator at no load. It is understood that M_e, as a rule, is different from the actual excitation M at which the motor is supposed to be running during the overload test. It is not absolutely necessary that the straight line should pass through A, but this assumption simplifies the problem, without impairing the accuracy of the result. The other point, B, through which the straight line passes is determined by the slope of the line. This slope must be selected so as to cover the working part AC of the saturation curve. Since the point C is not known, it is possible that the straight line is not selected properly at the first trial, and the result may need a slight correction.

The position of point B can be defined by the value $AH = e$. In order to obtain the equation of the straight line, take some value E_1 on it, such as NL, and denote the corresponding excitation ON by M_n. From the similar triangles AKL and AHB we have

$$AK/AH = LK/BH, \qquad (45)$$

or

$$(e - E_1)/e = (M_e - M_n)/M_e. \qquad (46)$$

This is the required equation of the straight line, or the additional relation between M_n and E_1. The unknown excitation M can be eliminated from this equation by means of equation (37). The latter can be written in the form

$$M_n = M - c_2 T_1, \qquad (47)$$

where from equation (5) the *effective* number T_1 of demagnetizing ampere-turns is

$$T_1 = k_1 k\, k, n\; T. \qquad (48)$$

Substituting the value of M_n from (47) into (46) and solving for E_1 we get

$$E_1 = e + e(M - M_e)/M_e - c_2 e T_1/M_e. \qquad (49)$$

Segregating the known quantities, this equation can be written in the following simple form:

$$E_1 = e_c - c_2 x_1 \qquad (50)$$

where the following notation is introduced for the sake of abbreviation:

$$e_c = e + e(M - M_e)/M_e, \qquad (51)$$

and

$$x_1 = e T_1/M_e. \qquad (52)$$

It is hardly proper to ascribe a definite physical meaning to e_c and x_1. The quantity e_c has the dimension of a voltage and may be called the "corrected no-load voltage." The expression for x_1 has the dimension of a reactance, and may be named the "saturation reactance," because its value depends upon the slope of the line BF.

The problem is now reduced to its final mathematical form: It is required to find a maximum of the expression (30) when the six variable quantities E_1, E_2, e_1, e_2, c_1, c_2, satisfy equations (32), (34), (36), (44a) and (50). This is a problem in relative maxima and minima and can be solved according to

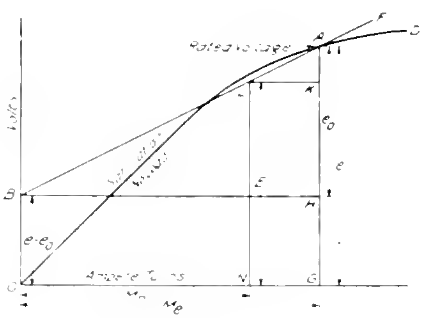


Fig. 7

the well-known rule of the differential calculus. The solution leads to a rather complicated equation of fourth degree which has to be solved by successive approximations. The details of the solution are not given here because it is believed that practical engineers will hardly go to the trouble involved in the numerical computations. The general method is indicated at the end of the appendix.

The problem is much simplified by neglecting the small ohmic drop in equations (32) and (34). An approximate correction in the value of P can be introduced afterwards by subtracting the i^2r loss in the armature. In special cases, when the ohmic drop is of considerable magnitude, the first method (described in the preceding article) is preferable. In order not to obscure the exposition by mathematical transformations, the solution of the above mentioned six equations (with the ohmic drop neglected) is given in the appendix below. The result is that the input P into the revolving field is a maximum when the projection e_1 of the line voltage (Fig. 6) has the value

$$e_1 = \sqrt{\tfrac{1}{2}\, e^2 + q^2} - q. \qquad (53)$$

In this expression, q is an auxiliary quantity; namely

$$q = \tfrac{1}{4}\, e_c (x + x_2) / (x_1 - x_2). \qquad (54)$$

Knowing e_1, the other component, e_2, is calculated from equation (36):

$$e_2 = \sqrt{e^2 - e_1^2} \qquad (55)$$

Now, from equation (34), neglecting the term $c_2 r$,

$$c_1 = e_2 / (x + x_2) \qquad (56)$$

Equating expressions (32) and (50) and solving the resultant equation for c_2 we get (neglecting again the ohmic drop):

$$c_2 = (e_c - e_1) / (x + x_1) \qquad (57)$$

After this, E_1 can be calculated from either equation (32) or (50), and E_2 from equation (44a). These values, when substituted into equation (30), give the value of the maximum input per phase into the revolving part.

Before substituting the calculated value of E_1 into (30) it is necessary to see if the selected slope of the line BF has been estimated correctly. That is, the ordinate E_1 must be sufficiently close to the point C (Fig. 7) at which the actual saturation curve crosses the straight line. If such is not the case a somewhat different slope must be selected on the basis of the first value of E_1, and the results of computations correspondingly corrected. With some experience the second approximation ought to be accurate enough for most practical purposes.

Numerical Illustration. The same machine is used as in the preceding article. The straight line which is to replace the no-load saturation curve is selected so that $OB = 1600$ volts (Fig. 7); hence $e = 6600 - 1600 = 5000$ volts. The other necessary constants are:

$T_1 = 0.75 \times 0.966 \times 3 \times 16 = 35$ turns per pole;

$e_c = 6600 + 5000(6300 - 5700)/5700 = 7126$ volts,

where $M_c (= 5700$ ampere turns) is the excitation corresponding to 6600 volts on the no-load saturation curve.

$x = 14$ ohms;

$x_1 = 5000 \times 35/5700 = 30.7$ ohms;

$x_2 = 14.2$ ohms (see numerical illustration in the preceding article);

$q = 0.25 \times 7126 \times 28.2/16.5 = 3043$ volts.

Consequently, from equations (53) and (55)

$$e_1 = [\sqrt{\tfrac{1}{2}(6.6)^2 + (3.043)^2} - 3.043] \times 1000 = 2525 \text{ volts;}$$

$$e_2 = [\sqrt{(6.6)^2 - (3.043)^2}] \times 1000 = 6100 \text{ volts.}$$

Using these values in equations (56) and (57), we find

$c_1 = 6100/28.2 = 216.2$ amps.;

$c_2 = (7126 - 2525)/(14 + 30.7) = 103$ amps.

Equation (50) gives

$E_1 = 7126 - 103 \times 30.7 = 3966$ volts.

This value of E_1 lies sufficiently close to the point C on the saturation curve, therefore the slope of the straight line has been assumed correctly* and it is not necessary to repeat the calculations. From equation (44a) we find

$E_2 = 14.2 \times 216.2 = 3070$ volts.

The maximum input into the revolving part, according to equation (30), is for the three phases

$[3966\times 216.2+3070\times 103]\sqrt{3}/1000=2030$ kw.

The armature current at this load,

$i=\sqrt{(216.2)^2+(103)^2}=239$ amps.

At this load we have the following losses:

Armature copper loss	= 135 kw.
Iron loss, corresponding to 3966 volts	= 6.5 kw.
Friction and windage	= 4.2 kw.
Total loss	= 145.7 kw.

Maximum output of the motor = $2030-145=1885$ kw.

The overload ratio $=1885/530=3.56$

An overload ratio of 3.6 was found by the first method, so that the two methods give practically identical results. With the first method, the iron loss and friction only are subtracted from P, because the ohmic drop is taken into account when determining the values of E_1 and c_1. With the second method, the effect of the ohmic drop is accounted for (not quite correctly) by subtracting the armature i^2r loss from P, as is done in the foregoing numerical illustration.

The power-factor at the pull-out load is

$\cos\phi=2030/(6.6\times 239\times\sqrt{3})=74.2$ per cent.

In order to determine whether the current is leading or lagging, the same criterion is applied which is given in the preceding article. Namely, 103/216.2 is smaller than 3070/3966; consequently, the angle ϕ is negative and the current lags behind the voltage. It will be noted that with the same field current the motor takes a small leading current at full rated load. As the load increases the field "slips back" and enables the armature to take in a lagging current which strengthens the field and thus automatically increases the torque.

Experimental Check. It is difficult to obtain experimental data on overload capacity of large synchronous motors on account of large amounts of energy involved. The "second" method has been applied to the General Electric synchronous motor No. 62469 direct connected to a direct current generator (testing record 70960, sheet No. 30840). The generator load was gradually increased until the motor fell out of step. The voltage at the armature terminals of the motor was kept constant, at one-half the normal value. Tests were made at three different values of the field excitation of the synchronous motor. The following table gives the results:

Field Current of the Motor Amp.	Calculated A.C. Input Kw.	D.C. Output from Test Kw.	Efficiency of the Set Per Cent.
5.35	75.0	61.6	82
6.05	77.1	67.3	87
7.08	80.0	74.0	92

The values in the last column were obtained by dividing the observed output by the calculated input. Since the values of efficiency come out within the usual range it is reasonable to conclude that the method is at least approximately correct.

APPENDIX

Proof of Equation (53)

The problem is to find a maximum of the expression

$P=E_1c_1+E_2c_2=\text{max.}$ (30)

where, according to equation (44a), $E_2=x_2c_1$, and the following limiting conditions must be satisfied:

$E_1=e_1+c_2x$ (32a)

$e_1=c_2(x+x_2)$ (34a)

$e_1^2+e_2^2=e^2$ (36)

$E_1=e_c-c_2x_1$ (50)

In these equations the variable quantities are E_1, E_2, e_1, e_2, c_1, c_2. Equations (32a) and (34a) are obtained from equations (32) and (34) by neglecting the terms with r. Select e_1 as the independent variable and eliminate all other variables; express E_1 and c_1 for equation (30) through e_1. For this purpose substitute c_2 from (32a) into (50) and solve the result for E_1. This gives

$E_1=(e_1x_1+e_cx)/(x+x_1)$

From equations (35a) and (36)

$c_1=e_2/(x+x_2)=(e^2-e_1^2)^{\frac{1}{2}}/(x+x_2)$

and from equation (32a)

$c_2=(e_c-e_1)/(x+x_1).$ (57)

Substituting these values of E_1, c_1 and c_2 into (30) and omitting the constant denominator, we obtain

$[e_1(x_1-x_2)+e_c(x+x_2)](e^2-e_1^2)^{\frac{1}{2}}=\text{max.}$

This expression contains only one variable, e_1. The function becomes a maximum when its first derivative with respect to e_1 is equal to zero, or

$$(x_1-x_2)(e^2-e_1^2)^{\frac{1}{2}}-e_1(e^2-e_1^2)^{-\frac{1}{2}}[e_1(x_1-x_2+e_cx+x_2)]=0.$$

Multiplying this equation by $(e^2-e_1^2)^{\frac{1}{2}}$ and dividing the result by $2(x_1-x_2)$, the equation is reduced to a quadratic of the form

$e_1^2+2qe_1-\frac{1}{2}e^2=0$ (60)

where, for abbreviation,

$q=\frac{1}{4}e_c(x+x_2)/(x_1-x_2).$ (54)

Equation (53) represents the solution of this quadratic; the positive sign only is retained before the radical sign, because e_1 is essentially positive.

If the terms with r were retained in equations (32) and (34), then by a similar process an equation of the fourth degree would be arrived at. In this equation of fourth degree the terms with e_1^3 and e_1^4 are small as compared with the other terms. Therefore, as a first approximation, these terms can be neglected and the resulting quadratic equation solved for e_1. Let e_1' be this solution, and let $e_1 = e_1' + \epsilon'$ be the correct solution of the equation of the fourth degree; ϵ' is a small correction. Substitute $e_1' + \epsilon'$ in the equation of fourth degree for e_1, and consider the correction ϵ' to be the unknown quantity. Neglect the third and the fourth powers of ϵ' and calculate ϵ' from the quadratic equation. In so doing the terms with the higher powers of e_1' must not be neglected any longer because e_1' is now a known quantity.

If ϵ' comes out small the corrected value $e_1 = e_1' + \epsilon'$ can be assumed to be final. Otherwise, the corrected value of $e_1'' = e_1' + \epsilon'$ is considered as the second approximation, the correct value being $e_1 = e_1'' + \epsilon''$, where ϵ'' is a new small correction. Substituting $e_1'' + \epsilon''$ for e_1 into the given equation of fourth degree and solving it as a quadratic for ϵ'', a third approximation is obtained for e_1. The process may be repeated any number of times, but for all practical purposes the third approximation ought to be sufficiently accurate.

THE APPRENTICESHIP SYSTEM OR THE SHOP TRAINING OF THE BOY*

By A. L. Rohrer

Benjamin Franklin is always referred to as being the foremost citizen of his time. He was a printer, a writer, a scientist, a philosopher, a patriot and a diplomat. The facts about Franklin as a printer are simple and plain, but impressive. His father selected the printer's trade for him after giving him the opportunity of seeing members of several different trades at their work. He was twelve years old when the indenture was signed; by the time he was seventeen, he had mastered the trade in all its branches so well that he could venture, with very little money in his pocket, first into New York and then into Philadelphia, where, without a friend or acquaintance, he promptly succeeded in earning his living.

When he was a little more than eighteen years old, he was sent to London to purchase a complete printing outfit. Here he was thrown on his own resources by the faithless man who had sent him on the errand; yet he was able to support himself by his trade in that great city, where in a short time he was promoted to the most famous printing house in London.

The decline of the old type of apprenticeship system has been under discussion for years, and the general cause for its decline was given as due to the introduction of the modern factory, or as it is sometimes called, "the aggregated system of labor and the subdivision of labor." A few firms were far-sighted enough to give serious attention to the subject, and revived in a systematic way the shop training of boys for the trades. Gradually other firms followed their lead, met many difficulties and overcame some of them. The principal problem was to get the boys who were really interested in the trade—they were very scarce.

I think it was just as well that this old apprenticeship system did decline, for under it the boy had to "pick it up." The men who had served their time in this same way took no special interest in the education of the boys, further than sending them on errands for left-hand monkey wrenches, right-hand squares, flimflam molds, etc.; a sort of schooling that is even now not out of date, for rather recently an apprentice in our shops was sent with an order for one smoke-stack for a mining locomotive. Under this old system, once in a while a lucky boy would attract the attention of a studious mechanic, who would answer the boy's questions by explaining to him how the weight of certain castings could be obtained, how steam was admitted to the cylinder of a steam engine, and many other daily problems. Many successful men of to-day got their start in just this way, and it is splendid to hear them speak with a feeling of veneration for the men who thus assisted them.

So far as we know, the first man to discover the weakness of this old system was Mr. Robert Hoe, founder of the firm of R. Hoe and Co., manufacturers of printing presses. This firm had apprentices back in the 'forties, but found later that the constantly increasing demand for improved machinery made it necessary to have a more intelligent class of workmen, especially in the construction department. So some forty years ago they established a school or a classroom, where boys could acquire a knowledge of such things as would enable them better to understand the work in which they were engaged. For a while this class-room work was located in an unused loft of an old

* Abstracted from a lecture delivered before the Society of Engineers of Eastern New York. The substance of the lecture has been specially re-written by the author for the REVIEW.

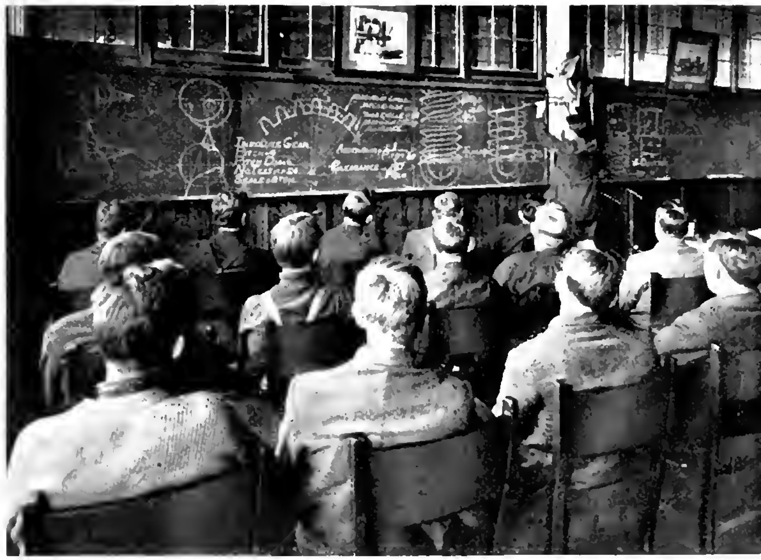
building, and later was changed to night classes. Shop work stopped at six p.m., the boys were given a light lunch (coffee and sandwiches), and then reported at the class-room at 6:30. The principal instruction at first was mechanical drawing; fifteen or twenty years ago other branches were added.

Now I may refer, somewhat in detail, to what has been done at the Schenectady Works of the General Electric Company in training apprentices. In common with many manufacturers, the systematic training of boys was frequently discussed ten or twelve years ago. At that time there were a few boys who had the friendly interest of some of the foremen, and had been placed in the shops and given a variety of work on the bench and on machine tools; and those that were apt did secure a sort of practical training and became fairly good mechanics, more from watching and imitating than from any real instruction. This sort of training does not get very far into the reason for doing work by certain processes. A wolf learns the habits of its tribe by watching and running with the pack, and the child of the savage learns the arts of the tribe by watching and imitating the building of fires and the making of weapons.

After much discussion it was decided to inaugurate a systematic training for boys who had been under observation for a time, to ascertain if they were really interested in learning a trade. This work was started in 1901 and an experienced man was employed to look after the boys and transfer them periodically from one class of work to another, or from one shop to another, so that they might get experience on all kinds of work in the shops. At first the trade of the machinist had our attention, then drafting room apprentices, molders, patternmakers, blacksmiths and tinsmiths followed in their order, so that we now have a total of 374 classified as to trade and year of apprenticeship. (See table.)

There is no great demand for tinsmiths in our works, which is also the case with the blacksmiths, and we also find that neither of these trades appeals strongly to the boys.

We soon discovered that the boys needed something in addition to their work in the shops. Many of them could not follow or understand the ordinary shop computations, and we decided to introduce classroom instruction. Our first attempt was with the night school, and we received permission in the fall of 1904 from the Board of Education to use the Union Street School. A corps of teachers was selected, some of them being employees of the General Electric Company who had had previous experience in teaching; the others were teachers in the city day schools. Eight classes were organized, four in English and four in arithmetic, with a total registration of 162 boys.



Shop Apprentices in Class of Mechanical Drafting, Schenectady Works

	First Year	Second Year	Third Year	Fourth Year	Total
Machinists	93	45	20	42	200
Draftsmen	42	34	12	16	104
Molders and Coremakers	5	8	15	6	34
Patternmakers	21	6	3	3	33
Blacksmiths	1				1
Tinsmiths			2		2
Total	162	93	52	67	374

The only subjects we attempted to cover were arithmetic and English; the drafting apprentices were at that time doing their classroom work during the day. The sessions were held two nights per week, Tuesday being devoted to English and Thursday to arithmetic.

regular classes for our drafting apprentices were held in a small room which was partitioned off from the space occupied by the drafting room.

Training Room for Patternmaker Apprentices, Schenectady Works

Among our other problems we found that the foremen were not especially pleased to have new boys who had no knowledge of tools nor of any of the ordinary operations at the bench, sent to their departments; they would always ask for, and insist on having, boys who had spent some time in other departments, and we experienced great trouble in placing the new boys—we had really to force them into the shops. We solved this problem by establishing a small training department with a tool equipment for a dozen boys, and a sufficient amount of repair work and production work was brought in from the other departments to give them some training in machine tool operations; so that a few months spent here was a fair training, and they had some idea of what a machine tool was, and how the work should be handled on any of the tools which made up the equipment. This was a decided advance in our system of training; and soon after this, when it was decided to add several floors to one of our buildings, one of these floors was reserved for an extended training department and classrooms. This was occupied in March, 1908.

We met many problems. The most difficult and perplexing one was the absentees; but on the whole we were well pleased with the results, and had the pleasure at the close of the winter of commending a number of the boys for the progress they had made, as shown by the results of the written examinations. There were a number of boys who did not miss a session.

All of us who were interested in the apprenticeship system gave this classroom work our personal attention, and as a result we knew the boys better, especially those who showed real mental ability. It gave them the opportunity to call themselves to our attention. We also noticed the tendency towards better progress in their shop work; they appeared to take more interest in the machine tools and the reasons for carrying on certain operations.

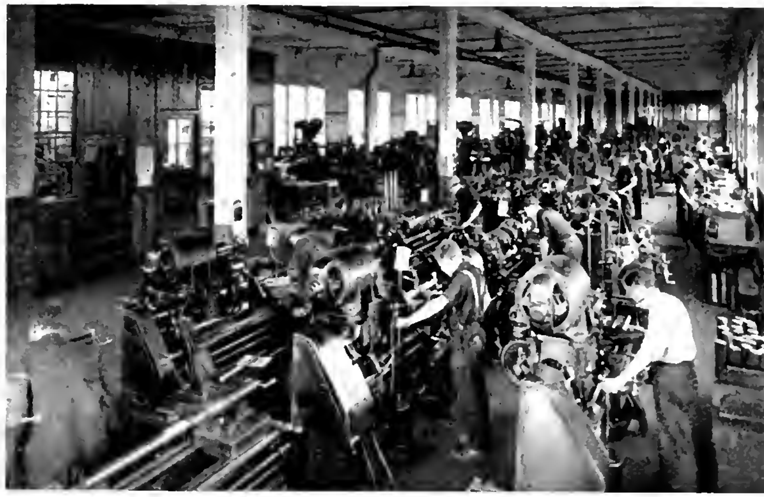
I am sorry to say that we were forced to abandon this classroom work temporarily. The night schools operated by the Board of Education were so successful that more buildings had to be used and they could not spare the building that we occupied. We surveyed the buildings of our own plant and found that no suitable space could be spared for this purpose. In the meantime,

The total floor space is 50 x 250 ft. (12,500 sq. ft.), with three classrooms each 20 x 40 ft., (page 435). We have a capacity in this room for 75 boys, and a large percentage of their work is production. The boys work under the guidance of two experienced machinists, who instruct them in all the details of machine tool operations, as well as bench work. A small forge is a part of the equipment, so that some bending and rough forging work can be done. All boys spend their period of probation under close observation in this department, and after they are accepted spend six months here before they are sent to the other departments of the works, where they settle down for their real training, because they are thrown directly in contact with all problems of production, so far as machine tool operations are concerned. Regular transfers from one department to another are made, so as to give them a wide experience. The output of this department is subjected to the same rigid inspection as is found in our other departments, and I am of the opinion that our inspectors are more vigilant in looking over the output than is the case in the shops. Every piece is held up strictly to gauge and to our standards of finish, etc.

We require that every boy who applies must have a definite idea as to the trade he wishes to take up. He must come with some sort of a recommendation, able to read and write English and pass an examination in common and decimal fractions, and denominate numbers. The drafting apprentices are required to pass in square and cube root, mensuration and metric system; and their classroom work includes instruction in algebra, plane, solid and descriptive geometry, trigonometry, mechanics, and strength of materials. This last subject takes them into our testing laboratory for some work on the testing machines. After a year is spent on work at the board, they go to the shops for a year or more, and work under the same methods and conditions as do the shop apprentices.

The classroom work for the shop apprentices includes considerable instruction in reviewing the arithmetic of their grade school work; and I am sorry to say that we have spent a great deal of time in doing the work of the grade schools. At least fifty per cent. of one teacher's time is devoted to such part of arithmetic that should be done in the seventh and eighth grades.

All instruction is made as practical as possible and problems are used which apply to shop work. Mechanical drawing and the reading of blue prints are very important features, and much time is devoted to them in the classroom. The apprentices are required to do a certain specified amount of home work, in the making of finished drawings and in study, which, with their three hours per week in the classrooms gives each boy at least six hours or more each week in the training of his mind. Fifty-two hours in the shops per week for the training of his hands make up his entire work for each week. Some attention is paid to English and occasionally each boy is asked to describe some thing or some operation; a favorite topic is, "Describe a half day's work in the shop." Classroom work begins each year on the Tuesday following Labor Day and continues until the first week in August, when the examinations are held. When both shop and drafting apprentices are advanced to their third year, they enter a special class for practical instruction in mill-gearing, hoisting, and elementary mechanics, and one of the classrooms has been equipped with appliances for demonstration.



Training Room for Apprentice Machinists, Schenectady Works

The following is the machine tool equipment of the Training Department:

Lathes	32
Shapers	5
Milling machines	10
Boring mills	3
Drill presses	14
Planers	2
Slotters	1
Grinders	5
Chucking machines	1
Hack saws	2
Centering machines	1
Total	76

The success of the training room work for machinists' apprentices led us to adopt a similar plan for the training of the pattern-makers, and a space of 2300 sq. ft. in the pattern shop was set apart for this work and equipped with the necessary benches and tools. An expert patternmaker was selected to train the boys, and started the work in the spring of 1910. It was a decided success from the start, and boys after only three or four months in their first year have produced patterns that would do credit to a journeyman. Of course, they were comparatively simple patterns.

Up to Jan. 1st the number of boys who satisfactorily completed their time and received the bonus of one hundred dollars is shown by the following list:

Machinists	344
Draftsmen	74
Molders	59
Coremakers	8
Patternmakers	20
Blacksmiths	6
Total	511

Nearly four hundred of these are in our employ today; so that we have made for ourselves a large number of good mechanics, and a half-dozen or more have succeeded so well that they have been appointed assistant foremen. One of these showed that he possessed considerable executive ability even before he finished his third year, and about six months in advance of his completing his time he was booked for the position he now occupies.

Now all this, no doubt, seems very interesting, and the conclusion that we have solved the problem of training the boy for a life of usefulness may be drawn. We engineers are always glad and willing to recount in detail our successful experiences; we should be just as willing to mention our failures, or give the reasons why we have not always been successful in working out our plans. Our greatest difficulty is to find or attract the boy—I mean the boy with an aptitude and a real liking for the trade, and the proper training in his elementary school work. We require a knowledge of common and decimal fractions, and any boy who has had the seventh or eighth grade work in the public schools should be able to satisfy our standard in these subjects. We aim to be practical in our test questions and ask to have certain decimals expressed in words, to change common fractions to decimals; then we follow with certain simple problems, in order to get some idea of the boy's capacity to analyze commonplace things.

Our records for the past twenty months are very complete, and I find that during that period we received 413 real applications from candidates who showed an interest by trying the examination. Of that number 125, or 35 per cent., failed to pass, leaving 288 as eligible to serve the probation period. Of this number 71 were dropped for the following reasons:

No aptitude for the trade	23
Failed in class work and drawings	16
Left giving no reason	12
Discharged for misconduct	12
Ill health	8

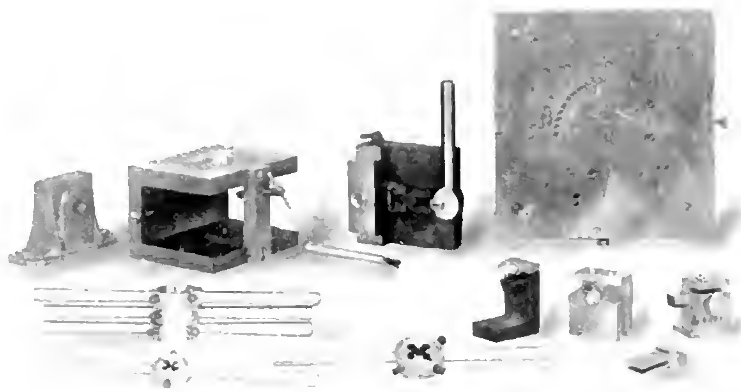
It will be noted that 35 per cent. of the applicants failed because of their lack of training in the elementary schools, and only 5 per cent. because of not being fitted for the trade. We have not the information which will tell us from what grades these failures have come; but as a rule we find that about 50 per cent. of the seventh grade boys pass, and about 80 per cent. or 90 per cent. of the eighth grade boys pass; while very few sixth grade boys are able to satisfy us in either their examination or their work—perhaps one in twenty-five. This is not surprising, because they have all been out of school for two years, working maybe in a grocery or livery stable before they apply to us.

Patterns and Core Boxes for Commutator Turning Tools and Armature Flange, Made by Patternmaker Apprentices Six Months on Course. Training Room, Schenectady Works

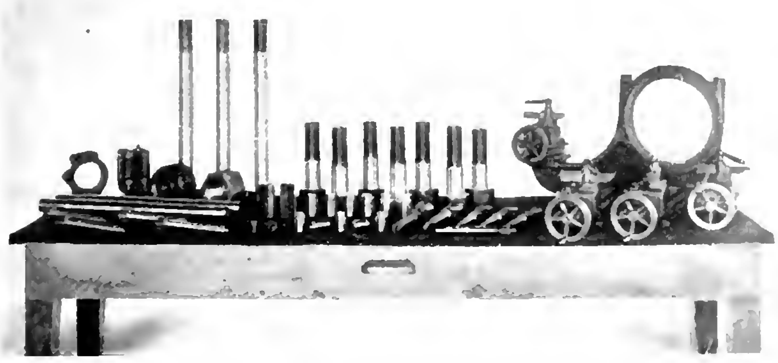
Our next great difficulty is to find the boy with the right kind of a father. Perhaps, if I may be allowed to recite several experiences, my meaning will be clear.

A boy of sixteen, large for his age, was accepted by us; his father, who is a fair mechanic, signed the agreement, and the boy made satisfactory progress the first year. During his second year he had to be looked after, both in his classroom work and his general behavior in the shops, and he became defiant, especially towards his boss in the shop. After repeated heart-to-heart talks, with no improvement, the cancellation of his agreement was taken up with his father; and in the interview, at which both father and son were present, the boy was more defiant than ever. Strange to say, the father upheld the son, and stated that he did not see any benefit to be derived from the classroom work and could not see why we insisted on it. The agreement was cancelled. As the boy weighs nearly two hundred pounds, we shall probably see him on our streets, swinging a club and wearing the garb of a policeman.

A boy of seventeen, who had attended the high school for two years in a neighboring city, applied for a position and was accepted as a drafting room apprentice. His father, who is an official of a publishing firm that runs a daily paper, and therefore ought to be rated above the average citizen in intelligence, signed the agreement. The boy at first was interested in his work at the board, and appeared to be anxious about his classroom work. Later he showed signs of lag, and had to be disciplined for misconduct. He lost time, pleading illness. Finally after several weeks' absence his father was notified and he replied by letter: "the circumstances at present are such that I do not think he can very well return. Owing to financial reasons, it is necessary that he should earn more money than he can with the General Electric Company." The father evidently had no interest in the boy's work or progress, for he made no inquiry.



Drilling Jigs Designed and Made by First Year Apprentices. Die Holders Made by Four Months Apprentice. Training Room, Schenectady Works



Axle Collar, Cable Guides, Bolts, Commutator Turning Tools, Worms, Milling Cutters, Counter Boxes, Motor Shaft. Made by Apprentices Three to Nine Months on Course. Training Room, Schenectady Works

Another case may be cited where a bright boy in his second year, whose shop work was good and whose classroom work was satisfactory except that he had to be followed up on his drawings, suddenly took the notion of leaving without notice. After his continued absence was noticed, his father, who is an intelligent man with a good trade living in a nearby town, was notified. I quote from his letter. "I did not know that he was going to leave. I do not think he would have left if he had received just treatment at your hands; he certainly has been more sinned against than sinning. He has taken this step of his own accord and I shall not try to have him go back."

I regret to say that it is the American father who gives us trouble. In many cases he does not interest himself in what we are trying to do for his boy, and we hear the story from him over and over again, "I am a good mechanic earning good money. I got my trade without this school business and making drawings, and I don't see why you insist on my boy doing it." These discouraging words said in our presence and no doubt repeated at home while the boy is attempting to do his home work which we require, impede our progress. The foreigner, whose son usually makes good, is our strong ally. He is ambitious to have his boy occupy a better position than he; and it is a very rare case when we have to take up any matter with him. Every Polish boy on the course—and we have a number of them—is ahead on his work. The Italian boy is not so satisfactory, but he seldom needs following up on his home work.

I am a firm believer in all kinds of industrial schools, all kinds of trade schools by whatever definition you may know them, all kinds of continuation schools, half-time schools or any other fractional-time schools, or even manual training schools; because I believe that in them all and through them all the boy will be trained up to the right attitude towards shop work. The right boy will be trained away from the grocery store, the drug store, the livery stable and the clerical position; and he will come to the apprenticeship system from the elementary school better prepared, so that instead of 35 per cent of those who apply being turned away, less than 5 per cent. will fail to pass according to our standards.

The General Electric Company is doing only a small share of this work of training the boy; it did do some pioneer work which may have been of assistance to others. The steam railroads are doing good work, notably the New York Central lines and the Santa Fe system. The United Shoe Machinery Company and the authorities of the city of Beverly, Mass., jointly maintain a trade school for machinists and 70 boys are receiving instruction. A separate training department like ours is maintained with a capacity of 35 boys, and the two groups alternate between the shop and the Beverly high school, where a good equipment of laboratories and tools are located. The company furnishes all materials, and purchases at established prices all machine parts made by the boys principally in the training department.

In Fitchburg a similar plan has been worked out by an association of the manufacturers of the city and the school authorities. In St. Louis, Mr. David Rankin, Jr., gave three million dollars for the establishing of a school for the mechanical trades, as he puts it, "for the purpose of giving the poor boy a chance to be a useful citizen." This extraordinary man lived like a recluse in a humble flat over a grocery store, and denied himself some of the comforts of life to carry out this idea. Unfortunately he did not live to see his ideas carried out, for he died a few months ago.

A wealthy manufacturer of Boston, who made the bulk of his fortune in manufacturing the marble-topped furniture which was the rage some years ago, died a few months ago, and left his fortune for a similar school. The general plan of this school was outlined to me a short time ago by the gentleman selected to arrange and supervise the work.

These are samples of what is being done all over the United States by corporations, by school authorities, by private individuals. Truly, the boy and the girl—because they are getting a share of this work—are being looked after and the result is inevitable. The boy of the near future will not be so much of a problem for us. How about the father, especially the American father? Where and how is he to be educated?

THE DIARY OF A TEST MAN

[CONTRIBUTED]

V. EXPERIMENTAL METHOD OF SYNCHRONIZING

The following description relates to a method for synchronizing two alternating current generators which was tried out recently in a small power station with disastrous consequences.

Some readers of this story may have noticed the following curious condition in any power house which is illuminated by alternating current arc lamps supplied from some generator running in the station. When a second alternator is run up to a speed a little below the speed of the alternator supplying the arc lamps, if attention is concentrated upon one point on the field when it is rotating, say, in a clockwise direction, then there actually appears to be a very slow rotation of the field in the opposite direction. At synchronous speed, this slow motion appears to cease, and at speeds above synchronous speeds, the rotating field appears to be revolving in the opposite direction to that first noticed, i.e., clockwise.

The explanation of this is as follows: Consider a point P on the inside periphery of the stator, and assume a frequency of the busbars of, say, 50 cycles. If the light from one of the arc lamps is shining so as to illuminate P, such illumination consists actually of a succession of flashes, 2 per cycle. There will thus be one flash in every one-hundredth part of a second. Now the number of poles of the rotating element passing point P in one second, will be equal to twice the frequency of the incoming generator. Thus, at synchronous speed one pole will pass P in every one hundredth of a second. We may consider the point P to have such a position that at synchronous speed, it will, at any instant, be exactly opposite a pole, and that at another instant, one-hundredth of a second later, it will be opposite the next pole and so on. If the incoming generator is running at exactly synchronous speed (the speed of the generator supplying the lamp), then at every flash of the lamp there will be a pole exactly opposite P. If the frequency of the incoming generator is less than the frequency of the busbars supplying the lamps, at every flash a pole will be illuminated at a position on the periphery just a little behind point P; at the next flash the pole will be still a little farther behind P, and so on; and since this is happening 100 times a second, a continuous effect is produced which results in the appearance of this slow rotating movement.

If the frequency of the incoming machine is above that of the lamps, then each pole in the interval between flashes will travel a greater distance than one pole arc, and thus give the effect of a rotation in a forward direction.

In the present case, up to the time at which the incident occurred, all the load of the plant had been handled by one alternator, but subsequent increase in the demand required a further machine, which was accordingly supplied. A synchroscope was included in the switchboard equipment, but for some reason or other this had not been connected in at the time of the first start-up of the second alternator, and some other means of getting the machines in phase was necessary. The attendant had not had an extensive technical training, but was of an observant turn of mind and had noticed the phenomenon which I have described above. The question he asked himself was, "When this apparent slow rotation ceases and the field appears to become still, does not this mean that the machines are in phase?" He thought it did, acted accordingly, and switched the second generator on to the busbars. As a matter of fact, the incoming machine was indeed rotating at the same speed as the first generator, but their voltage waves were considerably out of phase. It is not known exactly how great the phase displacement was, but it may have been anything up to 180 degrees. The two machines were therefore short-circuited upon one another, and the excessive load thus placed upon them pulled in the end windings and resulted in considerable damage to both stators. In other conditions both of the machines might have been entirely wrecked.

The point of this story is, that, though the cessation of the slow rotating motion described above means that the machines are running at the same speed, it does not mean that their voltages are necessarily in phase, and indeed the chance of their being in phase is an extremely remote one. 180 degrees difference would represent the worst possible condition, and any of the intermediate positions between 0 and 180 degrees might by chance be encountered. Questions are sometimes asked as to whether this method may be used for synchronizing alternators, and in the light of this occurrence, the answer should obviously be a decided negative.

It should also be mentioned that the trouble cannot be attributable to incorrect polarity of the incoming alternator, as the phase rotation had been checked up before an attempt to parallel the two machines was made. LYNN

VI. TESTING LARGE FREQUENCY-CHANGER SETS

The testing department of the General Electric Company has recently tested three large frequency-changer sets under full load and overload conditions, to determine their heating, excitation and efficiency. Each set consisted of a quarter-phase generator (AQB 20-1250-375-5400 volts), direct-connected to a three-phase synchronous motor (ATI 8-1080-375-6600 volts), with a direct-connected exciter (MP 6-60-375) which was also used for starting and bringing the set up to synchronism. The sets were designed to meet certain guarantees as to heating and excitation of the generators, and efficiency of the complete sets, and tests were made under load conditions to determine the ability of the machines satisfactorily to meet these guarantees. All guarantees were based on 80 per cent. power factor load on the generators.

The actual loading of a large machine on water rheostats entails a considerable expense, since all the power generated is lost, while often it is impossible to secure enough power to test the machine at full load by this method. To obviate this loss and overcome the lack of power, the "pumping back" method is used when possible, especially in the case of large motor-generator sets. This was the method employed in testing these frequency changer sets. In this test two sets of the same rating were used, and the total machine losses of both sets were supplied electrically from an external three-phase source, Fig. 1.

In testing two similar motor-generator sets, each set consisting of a synchronous motor or an induction motor and a direct current generator, the alternating current and direct current ends of the respective sets are connected together, one set being run normally and the other inverted. The two sets are started, one at a time, from the alternating current machines, and the direct current machines paralleled by means of a voltmeter across the main line switch. The direct current motor field is weakened, which decreases the counter e.m.f. of the motor by a sufficient amount to allow the required load current to flow in the direct current circuit. It will thus be seen that by weakening or strengthening the fields of one of the direct current machines of one of the sets, load may be put on the two sets. But this is not the case where both machines of the two sets are alternating current machines. The method of loading two sets of this kind, "pumping back," is known as "shifting the phases," and the "cut and try" operation must be resorted to in order to obtain the desired armature current and load on the sets.

The two sets are first brought up to normal speed and the synchronous motors phased in on the loss supply alternator. Then the oil switch is closed between the two quarter-phase generators, the fields of which are then excited and adjusted to give the required

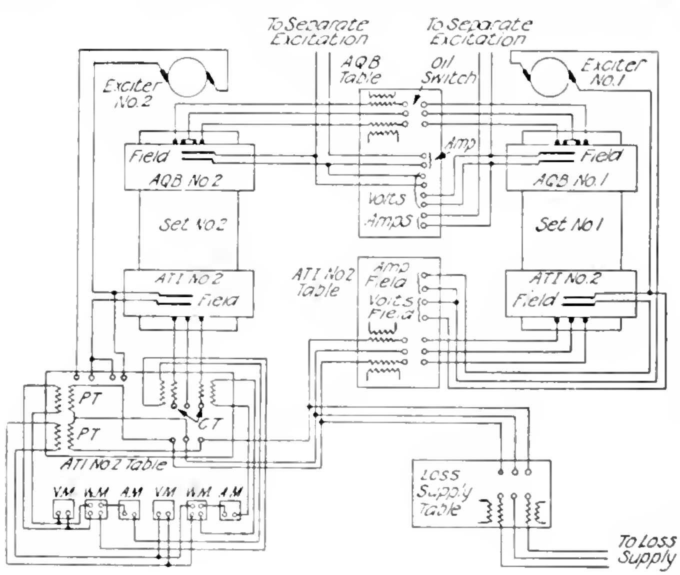


Fig. 1

power factor. One quarter-phase machine now acts as a generator feeding back on the other as a motor. Readings of the load were now taken and found to be considerably less than one-half load with stators set in central position. Then the field of the quarter-phase generator was reversed, or what is known in the test as "slipping a pole," making a phase displacement of 180°, and readings were again taken showing a value nearer normal load. Then with this connection which gives the nearest value of load required, a further adjustment was made by rotating the stators of the three-phase machines. It was also noticed that change of load might be obtained on the quarter-phase generator by changing the field excitation on the three-phase machines; and as the heating test was made on the generator only, the adjustment was made so as to give normal load with the current lagging on the ATI's and with the same setting of stators and polarity of fields. 150 per cent. load was obtained by strengthening the fields of both ATI's, at the same time causing a leading current to flow instead of lagging. Thus it was possible to put on the overload heat run after normal load temperatures had been reached, without shutting down to shift the stators.

Efficiency tests were made by the input-output method. The total losses were also measured as a check on the difference of the input and output of the two sets. Readings of amperes and volts were taken of two phases on each machine, as well as on the loss supply, and the three-phase power was read by the two-wattmeter method. These efficiency tests necessitated a close approximation to unity power factor conditions on the loss supply, as at low power factors the meter transformer ratios become inaccurate for wattmeter readings. Thus it was necessary to obtain a very accurate setting of the ATI armatures for each of the required loads.

A great deal of care is necessary to obtain reliable readings on input-output tests. Ten complete sets of readings were taken for each of the different loads. The input or output of each of the four machines was read, as well as the loss supply input of both sets. This necessitated reading 32 meters, all to be read at the same instant; and 16 men were required to perform the test, as each man could read but two meters. The illustration on page 394 shows the machines under test and the men reading the meters at two of the tables.

H. B. BRODERSON.

VII. POLYPHASE INDUCTION MOTOR WITH SINGLE-PHASE SHORT-CIRCUITED ROTOR

A description of the following incident, with the accompanying theoretical explanation, may prove of interest to operating engineers. The matter relates to an excitation test which we were taking on a three-phase induction motor a short time ago. The machine had been run up to speed, the collector rings had been short-circuited and the brushes raised from the rings, when it was discovered that the ammeter needle was swinging with a perfectly regular period of oscillation, in a manner quite different from any which we had noticed in previous tests on other machines. Attention was directed towards locating the reason for this oscillation, but without success. The motor was a new experimental machine, and owing to the fact that we were ignorant of the exact respects in which a departure was made from standard design, an excellent opportunity was presented for allowing our imagination free play in assigning a cause for the trouble, though it is needless to say that most of these were very wide of the mark.

Relief finally came from one of the older hands who happened to pass by our table. It only took him an instant to have the brushes back on the collector rings, and the latter properly short-circuited by the last steps of the starting resistance. The ammeter immediately stopped its swinging; and after the machine was shut down we discovered that the device for short-circuiting the brushes had not been properly installed and was actually short-circuiting only two of the rings. The motor was thus operating with a single-phase short-circuited rotor. The foregoing may not appear of much interest, but the theoretical explanation of what was going on will probably provide justification for mentioning our experience.

In the polyphase induction motor with single-phase rotor, the secondary conductors will cut across the field rotating in the primary, and an alternating e.m.f. will be induced in them, the frequency of which equals the frequency of the line multiplied by the slip of the motor. In other words

$$f_2 = \frac{n_1 - n_2}{n_1} f_1$$

where f_1 = frequency of primary current
f_2 = frequency of secondary current
n_1 = synchronous speed
and n_2 = speed of motor

We know that from the alternating current flowing in the primary of a single-phase induction motor two rotating fields result, rotating in opposite directions with the same speed which a polyphase motor would have with the same number of poles and the same frequency. In the single-phase rotor of a polyphase induction motor also two rotating fields will exist. One of these fields rotates in the same direction as the stator field, revolving in space with a speed equal to $n_2+n_1-n_2=n_1$, and provides the torque just as in the case of an induction motor with polyphase rotor. The other field, travelling in the opposite direction in the rotor, revolves in space with a speed equal to

$$n_2-(n_1-n_2)=2n_2-n_1,$$

and hence this field induces a current in the stator having a frequency f_3

$$=\frac{2n_2-n_1}{n_1}f_1$$

$$=\frac{n_1+2n_2-2n_1}{n_1}f_1$$

$$=f_1-2f_2$$

The torque resulting from this field counteracts the former, the operation corresponding to driving the polyphase induction motor against its field, in which case it acts as a brake. This torque, however, is small so long as the motor runs somewhere near synchronous speed. If the slip, however, is considerable, e.g., suppose n_2 should equal $\frac{n_1}{2}$, then

$$f_2=\frac{f_1}{2}$$

$$\text{and } f_3=0$$

In other words, we have arrived at the synchronous speed of the inverse rotor field, in which case the torque is equal to the starting torque due to the inverse field. That this torque is not negligible under such conditions is shown by the fact that a polyphase induction motor with single-phase short-circuited rotor will lock at half synchronous speed when started up from rest, due to the existence of this same torque.

From the above it follows that in the primary of a polyphase induction motor with single-phase rotor, two currents will flow of different frequency, the difference between the two frequencies being equal to twice the frequency of the secondary current. Hence these two currents of different frequency will reach at the same moment their instantaneous maximum and minimum values $2f_2$ times per second, which argument thus provides an explanation for the oscillation of the ammeter needle. The phenomenon is similar to the interference of sounds of slightly different pitch, the beat of the sounds corresponding to the oscillations of the ammeter.

The practical application of this is obvious. In the operation of polyphase induction motors, a defect in the controller or resistance box may open-circuit one of the rotor phases, leaving the machine with a single-phase short-circuited rotor, in which case the motor will be unable to deliver its rated output. Such a condition may be at once detected by watching the ammeter needle. It is advisable then to let the motor run unloaded, under any considerable load the number of oscillations of the needle becomes too great and their amplitude too small to admit of their being observed; just as with sound waves of greatly different pitch, the beat of interference cannot be noticed, although a dissonance is apparent. G. E. R.

VIII. BOOSTING

As testers of the old regime will well remember, one of the inflexible rules of the testing department was that no belt connected booster (separately excited, of course) should be run without the concentrated attention of a tester. This rule was wisely advised, as under usual circumstances should the belt slip off, the booster would race to destruction unless the armature circuit were opened immediately. The reason for this, of course, is that in most cases boosters are employed to add to (or subtract from) the supply voltage a voltage considerably less than the supply voltage, and often less than the rated voltage of the booster; a large current flowing through the armature at the same time.

To illustrate, let us assume that we have a 20 h.p. 550 volt motor to be operated from the 550 volt shop through a 5 h.p. 125 volt booster. The full load current of this motor is 27 amperes, which is a trifle less than the full load current of the booster. The voltage to be generated by the booster (50 volts), however, is only 40 per cent. normal, requiring a very weak field. Suppose now that the booster should become disconnected from its driver; the armature would almost instantly come to a standstill and reverse its direction of rotation, tending to increase in speed until a sufficient counter e.m.f. was induced to reduce the current flowing through its armature to running-light value. Even with normal field, this would necessitate a destructive speed, with the result that the armature would fly to pieces.

I can recall one occasion, however, where the observance of this rule was not necessary.

A direct connected motor blower set arrived from the shops with instructions for a full set of tests, the motor of this set being a 20 h.p., 250 volt machine. The voltages of the shop circuits in reach were 125 and 500. No generator of sufficient capacity to operate the blower was on hand, but a 125 volt, 10 kw. exciter—one of a group, belt driven from a large motor—was available. It was decided to run the blower motor from the 125 volt shop circuit, boosting to 250 volts by means of the exciter. Here the booster armature carried practically normal current and generated normal voltage; consequently the field strength was normal. The supply voltage was equal to the booster voltage, and if the belt had parted or slipped off the pulley, the booster would simply have reversed its direction of rotation and come up to approximately normal speed, generating a counter e.m.f. that would have allowed only the running light current to flow; the motor on the blower, of course, coming to a standstill, since the field of this motor was connected to the armature terminals and because the voltage of the supply and that of the reversed booster would have been practically equal and opposite.

The realization of the above fact resulted in my securing considerable experience on blower work, that otherwise would have been lost; for it fell to my lot, according to custom, to keep watch of the booster, removed some distance from the blower. As it was, I was permitted to take an active part in the blower test. FARMER

THE MOST RECENT DEVELOPMENT IN OIL SWITCH DESIGN

By D. S. Morgan

The motor-operated "H" type of oil switch has for several years been the most successful and the most widely used oil circuit-breaking device for high rupturing capacities that has ever been placed in commercial service. It met with immediate favor and still retains the good reputation it gained upon its initial appearance. Oil switches of this type are installed and operated in every country in which electric power is being developed, and the switch as manufactured to-day is practically of the same design as the original, very slight changes only being necessary to meet special conditions due to the increasing demands of electrical development.

This switch was developed at a time when the kilowatt capacity of generating units was comparatively small, the operating speeds low and the regulation poor. The introduction of the high speed steam turbine for operating large generating units has brought about a demand for switching apparatus of very high rupturing capacity; and because experience has shown that this type of switch is capable of rupturing large amounts of power a new switch of similar design but with greater rupturing capacity has been developed for use in central stations where several large steam turbine generating units are installed. This switch is to be known as the "H-6" switch.

The main contacts of the improved switch are, with slight modification, similar to those used in the previous types, and consist of a movable cylindrical rod which makes contact with the inner surface of four segments of a cylinder, secured in position by helical springs. This arrangement insures heavy and uniform contact pressure, and, besides, auto-

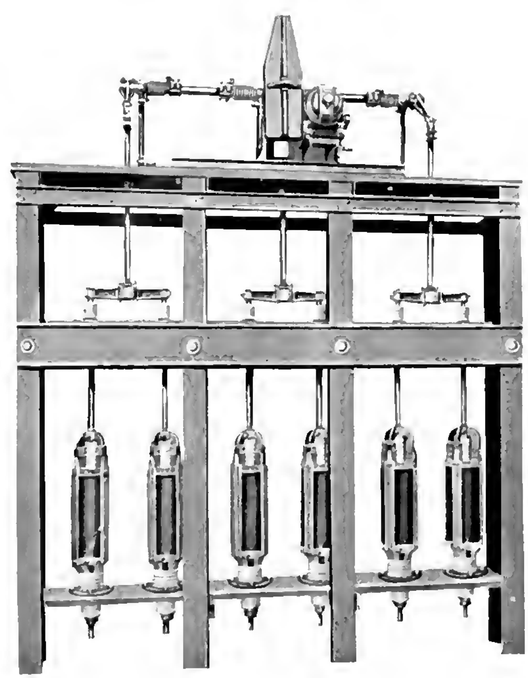


Fig. 1. New High Tension Oil Switch

matically compensates for any wear of the surface of either the stationary contact segments or the cylindrical contact rods. When the arc is ruptured, whatever burning results takes place on the bell-mouth of the stationary contact and the rounded tip at the lower end

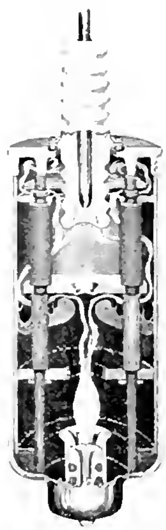


Fig. 2. Section of Switch Showing Baffle Plates

of the movable contact rod, and in no case causes damage to the working contact surfaces. The contacts are self-aligning and easily renewable.

For current capacities above 300 amperes, however, auxiliary contacts are also provided. These are shown in Fig. 1, and serve to carry almost the entire current while the switch is in operation. This is their only office; for in opening the switch, they break contact before the cylindrical rod which opens the circuit and ruptures the consequent arc in oil. The movable auxiliary contacts consist of a double set of contact fingers made of drop-forged copper, fastened to a movable cross-head by flat springs with copper laminations and reinforced springs; the tension of these springs insures good contact but does not retard the opening of the switch. The stationary auxiliary contacts are wedge-shaped copper blades fastened to the top of the oil vessel. This construction of contacts imparts a distinct rubbing movement in opening and closing, and insures perfect contact between the contact surfaces.

The diameter of the oil vessels has been increased from eight to ten inches; which gives a larger volume in the oil vessel. The larger oil vessels have also been made stronger by increasing the thickness of the steel walls.

Another improvement, to increase the rupturing capacity and the reliability of the switch, consists of baffle plates of new design. By these the movement imparted to the oil by the expansion of the gases, formed by the arc when the circuit is opened, is checked and diverted, in such manner as to allow the gases to separate from the oil and escape, while the oil itself drops back in the oil vessel. Fig. 2 is an illustration of the new baffle. The illustration indicates the movement of the oil away from, and towards, the center of the oil vessel on breaking the circuit. The oil looses its velocity before the cover on the top of the oil vessel is reached, and therefore its tendency to be thrown out is reduced.

As in the other types, the new switch is opened and closed by compression springs. The operating motor does not actually throw the switch, but serves merely to compress the springs. The weight of the movable parts of the switch is counterbalanced so that when the switch operates, the force of the springs throws the lever to approximately 1½ in. from the opposite position, after which the motor compresses the springs for the remainder of the distance. The switch closes and opens with equal ease. The operating springs are held in compression by the main operating toggle of the switch, and a dog bearing against a roller-stop, which, when released, allows the switch to operate. The main operating toggle is slightly over center when the switch is at rest, and the pressure of the dog against the roller-stop is merely sufficient to overcome the tendency of the

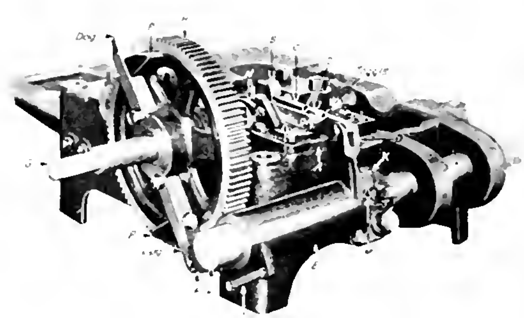


Fig. 3. Locking Mechanism

main toggle to buckle. The means of holding and releasing the dog always insures positive operation of the switch. When the switch is operated, it either closes or opens, as the case may be, in one single stroke and remains in the desired position.

A description of the new locking mechanism is of interest, since it is a vital part in the proper operation of the switch. The operation is as follows (see Fig. 3): When the control switch on the switchboard is closed, current is thrown on the tripping magnet *a*, the plunger is drawn up against the hook *b*, and moves the left-hand end of it to the left and away from the link *c*. This releases *c*, which is mechanically held in a locked position by the hook *b* when the switch is not in the act of operating. The plunger continues to rise, and by its force buckles the toggle and pulls trip lever *d*, and rotates cylinder *e* to the left and stop *f* to the right. This releases the dog allowing the shaft *g* and the gear *h* to revolve, and the switch immediately to operate.

Ordinarily the spring *i* would return the stop *f* to the left, in time to catch the dog before the switch had completed its stroke, but to guard against the possibility of failure in this connection, two cams *n* are placed on the same shaft as the dogs, which, when the switch is operating, press against the toggle links *o*. These are so arranged that the toggle is mechanically pushed back to the locked position before the gear *h* makes one-quarter of a revolution, or the dogs one-half of a stroke. This insures absolutely that the dog will not pass the stop until, by means of the control switch or relay, the current is again switched on the trip magnet *a*, to operate the switch in the opposite direction. As an additional precaution against pumping, a lug on the casting *k*, which is fastened to the shaft *l* and which rocks to the right when the switch operates, throws *m* to the right and the toggle back to the locked position.

The bearing surface on the ends of the dogs are made of hardened steel plate. The dogs can be easily renewed if necessary, and may be adjusted by shims under the plates *p*.

This new mechanism is an important improvement in the switch, and one which absolutely removes the chance of trouble which might occur with the old switches if the toggles were not properly set. Although primarily developed for the new "H-6" switch, this new feature will henceforward be embodied in the design of all switches of the "H" type.

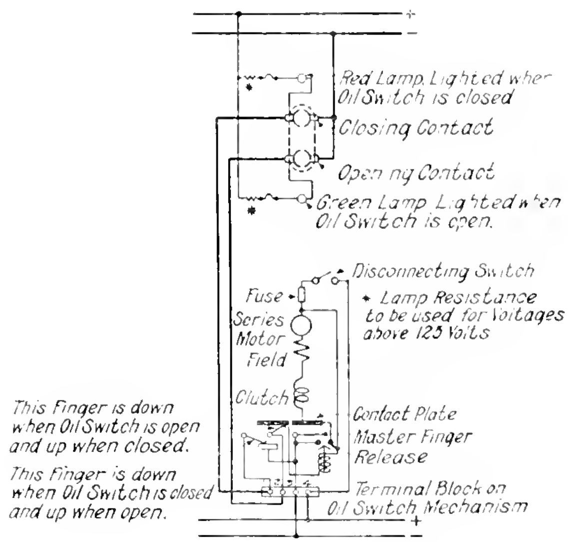


Fig. 4. Diagram of Connections

The switch is built in current capacities up to 4000 amperes and for voltages up to 70,000, and will operate satisfactorily on systems the combined load of which connected to the bus is not greater than 50,000 kilowatts. In many cases, however, it can be recommended for rupturing capacities far in excess of this, depending upon the particular features of the installation. The switch is made in two forms, one in which the poles are made in parallel sets of two, as in previous designs, and the other in which the poles are arranged in tandem. Each of these arrangements has its good points, which are determined by the shape and the extent of available space in which to mount the switch. One point of advantage in the tandem arrangement is that when arranged in a row, the vessels are very accessible. The back walls of oil switch cells are often omitted, however, which makes the parallel arrangement also easy to get at in such cases

NOTES

NATIONAL ONE-CENT LETTER POSTAGE

A large number of the business men of the country have banded themselves together under the name of the National One Cent Letter Postage Association for the purpose of securing a one cent letter rate, a reform which would cut in half the present postage accounts of large manufacturing and mercantile concerns.

Hundreds of business men have joined the association which has its headquarters in Cleveland, Ohio. It is a national movement, however, and Cleveland was chosen as headquarters simply because Charles William Burrows, its President, and George T. McIntosh, its Secretary-Treasurer, are residents of that city. The organization has members in every state in the union and plans an active campaign at the winter session of congress for the reduction of the present rate on all letter postage.

Every year the postoffice department is making a profit of over $60,000,000 on first-class mail matter. A vast deficit results from carrying second class matter at one cent a pound or $20 a ton while letters pay 84 cents per pound or $1680 per ton. The injustice of this is apparent to the business men who are seeking a lower rate.

This year Postmaster-General Hitchcock for the first time in seventeen years declared a surplus for the department. There is now in progress a general readjustment of methods of handling second class matter and it is expected that a saving of millions more will result.

An active, business-like campaign is being conducted by the officers of this association, who have devoted their time to the work for the past six months without compensation. Every concern in the United States is eligible to membership. It means money to them to join and secure this reform. Information and literature may be secured by addressing George T. McIntosh, Secretary-Treasurer National One Cent Letter Postage Association, 506 Chamber of Commerce, Cleveland, Ohio.

GENERAL ELECTRIC TEST

During the months of June and July the following student engineers entered the Testing Department of the General Electric Company.

Baker, G. B., Union College
Barker, J. D., Purdue University
Billingsley, F. N., Rensselaer Polytechnic Institute
Blair, N. D., University of Washington
Bopp, C. D., Purdue University
Brelsford, H. E., University of Michigan
Briggs, A. L., University of Nebraska
Brown, H. A., University of Illinois
Cameron, W. D., Iowa State College
Chapman, C. H., University of Kansas
Cooley, C. H., Iowa State College
Crellin, E. A., Leland Stanford University
Dix, H. W., Cornell University
Fisher, R. B., Tulane University
Gorton, W. S., Johns Hopkins University
Hale, J. C., Columbia University
Hertzog, H. S., Columbia University
Hunter, J. S., Union College
Jackson, R. N., University of Illinois
Johnson, J. R., Leland Stanford University
Kauffman, H. M., Rose Polytechnic Institute
Kegerreis, R., Ohio State University
Knight, R. M., Tufts College
Kornfield, F. H., Rose Polytechnic Institute
Krape, R. D., Pennsylvania State College
Latta, G., Louisiana State College
LeCount, C. M., Leland Stanford University
Leeds, J. H., Leland Stanford University
Lincoln, W. C., Union College
Little, W. P. Tufts College
Mandeville, L. H., Case School of Applied Science
Martin, E. R., Iowa State College
Miles, C. T., Purdue University
Miller, A. D., Pensylvania State College
Mittag, A. H., University of Minnesota
Neagle, R. J., Tufts College
Packard, S. D., University of Utah
Penn, M., Purdue University
Plaissance, S. F., Tulane University
Robinson, L. N., Union College
Rohr, C. A., Cornell University
Rue, Jr., J. R., Pennsylvania State College
Rutherford, R. K., University of Missouri
Spring, H. E., Purdue University
Steiglitz, A. G., Stevens Institute of Technology
Stewart, C. R., Pennsylvania State College
Towers, A. C., Cornell University
Travis, S. V., Union College
Ward, R. V., Throop Polytechnic Institute
Webb, L. W., Pennsylvania State College
Wightman, J. W., University of Colorado
Wooster, R. N., Leland Stanford University

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GENERAL ELECTRIC REVIEW

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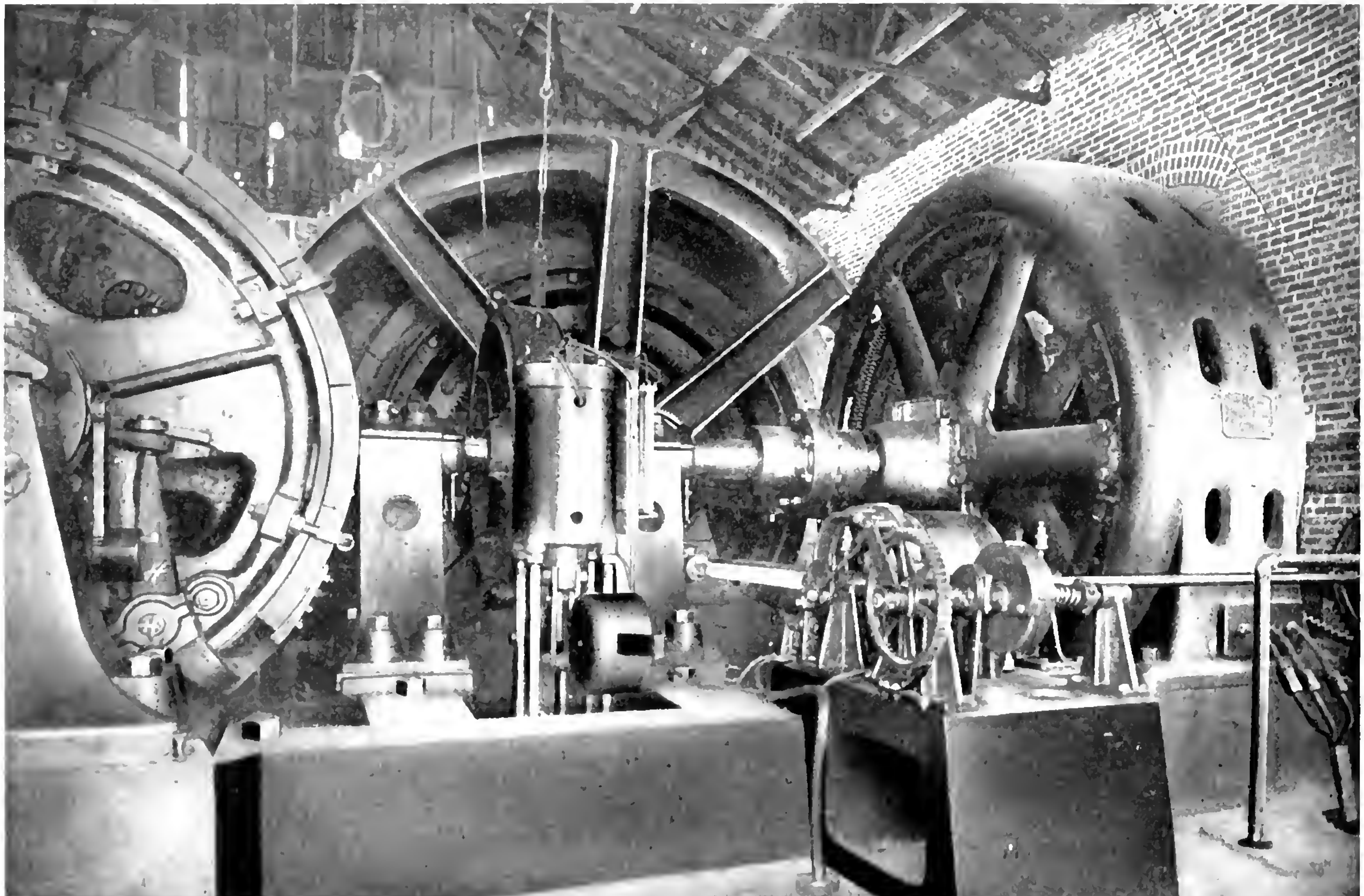

800 H.P., 2200 Volt, Squirrel Cage Induction Motor Geared to Water Hoist
Delaware, Lackawanna and Western Railroad Mining Dept., Hampton, Pa.

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GENERAL ELECTRIC REVIEW

CORONA

The sharp distinction made a number of years ago between "static" electricity and voltaic or dynamic electricity, has gradually disappeared. In the early days, the available electrical apparatus such as "friction" machines, influence machines, cells of battery, or relatively small capacity dynamo-electric generators, furnished on the one hand electrical energy in which the current was too small to be any appreciable factor, and on the other hand, electrical energy at such a comparatively low potential that insulation problems (other than mechanical separation of the conductors) were not serious.

The electrical engineering developments calling for gradual increases of both available energy and distance of transmission have now brought the normal operating potentials up to the point where phenomena, at one time studied only in connection with laboratory or lecture room experiments, are experienced. Difficulties experienced with friction and influence machines led to the use of well rounded metal parts of ample size. Sharp corners and needle points allowed dissipation of the charge in the air, thus preventing the machines working up to their maximum sparking distance. On some of the modern transmission systems the same phenomenon may prevent the economical operation of an expensive power transmission undertaking. If reliable and fairly exact information is not available regarding the energy that will be dissipated through flow of current into the atmosphere — the so-called corona loss — serious consequences may result. Various investigators have contributed valuable information as a result of their investigations in determining the voltage at which corona loss begins for variable conditions, and the amount of energy loss.

Without attempting in any way to belittle the importance of work done by others, perhaps the investigations recently conducted by the General Electric Company on an experimental test line, working up to and somewhat over 200,000 volts, have furnished information of the most immediate and practical application. In addition to description of this line and results of tests reported by Mr. F. W. Peek, Jr. recently to the American Institute of Electrical Engineers (Chicago Convention, 1911), we are publishing in this issue a further contribution from him, on the same subject which it would be well to consider in conjunction with his previous paper.

Mr. Peek explains the general conditions of stress about conductors under voltage and gives a formula for calculating the loss in kilowatts for any probable transmission line, based on this analysis and on the results of observations. This will be found of value to anyone doing preliminary or final engineering work on modern long distance high voltage power transmission. Curves are plotted showing graphically the corona characteristics at various conductor diameters and spacings, and providing a graphical method of determining corona loss. Certain of these curves show the effect of a change in spacing for given standard conductors, while others relate to a change in the size of the conductor for a constant spacing. Two of the sheets give two sets of curves showing the difference between the visual and disruptive critical voltage. An aluminum equivalent curve is also drawn which shows graphically the reduced corona loss obtained by using an aluminum conductor of equivalent resistance to that of copper, due to its larger diameter.

It may be well here to point out that a transmission line of operating voltage sufficiently high to make the consideration of corona losses an important factor, will probably be of such length that various factors entering into the loss formula will vary, and often vary widely at different points on the line. Even where the essential factors vary but slightly, their effect may be to leave the probable corona loss a matter of uncertainty, since once the critical voltage has been passed the energy loss increases so rapidly.

JOHN B. TAYLOR

THE FIXATION OF ATMOSPHERIC NITROGEN

Nitrogen in its free state, as it exists in the air, is an extremely inert gas. Nitrogen in its fixed state, combined with certain other elements, appears to be the most restless and powerful of all the elements, the active partner in an endless variety of compounds of great commercial importance. The problem of the fixation of atmospheric nitrogen is simply that of extracting the free nitrogen from the air, and setting it to combine with one or other of these elements for the formation of some useful compound.

United in this way it is invaluable industrially in a number of ways; in the preparation of various medicines, perfumes and dyes; in the extraction of gold; in the manufacture of gun cotton, gun powder, dynamite and so on; but the source of its greatest value, or rather the fact which renders its use indispensable to human existence, is the fact that we depend for our bread and meat on certain plants and animals, which, in turn, depend for their existence on the nitrogen which they extract from the soil. If this nitrogen which they extract is not replaced, the soil is impoverished and cannot continue to provide the necessary nitrogen in sufficient quantities without some artificial addition. Hence the function of the fertilizer: to give to the soil the nitrogen which it has lost, in larger quantities than would accrue to it from natural sources.

Various forms of fertilizer have been used; natural manure—the supply of which is totally inadequate to provide all that is required; guano, which is by now exhausted; ammonium sulphate produced as a by-product in coke oven plants—an extensive supply but nothing like adequate; Chili saltpetre, the supply of which would be exhausted in 15 or 20 years if it were the only source of fixed nitrogen. Finally nitrogen extracted from the atmosphere and fixed with some other element constituting a source of supply which will, for all practical purposes, be always unlimited.

The article on the fixation of atmospheric nitrogen, which we publish this month, by Dr. M. W. Franklin, is written as much from a commercial as a technical standpoint. Besides outlining the principles upon which the various processes depend, the author advances some tentative figures as to the operating cost of each system, as well as views which have been elsewhere expressed from time to time as to the relative merits of these systems. The industry is not an old one, and it is difficult to make comparisons where accurate data are hard to come by.

More important, however, than the question of cost is the question of the conservation of natural resources. The "direct-air" processes are actually based upon the original discovery of Priestley, who, towards the end of the eighteenth century, discovered that if air in which an electric discharge had taken place was treated with water a solution of nitric acid was formed. The principle today remains the same, and the problem is one of fixing atmospheric nitrogen and oxygen in the form of nitric acid and binding the acid with lime, the actual fertilizer, or "air saltpetre," being produced through combination with lime. The process is therefore quite in keeping with the principles of conservation, since the raw materials will always be available at a low cost.

In the cyanamide process, on the other hand, the nitrogen is obtained from liquid air by fractional distillation and passed over calcium carbide at a temperature of 800 to 1000 deg. C. Apart from any virtues or defects which the resulting fertilizer may possess, the gravest objection to the process is that every ton of fertilizer produced means a further depletion of the earth's coal supply, since the carbide used for fixing the nitrogen is itself a product of coke and lime.

The whole problem is of considerable interest to electrical men since the question of whether a given undertaking may be commercially profitable or not, depends to a very large extent on the rates at which electric power can be supplied, or the cost at which it can be generated.

DECEMBER ARC LAMP ISSUE

We propose to make the December number of the GENERAL ELECTRIC REVIEW a special arc lamp issue. Apart from the monthly installments of the serial articles now running in the REVIEW, the December number will be devoted exclusively to the subject of arc lighting. We shall endeavor to make the number a complete and up-to-date record of all that has been accomplished in this field. Articles of general information and interest will be included; while we shall also publish some description of the latest lamp developments as embodied in the G.E. luminous lamps, flame lamps and intensified arc lamps, as well as practical articles on arc lamp manufacture, testing, installation and maintenance.

ELECTRICITY IN COAL MINES

Part II

By John Liston

Mine Hoists

For haulage in slope mines or in drift or shaft mines where the different levels are connected by slopes of considerable length, the locomotive cannot be used and recourse is had to various forms of rope haulage with permanent hoisting drums located either on the surface or in chambers underground. In particular instances the use of endless chain haul, or conveyor belts or buckets may be advisable. Due to its rotary motion and high torque characteristics, the electric motor affords an ideal method of applying power to hoists. Its use for this purpose has numerous and well defined advantages as compared with steam and air systems, which can be outlined as follows:

The power is uniformly applied throughout the operating cycle, as there is no reciprocating motion and no intervening connecting rods or cranks with their varying torque at different positions, while the power demand is limited to the time during which the hoist is in actual operation. This feature not only minimizes the amount of power consumed, but under special conditions a system of regenerative braking may be employed, so designed that the weight of the descending carrier may be utilized to drive the motor as a generator, and thereby feed back an appreciable amount of current into the distribution system.

The intermittent service involves a necessity for certain precautions in resuming the operation of steam hoists after they have been shut down, which are entirely absent when the electric type is used. If water collects in the cylinder of a steam hoist it must be thoroughly drained before starting the hoist to avoid the danger of blowing out the cylinder head, and in cold weather this is frequently complicated by the formation of ice in both the cylinder and pipe line.

The power losses represented by the drop in voltage in the electric conductors is

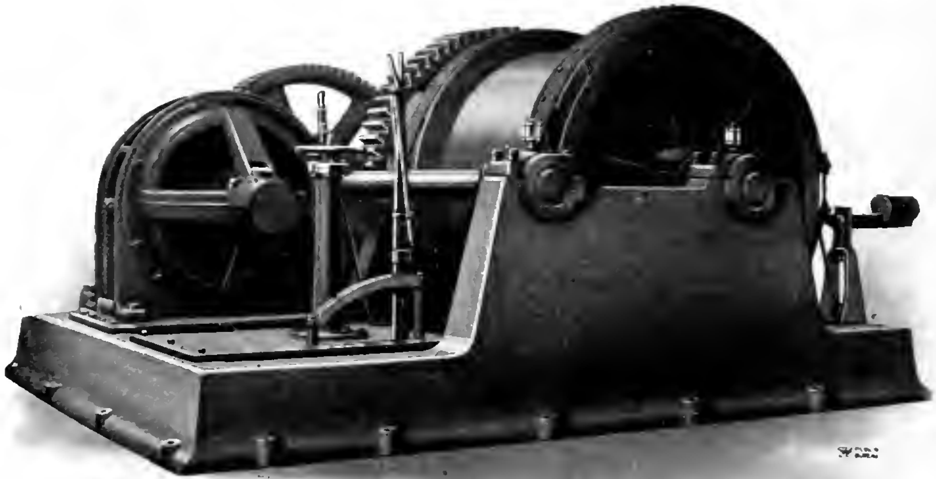
170 H.P. 220 Volt 385 R.P.M. Compound Wound Motor Driving "Trial" Slope Hoist. Contactor and Relay Panel Shown on the Left. Lincoln (Pa.) Colliery, Philadelphia and Reading Coal and Iron Company

practically negligible for the distances usual in coal mine transmission when compared with the condensation losses in steam piping or the pressure losses in air lines over the same distances.

With steam hoists the exhaust steam practically prohibits any extended use underground, while the exhaust from the air-operated type introduces a factor that may have an adverse effect on the mine ventilating system.

The motor-driven hoist is the simplest and most compact form, inasmuch as the motor can usually be mounted on a common base with the hoisting drum and arranged to drive it directly through gears, thereby forming an entirely self-contained unit and effecting an economy in weight and in the amount of space required for its installation which is often of appreciable importance when the hoists are located in the mine. Owing to the superior speed control of the electric type it has greater flexibility in operation and its extreme simplicity not only minimizes the cost of repairs, but obviates the necessity for the service of an engineer in running it, as the average worker is competent to receive the limited amount of instructions necessary and can be safely entrusted with its operation. Emergency demands on the ability of the operator are, as a rule, reduced by providing safety devices in the form of signal lamps, bells, or automatic cutouts; and for conditions such as those imposed by the use of motors for driving the type of water hoist commonly found in the anthracite fields, the hoisting equipment can be made entirely automatic in operation.

While the electric hoist has almost completely superseded other forms for service underground, there are still a considerable number of surface hoists in the older developments driven by steam engines; but their number is constantly diminishing in those mines and collieries where electric service can be obtained, as the manifold advantages of the electric type are becoming more widely appreciated by engineers of the coal mining companies.



175 H.P. Induction Motor Driving 225 H.P. Band Friction Hoist, with Double Band Brakes, The Mexican Coal and Coke Company, Las Esperanzaz, Coah, Mex.

Owing to the wider range of speed control which is obtained in hoists driven by direct current motors, this type is very largely used, but in many of the later installations polyphase induction motors having a resistance connected in the rotor have been applied to this service with entire success, and simple and thoroughly reliable controllers can readily be provided to secure the variations in speed required for coal mine hoisting.

The accompanying illustrations of General Electric motor-driven hoists in actual service indicate the adaptability of both the alternating and direct current motor-driven hoists to the varying demands of coal mine and colliery service.

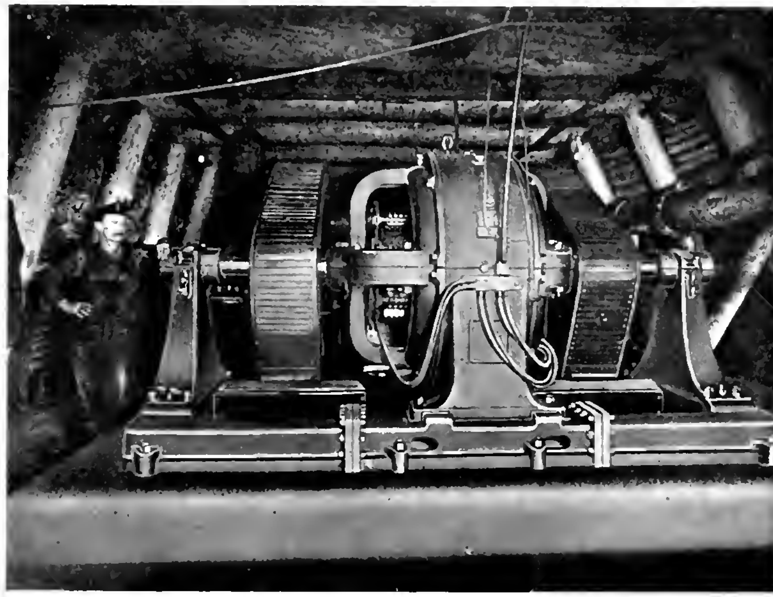
Mine Pumps

The relative importance of the pumping equipment in different coal mines is dependant upon the geological conditions encountered. In many mines the service required constitutes a comparatively negligible demand on the power station, owing to the possession of natural drainage facilities, with a resulting limitation of the pumping units to those required for boiler supply, fire protection, and a few dip pumps operating at low heads.

On the other hand, a large percentage of the mines situated below local water levels are absolutely dependent for continuous operation on the efficacy of their pumps or water hoists, and the cost of their operation has a vital influence on the obtainable margin of profit. The importance of this factor can be fully appreciated when it is realized that in many mines more than ten tons of water have to be elevated to the surface for every ton of coal mined. In addition to this the pumping outfit must ordinarily have sufficient reserve capacity to cope with excessive demands due to floods having their source either on the surface or in water bearing ground which is likely to be encountered in extending the workings.

As in the applications already referred to, the electrical operation of pumps renders possible increased economies and efficiencies otherwise unobtainable, and the benefits derived as compared with either steam or air power service increase in direct proportion to the diversity of the applications and the distances over which the power has to be transmitted.

Two facts have contributed to simplify the problem of the main pumping units in coal mines: First, the recent remarkable improvement in the efficiencies of multi-stage centrifugal pumps, which were formerly only applicable to comparatively low head service, but are now successfully delivering water from sumps located more than one thousand feet below the surface; the best results being obtained when they are driven by motors that are direct connected, thereby avoiding the friction losses of gear drive.



170 H.P. 220 Volt 300-450 R.P.M. Direct Current Motor Driving 10 Inch Quintuplex Pump Through Gears Operating Head 400 Feet. Kohinoor Colliery near Shenandoah, Pa. Philadelphia & Reading Coal & Iron Co.

The high speeds which are characteristic alike of the electric motor and the centrifugal pump render it a simple matter to design a very effective combined unit. Second, the feasibility of providing existing pumps or water hoists, originally designed for steam operation, with motor drive, which at once greatly reduces the amount of power required and the expense of attendance necessary, and can safely be made automatic in operation if desired.

Where motors are geared to reciprocating pumps their use insures the direct application of a larger percentage of the initial power developed than other methods, and many pumping sets of this class are still employed, although the centrifugal type is usually adopted for new installations.

The pumping units of a representative "wet" coal mine can be roughly divided into four classes, i.e., sinking pumps, used in development work, in sumps or for emptying flooded mines; main sump pumps, permanently installed in the mines; auxiliary pumps feeding into a central sump; and portable pumps for temporary service or removing small amounts of water from depressions beyond the reach of the stationary auxiliary pumps, or for fire fighting. There is also a fifth class which, however, is common to all power station service, and includes those units which provide for boiler feed and general water supply.

1000 H.P. 2300 Volt 720 R.P.M. Induction Motor Direct Connected to 5000 G.P.M. Six Stage Centrifugal Pump Operating Against 500 Ft. Head, Located at Hampton Water Shed Sump. D.L. & W.R.R. Co. Mining Dept.

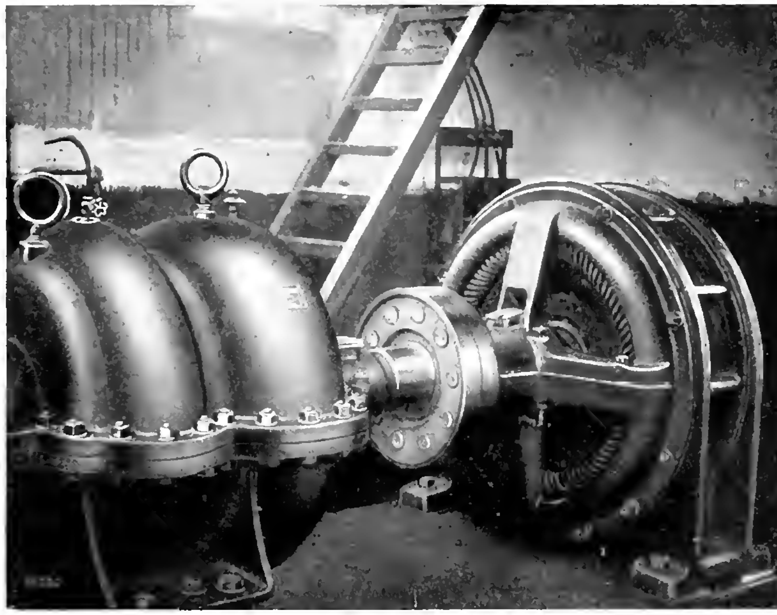
The motor-driven sinking pump must, of necessity, be capable of maintaining good efficiencies under fluctuating heads, and in some distances must be capable of operating when entirely submerged. When used in slopes, it is generally mounted on rails or a car to facilitate the movement necessitated by following the receding water level, but if it is serving a shaft it is either mounted on a float so that it will always operate at the surface of the water, or is supported by chains and cables so as to permit of the necessary adjustment. In all cases the power is supplied by flexible cables of sufficient length to meet all variations of the operating level, and as they occupy but little space they leave the shaft or slope practically free from any encumbrances; further, as provision need only be made for the discharge pipe and the electrical conductors, they can usually be run in one of the hoisting compartments. Induction motors should preferably be used for sinking pumps, especially if they are liable to be submerged, as this type, due to its simple construction and the absence of moving electric contacts, need not ordinarily be enclosed; but the factor of safety is very greatly increased by using an enclosed motor with waste packed bearings, the use of stuffing boxes not being essential. As an example of the serviceability of the standard General Electric induction motor, not in any way designed for submerged operation, reference to a test recently conducted may be of interest. A standard General Electric 2 h.p. 1800 r.p.m. open induction motor was run continuously, while totally submerged, for a period of ten weeks, throughout which time it gave satisfactory service with but slightly diminished output.

In sinking pumps the load increases inversely as the head against which the pumps are delivering water and, as a rule, the limits can be approximately predetermined and the motors so designed that at the start the efficiency increases with the increasing head. Both alternating and direct current motors with either horizontal or vertical shafts can be readily adapted to all forms of sinking pumps, the type of motor selected depending upon the service required and the character of the electrical energy available.

The main sump pumps are usually of large capacity, and their energy requirements often constitute a large percentage of the generating station output. Where the sump is of sufficient size to store the water normally collected during the day, the cost of this demand on the generating equipment may be minimized by running these pumps at night, in this way tending to equalize the power station load and permitting the operation of a mine or colliery with a much smaller capacity in generators than would be required if these large pumping sets were run as a day load.

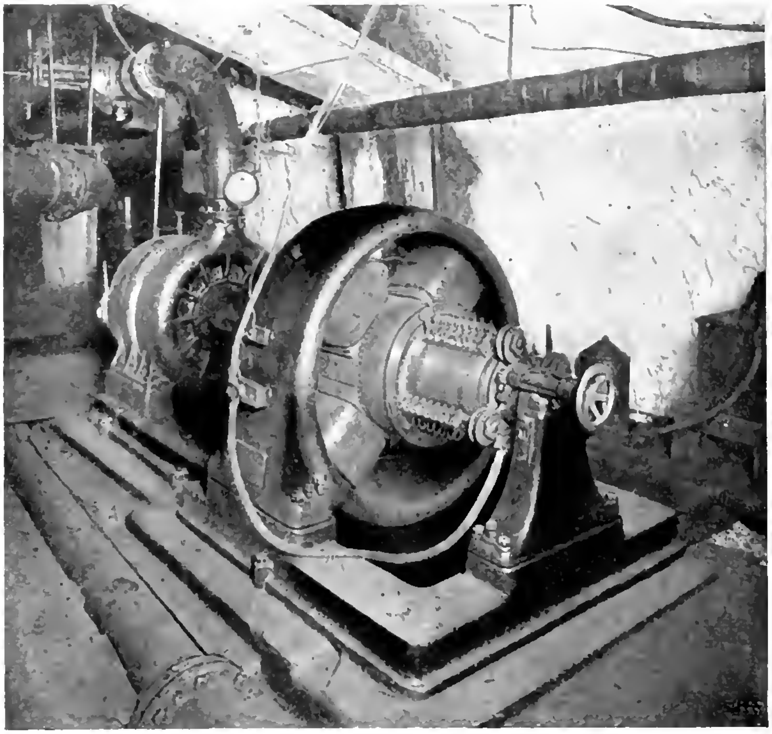
The adoption of the centrifugal type of sump pump in coal mines is due not only to improved efficiencies of the modern multi-stage form, but also to the ability of the centrifugal type to handle liquids containing a considerable percentage of solid matter in suspension more successfully than reciprocating pumps. Moreover, its design and practically uniform load when serving sumps permits direct drive by means of high speed motors, preferably of the constant speed polyphase induction type, where alternating current is obtainable. As single pumps capable of delivering water to the surface from any depth required in coal mining, at one lift, can now be run with greater economy both as to first cost and power consumption than a number of units of low head and equal capacity, the once common practice of raising the water to the surface in successive lifts to sumps located at different levels has been practically abandoned. Typical coal mine pumping installations utilizing both alternating and direct current motors are illustrated herewith.

For draining portions of the mine which are below the level of the sumps, a number of comparatively small pumps are ordinarily required, and as the difference in the water levels is not usually great, these pumps are as a rule standardized for the maximum head against which they will have to operate. This seldom exceeds 300 feet and in some mines is as low as 15 feet. Owing to their relatively large number and scattered location, these pumps are usually driven by direct current motors and operate from the locomotive feeder wires, although they are sometimes served by cables run into the mine through a centrally located bore hole. They are frequently semi-portable, so as to facilitate their movement or replacement to meet the varying requirements developed by the constantly changing conditions incident to coal mining. Like the main pumps, they normally operate without attendance, except for occasional inspection, cleaning and lubrication, and can be equipped with automatic control, if required.



Type I Form K 150 H.P. Induction Motor Driving Centrifugal Pump Rated 2000 G.P.M. 125 Ft. Head. United States Coal & Coke Co., Gary, W. Va.

Perhaps the best demonstration of the superior flexibility of electrical operation in coal mines is found in the portable pumping set, which can be lowered down the shaft or slope and rapidly hauled to any portion of the mine by a locomotive and immediately put into service by connecting the suction pipe, unreeling the discharge hose and connecting the motor leads to the locomotive feeder wires. The equipment varies in details but not in essentials at different mines, and consists of a centrifugal or plunger pump direct connected or geared to a direct current motor provided with a simple drum controller. There is also a suction pipe with a strainer end, and a discharge pipe or hose reel, and if the set is intended for fire service the necessary fire fighting auxiliaries are also included. The complete outfit is compactly mounted on a truck having the same wheel gauge as the mine locomotives. It constitutes a valuable adjunct to the ordinary pumping equipment, as it can be used in all emergencies to replace any pump of approximately the same capacity that may be shut down for repairs or other reasons, and for intermittent dip pumping in roadways where the expense of drainage grading would not be justified and a permanent pumping set would not be economical, owing to the short and irregular periods of operation.



150 H.P. 220 Volt 700-1200 R.P.M. Motor Direct Connected to Four Stage Ten Inch Centrifugal Pump Operating Against 330 Ft. Head, Capacity 1000 G.P.M. Installed in Mine, North Franklin Colliery, Trevorton, Pa. Philadelphia & Reading Coal & Iron Co.

Water Hoists

In the early days of coal mining there was developed in the Pennsylvania coal fields a method of raising mine water from the sump to the surface, which was elementary in design, simple in construction, and at the same time gave higher efficiencies than could be obtained with the pumps which were then available, and in fact compare favorably in this respect with many modern high head units. This was a form of water hoist of the balanced bucket type which rendered it possible to raise several thousand gallons at each lift from any depth required in coal mine drainage. Its adoption obviated the necessity for successive stage pumping to sumps located at different levels and did much to simplify the then existing drainage problems: it was widely adopted and many still remain in service.

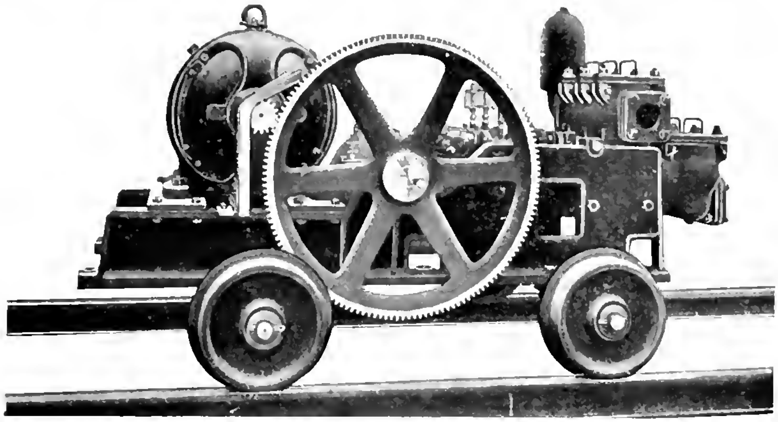
On the other hand, the installation of a water hoist usually involved a very heavy outlay, as a special shaft had to be sunk for the passage of the buckets, and on the surface a substantial hoist tower and an engine house were necessary.

In view of the investment represented by the steam equipment of these hoists many of the coal mining engineers hesitate to adopt electric drive for this portion of the mine equipment, and steam engines, each requiring the constant attention of an engineer, are therefore retained. The entire feasibility of automatic electric drive for these water hoists, with an indication of the economies in power consumption and maintenance thereby obtainable, is well illustrated by the motor-driven water hoists installed by the mining department of the Delaware, Lackawanna & Western Railroad which is shown herewith. This hoist is located near the Hampton (Pa.) power house and in conjunction with two motor-driven centrifugal pumps serves a large central sump in which the drainage of eight mines within a radius of one and one half miles is collected.

The hoist is of the usual balanced cylindrical bucket type and has a capacity of 250,000 gallons per hour. The electrical equipment consists of an 800 h.p., 2200 volt, 225 r.p.m. Type I, Form K induction motor direct geared to a cone drum hoist, the main drum having a maximum diameter of 16 ft., tapering to 10 ft., the normal speed being 145 r.p.m.

The depth of the sump shaft is 500 ft., while a 2 in. steel cable having a weight of 63 lb. per foot is used to lift the buckets, each of which has a capacity of 3100 gallons.

The power demand during the hoisting cycle is naturally variable, as the speed of the load ranges from 750 ft. per minute maximum, to 445 ft. per minute, and the load is constantly changing with the location of the buckets. The nature of the power requirements is graphically illustrated by the curve, Fig. 1, which shows the current consumption for a complete operating cycle, including a period of six seconds during which time the lifted bucket is held stationary while the contents are discharged; the motor, however, running constantly.



7 1/2 H.P. 925 R.P.M. CQ Motor Driving Portable Mine Pump

Exterior View of Hampton Water Hoist and Motor House, Showing Bucket Discharging. D. L. & W. R. R. Co. Mining Dept.

The equipment is entirely automatic, the motor shafting running at right angles to the drum shaft, which is controlled by a reversing gear device; the change in the direction of the drum rotation being automatically accomplished by means of a solenoid-operated ring clutch, actuated pneumatically. Safety in operation is arranged for by the addition of a governor and a pneumatic brake mounted directly on the motor shaft.

Inasmuch as the sump has sufficient capacity to store the normal day drainage and in order to keep down the peak load, the hoist is put into service toward the close of the working day as the power requirements of the mine machinery diminish; in this way tending to equalize the generator load.

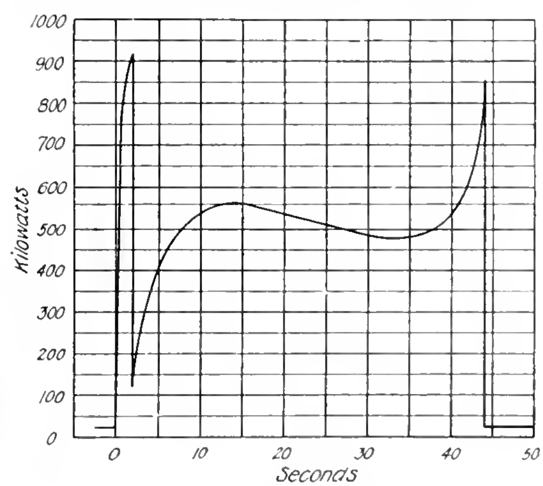


Fig. 1. Curve Showing Power Demand for One Hoisting Cycle

Since its installation this hoisting equipment has operated with entire satisfaction, without involving any shut downs, and it constitutes a cogent argument for the general application of electric drive to those water hoists in electrified mines and collieries which are at present driven by steam engines.

(To be Continued)

THE LIMITING EFFECT OF CORONA ON THE ELECTRICAL TRANSMISSION OF ENERGY AT HIGH VOLTAGES

By F. W. Peek, Jr.

Economic conditions from year to year have called for higher voltages and greater distances of electrical transmission of energy. It is likely that the call for greater transmission distances will continue until some day the whole country is interconnected in a continuous mesh work of conductors. At the present time energy is being transmitted successfully and economically at over 100,000 volts.

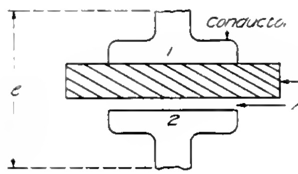


Fig. 1

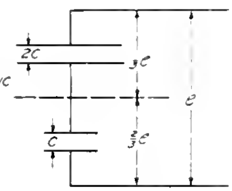


Fig. 2

Experience shows that if the voltage on a given transmission line is raised beyond a certain point, the air at the surface of the conductors becomes luminous and a loss occurs, which increases at a startling rate as the voltage is increased above this luminous or so-called "visual critical corona point." It can thus be seen that the use of high voltage without a previous knowledge of the laws governing corona formation and loss, and the applications of these laws in design, might defeat the very purpose for which the high voltage was used—namely, decreased transmission loss.

In order to determine the laws of corona, very extensive experiments were carried on by the Consulting Department of the General Electric Company, and were the subject of a recent paper.* As a result of this investigation such questions as: "What is the limiting transmission voltage due to corona?" "What voltage may be used, and what will be the loss on a given transmission line?" etc., may be answered.

The object of the present article is to give some physical and graphical conception of the laws of corona. It is not intended to treat fully any special case here, but to give a general idea of what is taking place.

Transmission lines, insulators, generator coils, cables, bushings, etc., are immersed in an ocean of insulating material, air. It is the dielectric strength of this air that very often determines the safe voltage of any given piece of apparatus. This fact is too often not realized. For instance, in practice a combination often exists, as shown in Fig. 1. This may be shown diagrammatically as made up of two condensers in series, Fig. 2. It is assumed that the combination of conductor (1) and the solid dielectric in this special case has a capacity of 2 C, while the combination of the small air space and conductor (2) has a capacity C. Then, as condensers in series take up an applied potential inversely as the capacity, it means in this case, that one-third of the total potential e, is taken up by the solid dielectric, while the air takes up two-thirds of the potential e. If the potential across the air space anywhere exceeds 76,000 volts per inch, the air will become luminous, or, we say, it breaks down, and we have corona. This does not necessarily mean that the solid dielectric will break down and dynamic current follow as an arc between (1) and (2). The solid dielectric may be able to withstand many times the potential e. It may be that no damage will result at all. Then what may take place is this: The solid dielectric may be of such material as to gradually disintegrate under the local heating, mechanical bombardment, or chemical combinations formed in this over-stressed air, as ozone and nitric acid, etc., and finally break down after several months of operation.

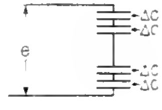


Fig. 3

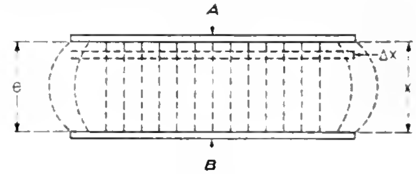


Fig. 4

A practical instance of Fig. 2 might be a metal cap on a bushing, tie wire on an insu-

* "The Law of Corona and Dielectric Strength of Air," by F. W. Peek, Jr. July Proceedings A.I.E.E.

lator, etc. From this example can be seen the importance of so proportioning insulations in series, that their respective capacities cause the stress to be taken in proportion to their dielectric strengths.

If two parallel plates, A and B, are taken x inches apart, as in Fig. 4, and the potential e is applied between them, the dielectric field consists of parallel lines and is everywhere uniform (except for distortion at the edges). A plane of unit area placed anywhere between, and parallel to, A and B, would cut the same number of lines; that is, the density is uniform. As a mechanical conception we may think of the dielectric between the plates as an elastic material under strain due to the stress along the lines of force. This stress is proportional to the field density. For convenience in practice this force or stress is measured in kilovolts per inch, and it is called the voltage gradient and is represented by g. In Fig. 4, where the field is uniform,

$$g = \frac{e}{x}$$

We may think of Fig. 4 as made up of an infinite number of equal condensers in series, then the potential across each condenser is equal (Fig. 3), or

$$g = \frac{e}{x}$$

When g is greater than the "elastic limit," 76,000 volts per inch, the air breaks down and we have corona.

Between two parallel wires of a transmission line the field is not uniform, as in

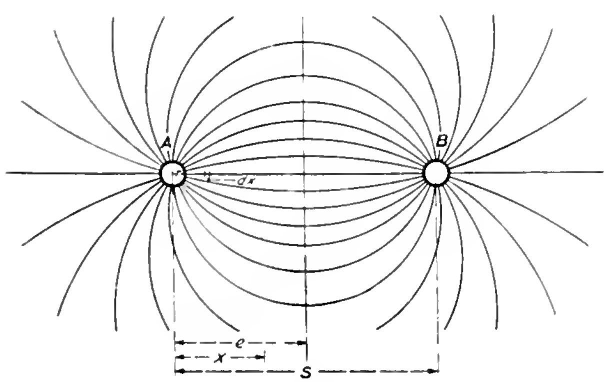


Fig. 5

Fig. 4, but the dielectric lines of force are as in Fig. 5. The densit of the field is much greater at the conductor surface. This means that the gradient is greatest at the surface, and as the potential is gradually raised the "elastic limit" is first exceeded

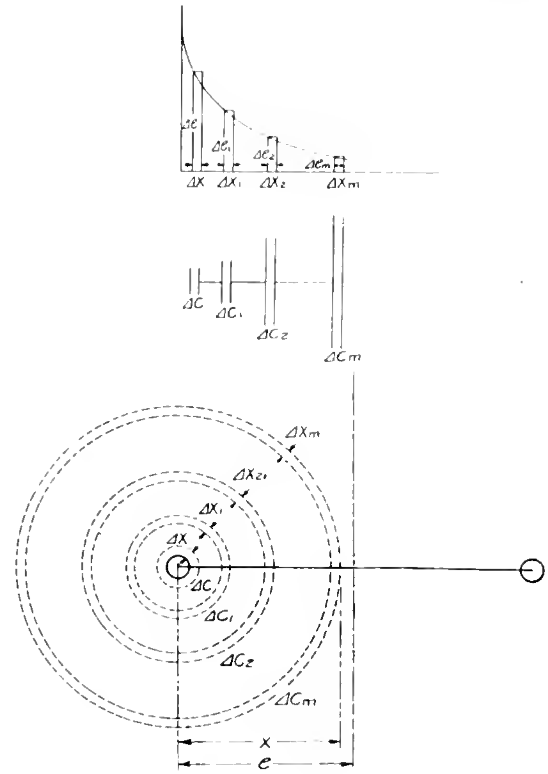


Fig. 6

at the conductor surface, and corona first appears near there. It also means that we *cannot* write

$$g = \frac{e}{x}$$

as in the case of the uniform field, Fig. 4, but must write:

$$g = \frac{de}{dx}$$

This may also be considered from the capacity standpoint: Looking at Fig. 6, we may conceive of the space between the conductors made up of a number of unequal capacities Δc, Δc_1, ... Δc_m in series. The potentials across the capacities are Δe, Δe_1 ..... Δe_m. Δe is greatest across the lowest capacity or at the surface. In the limit we may represent this distribution of potential by a smooth curve, as in Fig. 6. It can be easily proven that for the two parallel wires,

$$g = \frac{de}{dx} = \frac{e}{x \log_e \frac{s}{r}}$$

Where:

e is the voltage to neutral,
x is the distance from the conductor center in inches,
s is the distance in inches beween conductor centers,
r is the conductor radius in inches.

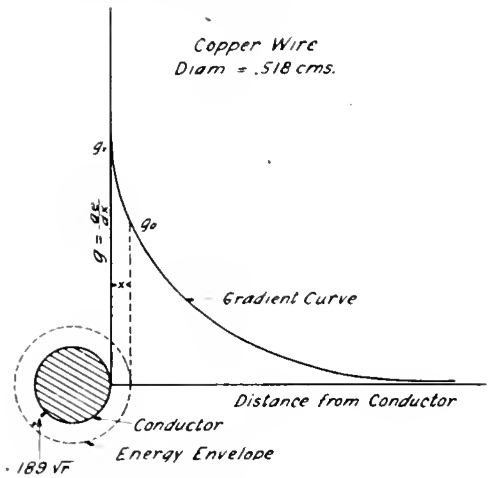


Fig. 7

It may be clearer to understand the potential gradient in the dielectric field by comparing it with the gradient or voltage drop in a conducting material. Looking at Fig. 4 consider A and B as two metal plates in a conducting solution. The current flows across from A to B and is everywhere uniform as shown by the parallel lines. Hence, the drop between A and B is uniform and the gradient g, or voltage drop per inch between the plates, is:

$$g = \frac{e}{x}$$

If we consider a dielectric to take the place of the conducting solution, the dielectric flux shown by the parallel lines, takes the place of the current, and $g = \frac{e}{x}$ is the gradient in the dielectric.

Now, looking at Fig. 5, consider A and B as two conducting electrodes in a conducting solution as before. Then, when voltage is applied we say current passes from A to B. As the cross-section is smallest at the conductor surface the resistance is highest there. Therefore, the drop is greatest at the electrode and gradually decreases as the distance from the electrode, or the cross-section of the conducting solution, is increased. In other words, most of the applied voltage is taken up near the electrode surface, or the volts per inch or gradient is greatest there. We may consider a dielectric, as air, to take the place of the conducting material, and the dielectric flux to take the place of the current as shown by the flux lines. Then most of the applied voltage maintaining this flux is used up, so to speak, in the dielectric near the conductor surface, or we may say the dielectric drop or potential gradient is greatest at the surface. This gradient at any place in the air between the conductor and neutral is approximately:

$$g = \frac{e}{x \log_e \frac{s}{r}}$$

To find the stress at the conductor surface put $x = r$, then,

$$g = \frac{e}{r \log_e \frac{s}{r}}$$

The stress in the air at different points between two parallel conductors may be represented by the curve, Fig. 7. If the voltage e_v, at which visual corona starts

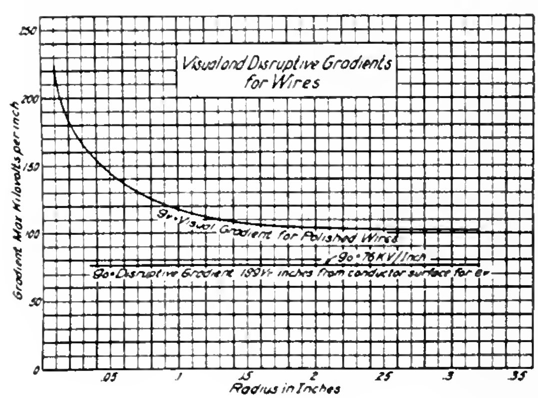


Fig. 8

is found by experiment * for a number of different sizes of wire, and g is calculated from

$$g_v = \frac{e_v}{r \log_e \frac{s}{r}}$$

*e_v is found by gradually raising the potential between two parallel polished wires of equal size, in a dark room, and noting the voltage at which glow starts.

it is found that g_v is not constant, as would at first thought be expected, but g_v is greater for small conductors than for large ones (see Fig. 8). In other words, as g_v is a

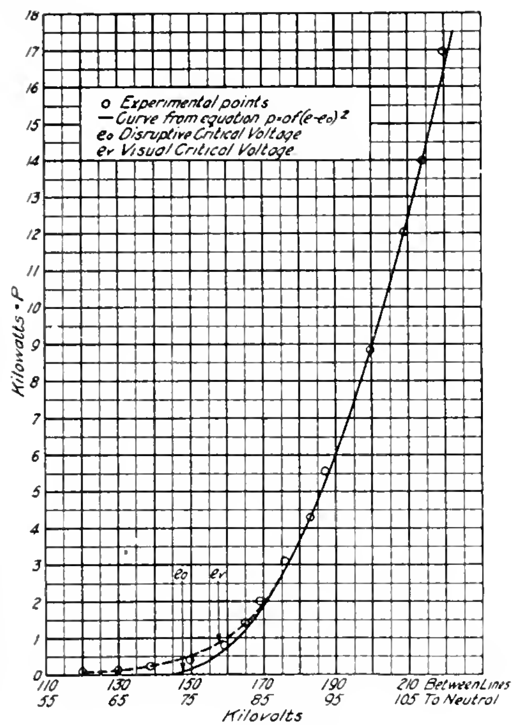


Fig. 9 Corona Loss for Large Conductor

measure of the dielectric stress at the conductor surface, at which visual corona starts or breakdown occurs, the air apparently has greater strength around small conductors than large ones, and it would *appear* that air has not a constant strength of 76,000 volts per inch, as stated above. From our investigation it was found, however, that we may write:

$$g = \frac{e_v}{(r+0.189\sqrt{r})\log_e \frac{s}{r}}$$

$$= \text{constant} = 76 \text{ kv. inch.}$$

Looking at Fig. 7, this means that the gradient g_v at the surface of the conductor must be raised above the actual breakdown gradient, in order to store sufficient energy in the air immediately surrounding the conductor to cause breakdown at a distance $0.189\sqrt{r}$ inches from the conductor surface. The gradient at this distance is the breakdown gradient and is constant, and is $g = 76$ kilovolts per inch (see Fig. 8). This value of g is for a standard temperature of 77 deg. F. and 29.9 inches barometer. Both g, and g_v, therefore, also e_o and e_v are proportional to the air density, and therefore vary with the altitude and temperature. This is taken care of in the formulae by δ. Thus for a given voltage and spacing larger conductors are required at high altitudes.

Of first importance in the design of high voltage transmission lines and apparatus is:

(a) To be able to predetermine at what voltage corona will start.

(b) To be able to predetermine the power loss at different voltages in order to see if operation is economical above the critical voltage. Figs. 9 and 10 are typical loss curves for large and small conductors. The points are experimental values as read, while the curves are drawn from the equation:

$$p = af\,(e - e_o)^2$$

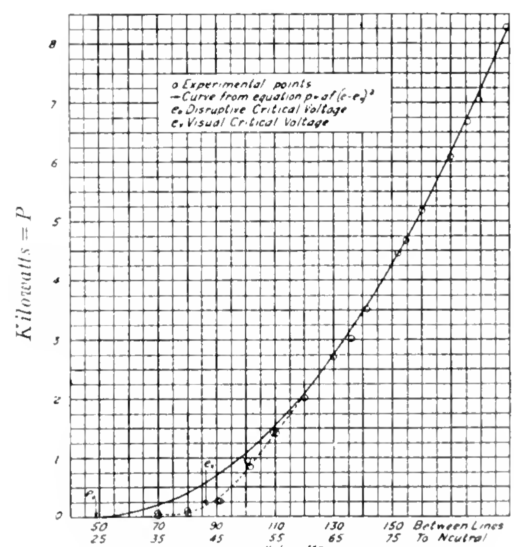


Fig. 10 Corona Loss for Small Conductor

Where:

p is power loss,

e is the applied voltage,

e_o is called the disruptive critical voltage: it is the voltage that gives a *constant breakdown gradient for air, of 76 kv. per inch.* That is:

$$g = \frac{e_o}{r \log_e \frac{s}{r}} = 76.$$

It is interesting to note the difference in the two curves for different sizes of conductors. For the upper part of the curve the loss in both cases follows the above quadratic law, i.e., the loss increases as the square of the excess voltage above the disruptive critical voltage. At the lower part of the curve for the large conductor the loss is in excess of the quadratic, while for the small conductor the loss is less than the quadratic until the visual critical voltage point is passed. The reason of this deviation is as follows:

For a perfectly smooth conductor no loss can start until the air "breaks down" or until the visual critical voltage is reached. That is, the loss cannot begin to follow the quadratic law at e_o, but only after e_v is reached. Now, considering the two different size conductors separately:

For a large conductor e_v and e_o are close together, hence the loss starts to follow the quadratic very near to e_o for a large smooth conductor. In practice, however, as there are scratches, spots of mud, etc., on the conductor surface, loss actually starts below e_o. With small conductors the scratches and irregularities increase the loss very little, because their radius of curvature is of the same order of magnitude as the radius of the conductor, also, for the small conductors e_o and e_v are farther apart and loss does not start until after the e_v point is passed. This means that it is possible in practice to operate a small wire at a voltage nearer e_v, or with a smaller factor of safety than for a large conductor. That is, for a small conductor it may be possible to operate the line considerably above e_o with very little loss, while for a large conductor it will generally be necessary to design the line to operate below e_o. As a matter of theoretical interest, it might be mentioned here that the excess loss for the large conductor follows the probability law

$$p_1 = q\epsilon^{h(e_o-e)^2}$$

which means that the excess is due to irregularities.

From our investigation the following equations have been derived. From these equations all of the fair weather corona characteristics for any transmission line can be predetermined.

e_v, the effective visual critical voltage to neutral in kv. is given by the equation

$$5(a) \quad e_v = 2.302\ m_v\ g\ \delta\ r \left(1+\frac{0.189}{\sqrt{r}}\right) \log_{10}\frac{s}{r}$$

e_o, the disruptive critical voltage in effective kv., to neutral, is obtained from the equation

$$3(a) \quad e_o = 2.302\ m\ g\ \delta\ r \log_{10}\frac{s}{r}$$

p = the total power loss due to corona in fair weather, in kw. per mile of single conductor.

6(a)

$$p = \frac{k^1}{\delta} f \sqrt{\frac{r}{s}} \left\{ e - 2.302\ m\ g\ \delta\ r\ log_{10}\frac{s}{r} \right\}^2 \times 10^{-5}$$

Where:

e = effective kilovolt to neutral (appiied),
k^1 = 552,
g = 53.6 kv. per inch effective,
δ = air density factor = $\frac{17.91b}{459+t}$,
δ = 1 at 77° F. and 29.92 bar press.,
b = barometric pressure in inches,
t = temperature degrees *Fahr.*,
r = radius of conductor inches,
s = distance between conductors inches,
f = frequency cycles per second,
m = irregularity factor,
m 1 for polished wires,
= 0.98 to 0.93 for roughened or weathered wires,
m_v = m for wires,
m_v = 0.72 local corona all along cable,
= 0.82 decided corona all along.

Altitude and temperature are taken care of by the factor δ.

The weather conditions that seriously affect the critical voltage and loss are fog, rain, sleet and snow storms. The effect of snow is the greatest. THIS MUST BE TAKEN INTO ACCOUNT IN THE DESIGN OF TRANSMISSON LINES. On the average snow has approximately the effect of lowering e_o to 80 per cent. of its fair weather value.

As an example of the use of the formulae in design, the following problem is solved:

Calculation of Corona Characteristics of a Transmission Line

Given:

Three-phase line.
Length, 150 miles,

Conductor spacing, 120 inches.
Conductor—7 strand cable 3/0 radius $= 0.235$ inches.
Maximum temperature, 100 deg. F.
Altitude—500 ft.—Bar. press. 29.4 inches.
Present working voltage:
Between lines, 100,000
To neutral, 57,800

(1) To find e_o for fair weather:

$$e_o = 2.302\ m_o\ g_o\ r\ \delta \log_{10}\frac{s}{r} \qquad 3(a)$$

$m_o = 0.87$

$g_o = 53.6$

$r = 0.235$

$s = 120$ in.

$t = 100$

$b = 29.4$

$\frac{s}{r} = 511$

$$\delta = \frac{17.91 \times 29.4}{459 + 100} = 0.945.$$

From 3(a)

$e_o = 64.6$ kilovolt to neutral.

(2) To find e_o during storm:
Assume storm $e_o = 80$ per cent. fair weather e_o.
Then storm $e_o = 0.80 \times 64.6 = 51.7$

(3) To find e_v:
$m_v = 0.72$.

Then from 5(a)

$$e_v = 2.302\ m_v\ g_o\ \delta\ r\left(1 + \frac{0.189}{\sqrt{r}}\right)\log_{10}\frac{s}{r} = 74.2.$$

(4) To find loss during fair weather:
From 6(a)

$$p = \frac{k^1}{\delta} f \sqrt{\frac{r}{s}}(e - e_o)^2\, 10^{-5}$$

$k^1 = 552$

$$\sqrt{\frac{r}{s}} = 0.0442$$

Substituting in 6(a):

$p = 25.8\ f(e - 64.6)^2\ 10^{-5}$ kw. per mile for single conductor.

$p = 77.4\ f(e - 64.6)^2\ 10^{-5}$ kw. per mile for three conductors.

(5) Approximate storm loss:

$p = 77.4\ f(e - 51.7)^2\ 10^{-5}$ kw. per mile for three conductors.

In the table below the fair weather and storm loss is calculated for a number of voltages at both 25 cycles and 60 cycles.

TRANSMISSION LINE CORONA CHARACTERISTICS FOR FAIR WEATHER AND STORM 60 AND 25 CYCLES

3/0 Cable—120 In. Spacing

Kilovolts		Line Loss				Total Line Loss for 3 Wires, 150 Miles			
		Kw. Per Mile Fair Weather		Kw. Per Mile Storm		60 ~		25 ~	
Between Lines	To Neut.	60 ~	25 ~	60 ~	25 ~	Fair	Storm	Fair	Storm
100	57.8	0	0	1.80	.74	0	447	0	184
110	63.4	0	0	6.40	2.66	0	1600	0	666
120	69.1	.94	.39	14.08	5.88	236	3540	98	1469
130	75.0	5.03	2.10	25.15	10.51	1258	6320	520	2630
140	80.7	12.07	5.03	39.20	16.30	3020	9800	1258	4080
160	92.2	36.30	15.10	75.40	31.75	9055	19140	3780	7940
180	104.8	75.10	31.35	136.70	57.10	18800	34100	7840	14300

A line similar to the above at 100,000 volts would probably be used to carry about 20,000 kw. Noting the table, the percentage loss for fair weather is very small for over 120,000 volts. At 120,000 volts the percentage storm loss is large. However, this loss was calculated for a storm over the whole line at one time, a condition not likely to be met in practice. In working out a design it must also be remembered that the storm loss occurs only at intervals, and it may often be economical to allow this to reach high values.

Barometric Pressure, 29.92; Temp. 77° F.; Seven Strand Cable

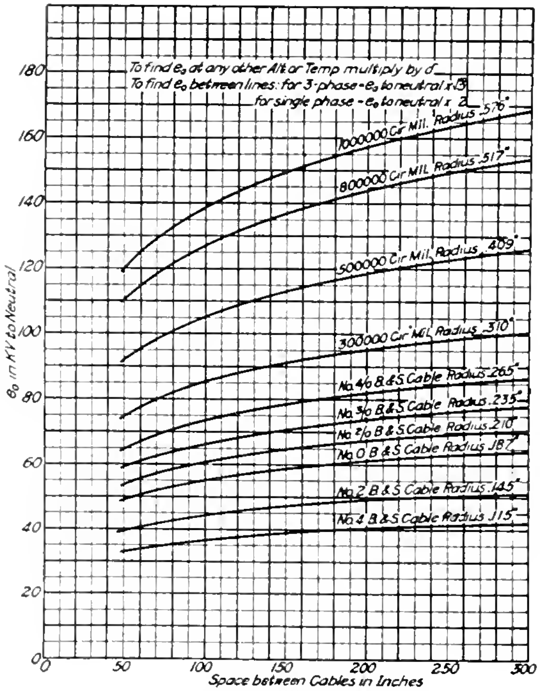


Fig. 11. Disruptive Critical Voltage to Neutral

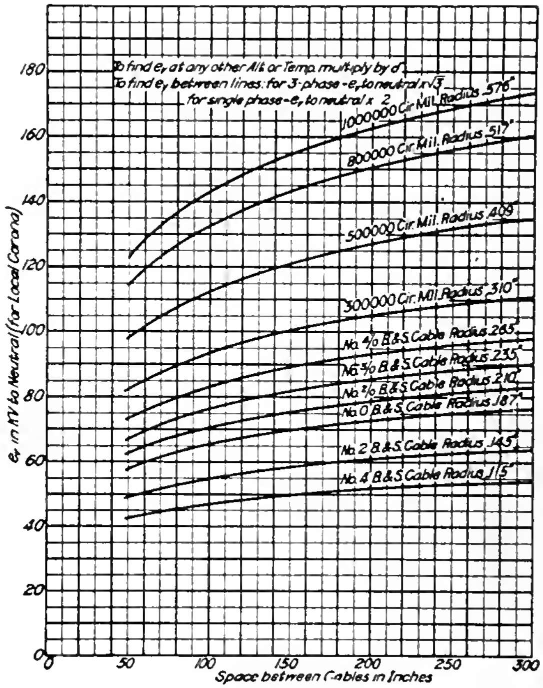


Fig. 12. Visual Critical Voltage to Neutral (m_v = .72)

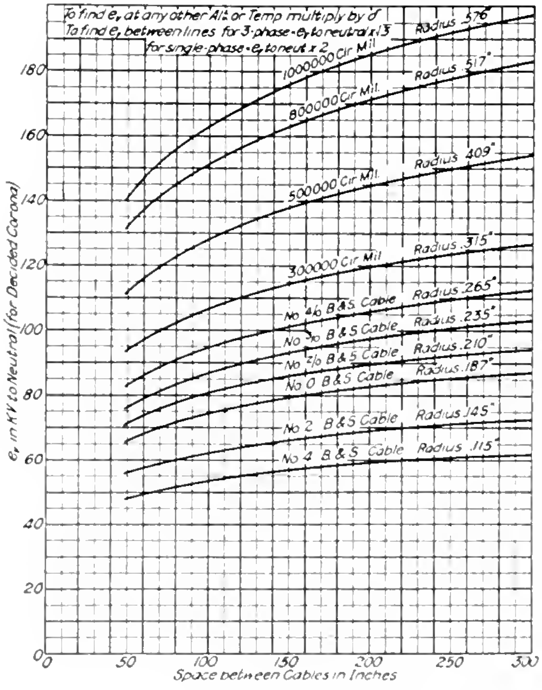


Fig. 13. Visual Critical Voltage to Neutral (m_v = .82)

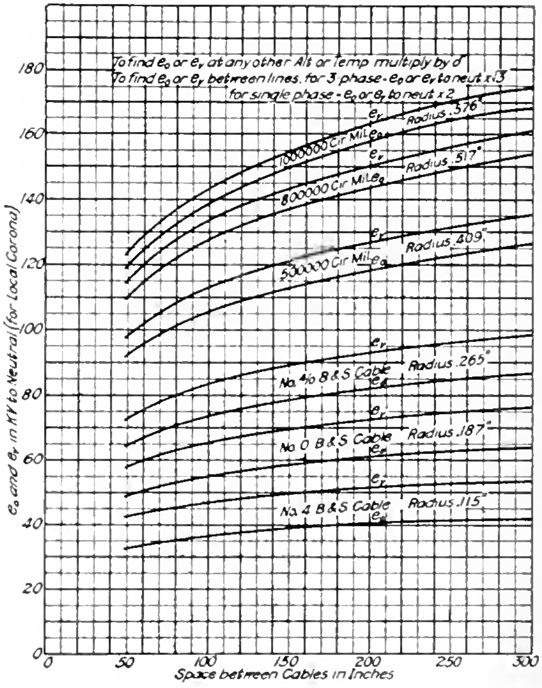


Fig. 14. Comparison of Disruptive and Visual Critical Voltages to Neutral (m_v = .72)

Barometric Pressure, 29.92; Temp. 77° F.; Seven Strand Cable

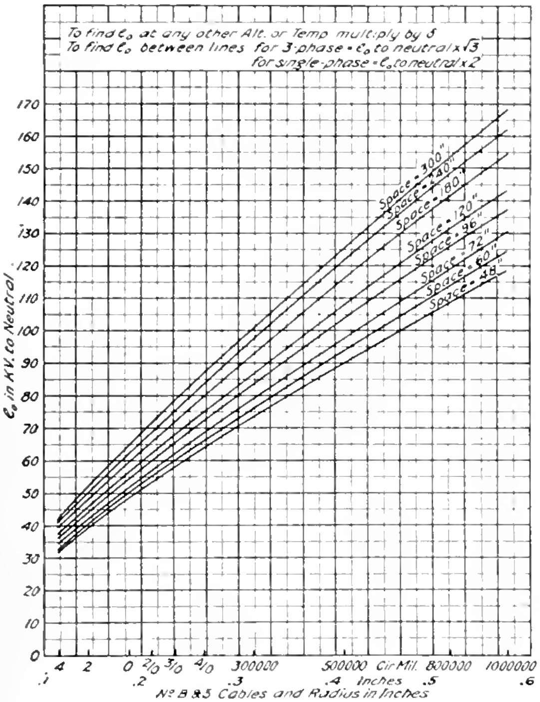


Fig. 15. Disruptive Critical Voltage to Neutral

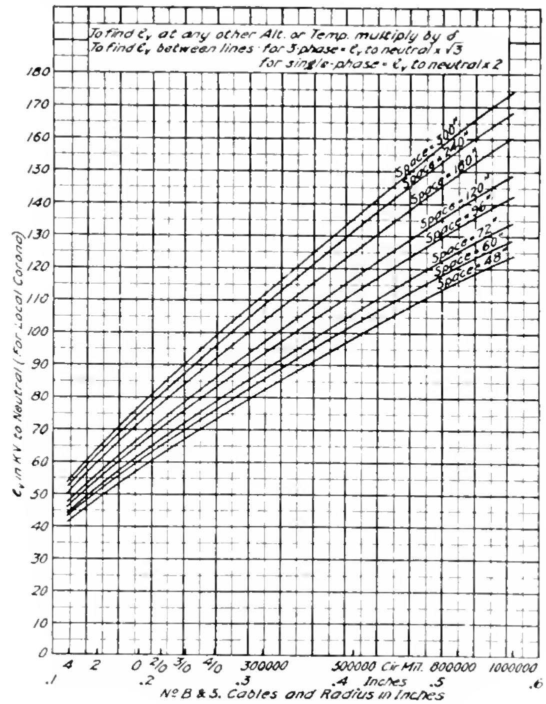


Fig. 16. Visual Critical Voltage to Neutral ($m = .72$)

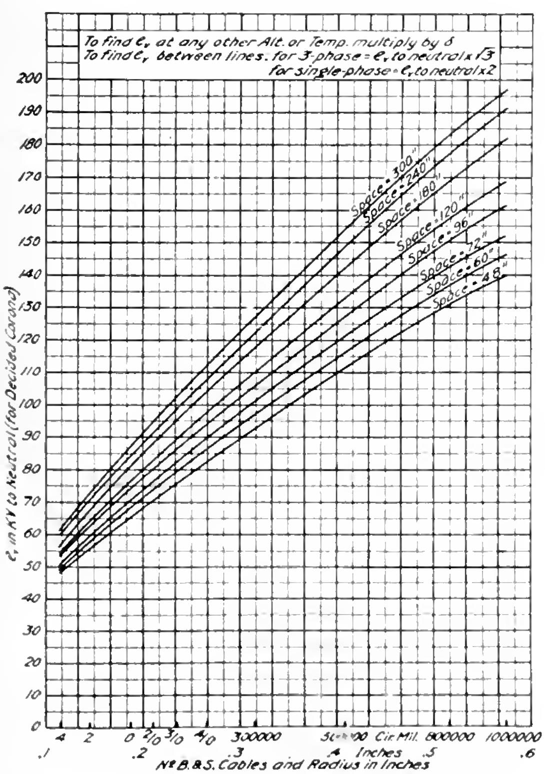


Fig. 17. Visual Critical Voltage to Neutral ($m = .82$)

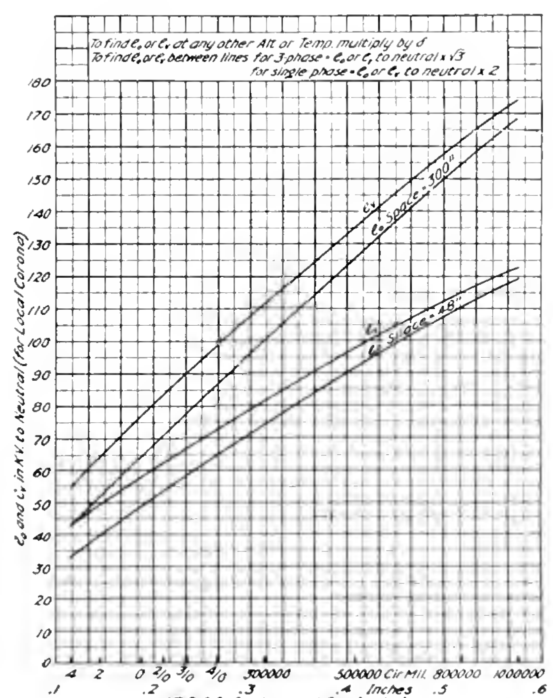


Fig. 18. Comparison of Disruptive and Visual Critical Voltages to Neutral

CRITICAL VOLTAGE CURVES AND GRAPHICAL SOLUTION OF CORONA LOSS

In order to show graphically the corona characteristics at various conductor diameters and spacings and to give a graphical method of determining corona loss, curves Figs. 11 to 21 have been calculated.

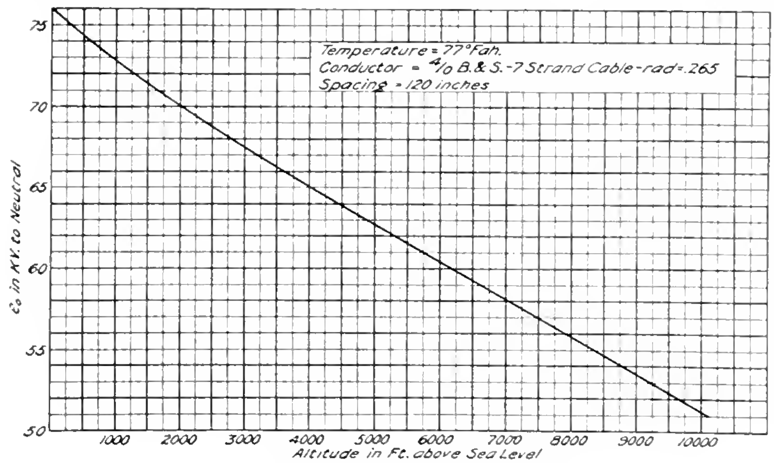


Fig. 19. Disruptive Voltage at Various Altitudes for 4/0 Cable

Disruptive and Visual Critical Voltages for Various Sizes and Spacings

Figs. 11, 12 and 13 show the effect of a change in spacing for given standard conductors.*

Figs. 15, 16 and 17 show the effect of changing the size of the conductor for a constant spacing.

The difference between the visual and disruptive critical voltage may be found from the corresponding curves.

In Figs. 14 and 18 the disruptive and visual critical voltages are plotted together for a few special curves to illustrate this difference.

The Effect of Barometric Pressure (Altitude) and Temperature

All of the above curves give the critical voltages at 29.92 barometric pressure (practically sea level) and 77 deg. *Fahrenheit*. To find the critical voltage at any other temperature and pressure, multiply the curve value by δ, using the barometric pressure corresponding to the altitude desired. Fig. 19 shows the effect of altitude change for a 4/0 cable at 120 in. spacing.

Aluminum Equivalent

An aluminum conductor with a conductance equivalent to a given copper conductor has a considerably greater diameter. This means the aluminum equivalent of a copper conductor, on account of its greater diameter, has a much higher critical voltage. This is illustrated in Fig. 21. It may thus often be advantageous to use an aluminum conductor. Of course, the same result may be obtained by using a hemp center copper conductor, or for still larger sizes a hemp center aluminum conductor to avoid skin effect.

Graphical Determination of Corona Loss

Fig. 20 is given in order that the power loss may be determined graphically, for any given condition, taking the problem already given on pages 464 and 465 and solving graphically.

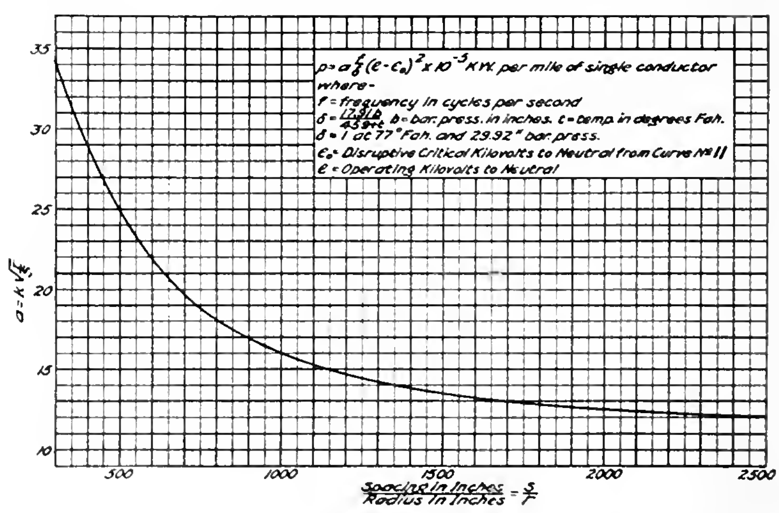


Fig. 20. Curve for Calculating Corona Loss

(1) Find e:

From Fig. 11 at $s=120$ in., and No. 3/0 cable ($r=0.235$)

e (curve) $=68.4$

* Two sets of visual curves are given, one for the irregularity factor at $m = .72$, the other for $m = .82$. The lower value is to be used in practice for weathered cables. For discussion see A.I.E.E. paper.

Reducing to 500 ft. altitude (barometer = 29.46)
and 100 deg. F. $\delta = 0.945$

Required $e = 68.4 \times \delta = 68.4 \times 0.945 = 64.6$

(2) Find e_v:

From Fig. 12 (curve) $e_v = 78.5$.

Then required

$$e_v = 78.5 \times \delta = 78.5 \times 0.945 = 74.2$$

(3) Find kilowatts loss:

$$\frac{s}{r} = \frac{120}{0.235} = 511$$

Then, from curve, Fig. 20, for $\frac{s}{r} = 511$,

$$a = 24.5$$

Reducing to 29.46 in. barometer and 100 deg. F.,

$$a = \frac{24.5}{\delta} = 25.8$$

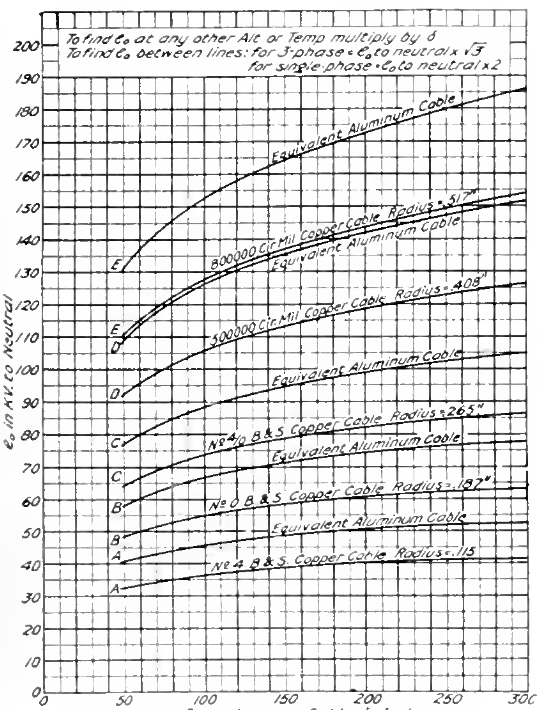


Fig. 21. Disruptive Critical Voltage to Neutral for Copper Cables and their Aluminum Equivalents

$p = 25.8\ f(e - 64.6)^2 \times 10^{-5}$ kw. per mile, single conductor; or multiplying by 3, since there are three conductors,

$p = 77.4\ f(e - 64.6)^2 \times 10^{-5}$ kw. per mile for three conductors. From the last expression the loss per mile may be found at once for any given frequency f and applied voltage to neutral e.

TELEPHONE SYSTEM IN A LARGE MODERN FACTORY

The General Electric Company with its headquarters at Schenectady, N. Y., employs a force of some 35,000 men. About half of these are resident at Schenectady, where are located the principal offices comprising purely executive offices, engineering, commercial, law, patent, auditing, production and purchasing. The largest shops are also located here, the rest being distributed in the Company's various works along the Atlantic seaboard and in the middle west. To maintain any cohesiveness between these widely separated parts, as well as in each individual factory, a means of intercommunication is required which, for rapidity and accuracy, can only be supplied by the telephone and telegraph. Leased wires, employed solely for the company's business, are maintained between Schenectady and New York, Boston, Lynn, Pittsfield, Harrison, N. J. and other points. The factory at Schenectady is also credited with one of the largest local private exchanges in the world, one indeed which rivals in size those of many of the smaller cities.

Necessarily many of the problems encountered are peculiar to the adaptation of the instrument to the particular needs of an unusual service. Here we have not only a seven story office building with 4.38 acres of floor space—the largest single concern office building in the world—but the rest of the factory extends over an area of 335 acres and has buildings with a total floor space of 4,350,000 sq. ft. In this small sized city of business, nearly all of the telephone calls necessarily occur during daylight hours, yet their total number rises far above the usual and standard average of calls per 'phone. In spite of a system of electric 'busses, a journey between the widely separated parts of the factory often consumes considerable time.

The present office building at Schenectady is a seven story fireproof structure equipped with elevators, mail and telegram chutes, pneumatic tubes, telegraph office and telephone exchange.

The telephone building is a two story concrete structure situated in the rear of the main office building. The first floor is used as power and terminal room, repair shop and store room while the upper story is used for the operating room. From 1900 until 1914 there was a gradual increase in the number of lines, as the following table will show:

Year		No. of Lines
January	1900	160
"	1901	168
"	1902	172
"	1903	239
"	1904	265
"	1905	315
"	1906	360
"	1907	450
"	1908	470
"	1909	498
"	1910	547
"	1911	722

The equipment consists of a central energy multiple switchboard of 1,000 lines capacity. The present installation of twelve positions is equipped to take care of 640 local or factory stations. One of the twelve positions is used for public service toll connections and one for handling leased wires to New York, Pittsfield and Lynn. For handling public service business there are 21 trunks to the city exchange, divided as follows: 8 outgoing local, 6 incoming local, 7 toll trunks, and in addition 1 recording trunk line to the toll room of the city exchange, which is used only for passing long distance calls. The incoming and outgoing trunks are multipled so as to be accessible from all positions, and are furnished with line and busy visual signals. On all toll business the time is checked by using the calculagraph.

The chief operator's desk consists of a ten drop board, which has the necessary equipment of switching trunks, listening and ringing keys for handling direct and transfer calls, and order wires to all positions.

Power Room

The power room contains main and intermediate distributing frames in position for 1,000 lines, eleven 400 ampere-hour accumulators, one 3 kw. motor-generator set for charging, two 1/4 h.p. dynamotors for ringing and operating the interrupter for howler. These ringing machines deliver alternating and positive and negative pulsating current, alternating current only being carried to the switchboard ringing circuits, and there wired for direct and two-party ringing service.

One machine is operated on a 120 volt lighting circuit as an auxiliary, the other being operated from the accumulators, for most, if not all of the time. The motor-generator set is also operated from the lighting and power service of the building, and has been the only source of charging the accumulators up to May 15, 1910, at which time a fifty-ampere mercury arc rectifier charging panel was put in operation. The rectifier panel is operated from a 40 cycle shop circuit at 120 volts, which is transformed at about a 1 to 1 ratio. This transformation is necessary to produce an insulation between the outside circuit and telephone system through the panel wiring, for protecting the telephone system from danger incidental to direct connection to an outside power source. Thus far, the rectifier has worked very successfully and satisfactorily, there having been no disturbances in the talking circuits, and the whole system having operated as well as before.

There are also installed two curve drawing ammeters, giving on a chart continuous ampere-hour discharge readings during the operation of the system, these charts being filed for reference. When used in connection with the electrically operated counter, which is located at the chief operator's desk, these ammeters furnish desired information as to switchboard load and energy consumed, the counter showing the calls of each individual operator, and thus giving an excellent check on the operating service and the distribution of load per operator.

The power panel consists of the necessary switches, fuses, circuit-breakers, voltmeters and ammeters, reverse current relay, starting rheostats, etc., used in connection with the power apparatus described above.

Distribution of Service

The method of distributing service throughout the plant follows the methods adopted in the city exchanges. For distribution of service in the office building, three 200-pair and one 150-pair lead-covered cables are taken from the main distributing frames to three convenient points in the basement, and terminate individually on connecting strips. From these points the final distribution is carried out in 10 vertical risers, the location and size of the risers being planned to cover the area of the building efficiently. The capacity of the risers varies, there being installed okonite cables of 10, 15, 25, 30, 50 and 100 pairs, these being multipled on each of the 7 stories and basement. The principal leads from the terminal room to the various points for distribution outside of the main office building (usually in some of the larger buildings), are caried underground in standard paper-insulated lead-covered cables, approximately $1\frac{1}{2}$ miles of this cable being in use in sizes of 100, 200, 300, and 400 pairs. From these buildings used as distributing points, the final cable distribution is carried further either in lead-covered paper-insulated cable or in rubber-insulated cable, depending on conditions, the cables being attached directly to the buildings, and, when necessary to cross avenues, carried aerially, suspended from the messenger wire, or run underground.

Cable boxes, with protectors installed, are used in all cases to furnish the necessary protection to cables and office equipment. All substations are individually protected against heavy current and lightning, except in cases where the line does not pass out of the building containing the cable distributing box. All factory lines are carried on porcelain, the equivalent of such devices used for wires of lighting potential. Underwriters' rules applying to telephone installation are carried out carefully.

Instruments in Use

Nine hundred and seventy-six instruments are in use, of which 516 are located in the office building. Of the 516 sets, 240 are direct lines, one station on a line; 202 are direct lines having the second and sometimes the third extension station used, particularly for convenience in the large offices where the calls are not numerically great enough to warrant additional individual circuits; while 74 are on two-party lines, selective ringing, and cover conditions where parties are located in different offices. In addition to the foregoing, 460 instruments are used throughout the factory offices and buildings. Of these, 204 are direct lines, one instrument on a line; 111 are direct lines, using second and third extension stations on a line; while the balance, 145, are two-party circuits, selective ringing.

Calling Rate

It is estimated, taking an average of the calls on three business days, that some 7,143,286 telephone calls are made annually. This includes incoming and outgoing messages between the various offices and factory departments as well as toll calls and calls over the leased wires to New York, Pittsfield and Lynn. This does not include calls made on Sundays or Saturday afternoons, at which time the factory and general offices are closed; however, an operator is on duty and some business is handled.

A record kept on February 2, 1911, from 8 A.M. to 5:30 P.M. showed the total number of local or factory calls to be 22,577, not including toll calls, which numbered 759. The total amount of business handled that day, including local or factory and toll calls, was 23,336. The calls during that night from 5:30 P.M. to 8:00 A.M. were 132, and are not included in the above figures for the day's work.

The maximum number of local calls on that day for any one half-hour was 2020 between 9:00 A.M. and 9:30 A.M., while the minimum number was 200, between 12:00 A.M. and 12:30 P.M. The maximum number of toll calls for any one half-hour was 79, between 4:00 P.M. and 4:30 P.M., and the minimum was 2, between 12:30 P.M. and 1:00 P.M.

The maximum number of calls for any one half-hour from 5:30 P.M. of that night and 8:00 A.M. the following morning were 148 between 7:00 A.M. and 7:30 A.M.; the minimum being 1 between 1:30 A.M. and 5:00 A.M., no calls being passed for 10 one half-hour periods, the longest period being from 12:30 A.M. to 3:30 A.M.

The greatest number of calls handled by any one individual operator during a half-hour period was 303 (between 9:00 A.M. and 9:30 A.M.); the smallest number was 40 (between 7:30 A.M. and 8:00 A.M.).

The outgoing calls to the city during 1910 were 211,543—an average of about 17,628 calls each month and about 676 daily.

Operating Force

The operating force consists of 15 girls, two of whom are toll operators, ten local operators, one relief operator, a chief operator, and assistant chief operator, with one electrician and an assistant to care for power plant, and to handle construction and maintenance of system. One toll operator acts as a recorder, receiving all outgoing toll business, and takes care of the two leased wires to Lynn and New York. The other toll operator takes care of all incoming and outgoing toll business, the Pittsfield leased wire, and times the long distance toll connections. The ten local operators take care of all factory calls and incoming and outgoing city calls. Each operator has a relief of fifteen minutes morning and afternoon. The chief operator, in addition to supervising the switchboard and operating room, keeps account and collects charges for all personal toll calls made by employes.

THE FIXATION OF ATMOSPHERIC NITROGEN

By Dr. Milton W. Franklin

One of the most pressing of modern problems is the supply of combined nitrogen for agricultural purposes. There are three substances, essential to the life of plants, which are being constantly extracted from the soil by the crops growing thereon. These are nitrogen, phosphorus and potassium.

The continual abstraction of these substances from the soil without any corresponding replacement renders essential their periodic application if the soil is not to be unduly impoverished. In early agricultural operations, animal fertilizer sufficed for the needs of the time; but during recent years the supply has become greatly inadequate, and it becomes essential that some form of artificial fertilizer be employed. Nitrate of soda and sulphate of ammonia have been extensively used for this purpose and have answered perfectly well. The supplies, however, are extremely limited and the consumption is increasing at an enormous rate. It is estimated that the consumption of Chili saltpetre increased from 250,000 tons in 1850 to 1,540,000 tons in 1903, and at the present time the rate of consumption is of the order of 2,000,000 tons per year. It is estimated that the supply cannot last more than about twenty years. Within the last year or two, the price in Germany has increased about 40 per cent. For many years Peruvian guano has been used, but the supply has become exhausted. The sewerage of cities, if utilized in an efficient manner, would prove at best but an insignificant item in the total world's demand. It has been estimated that in England alone there is wasted through her sewers 880,000,000 per year; and to date, no efficient method has been proposed for the satisfactory utilization of city sewerage.

Sulphate of ammonia is now manufactured in large quantities as a by-product in gas works, and also in the Mond Power Gas generating stations. It is, however, improbable that this class of combined nitrogen can successfully replace Chili saltpetre when the latter shall have become exhausted. The ratio in which the two substances are used at the present time is 2 : 5, the consumption of ammonia sulphate in Germany during 1904 being estimated at about 202,000 tons and that of Chili saltpetre about 500,000 tons. The above ratio applies to Germany, the largest user of artificial fertilizer, but the ratio for the whole world is placed at 1 : 4. At the same time it must be considered that the world's supply of coal is extremely limited, and that therefore even should the production of ammonia and sulphate by the Mond process be enormously increased, the limit is nevertheless defined.

The atmosphere surrounding the earth contains a supply of nitrogen equal to about $4.041 \times (10)^{15}$ tons. This is estimated on the basis of 31,000 tons of nitrogen per acre of surface of the earth, at which rate the air over every nine acres contains about 280,000 tons, equivalent to the amount of Chili saltpetre used in the year of 1907. Roughly speaking, four-fifths of the air which surrounds the earth is nitrogen.

Nitric acid is an acid compound of hydrogen, nitrogen and oxygen. The formula is HNO_3. It is interesting to know that in 1669 Mayo wrote of nitric acid as containing two components; one from the air and the other from the earth. In 1776 Lavosier demonstrated its oxygen content, and Cavendish demonstrated its complete composition by preparing it synthetically from oxygen and nitrogen in the presence of water. Nitric acid does not occur in a free state in nature; but after thunderstorms, traces of it may be found in the air and in rain water, and according to one authority, amounts up to 0.66 mg. per liter are found in rain falling on the Alps. It occurs largely combined in the form of alkalin nitrates in Chili and elsewhere, the formation of the nitrates being supposed to have originated in the putrefaction of nitrogenous organic matters. The latter are assumed to be converted into ammonia, and this to be oxidized in the presence of hydroxide, sodium, potassium and calcium. Chemically, it is an exceedingly inert element, and its compounds until recently have been produced artificially only from the decomposition of more complex organic compounds, as in the manufacture of coal gas.

Nitrogen compounds are essentially unstable chemically, and it is this instability which has rendered the fixation of nitrogen difficult of accomplishment by artificial means, the critical temperature of dissociation existing so near the temperature of combination that disintegration is prone to occur immediately the combination has been brought about. This in fact is but a phase of the instability of nitrogenous compounds.

There are two proven methods for fixation; viz, the Birkeland-Eyde process, and the Cyanamide process of Caro and Frank. A modification of the Birkeland-Eyde process, due to Dr. Schonherr and operated by the *Badische Aniline und Soda Fabrik*, is also worthy of description.

In the Birkeland-Eyde process, a high-tension alternating current flame is blown into a disk transversely to a direct current magnetic field. The gases mixed with steam are passed directly over lime. This process is modified in the *Badische Aniline und Soda Fabrik* in whose process long threadlike arcs are employed. The air is blown tangentially so as to circulate spirally around the arc.

The difficulties which have beset the development of these processes in the past have been the high cost of electric power, and the fact that the process of nitrogen fixation in the flame is a reversible one. At certain critical points the combined nitrogen is again decomposed: and it is with the perfection of this detail that the whole development has been concerned, cheap water power having been available in many places for some time.

In the processes based upon this principle, the object is to produce NO_2 and NO which combined with water give a mixture of nitric and nitrous acids. From this is produced calcium nitrate, in which form the fertilizer is sold.

In the Cyanamide process, of Caro and Frank, the calcium carbide is first produced in an electric oven, and, while red hot, is treated with liquid nitrogen, the result being a calcium-nitrogen compound.

The first attempt on anything like a commercial scale at the fixation of atmospheric nitrogen was made by Bradley and Lovejoy at Niagara Falls, but although the greatest credit is due to both of these experimenters the results were unsatisfactory technically. The Birkeland-Eyde process followed, and was really the first to produce satisfactory results. This was, however, owing in a large measure to the fact that cheap water power was available in abundant quantity. The Birkeland-Eyde process may be described briefly as follows:

The apparatus consists of a pair of water-cooled copper tubes 15 mm. diameter employed as electrodes. These electrodes are suitable for flames up to 750 kw. at 3500 volts with a gap of 1 cm. The electrodes are placed in a magnetic field of about 4000 to 5000 lines of force per square centimeter in the center. This field blows the arcs into the form of a large fan, the maximum diameter of flame being about 140 cm. The object of the magnetic blow and arrangement is to increase the rate of cutting of the flame and the air, which is also assisted by the air blast supplied. The furnace in which the discharge takes place is lined with fire-brick and is said to last about six months. The inside temperature of the lining does not rise above 700 deg. C. during normal working, owing to the cooling effect of the blast of air supplied, although the temperature of the disk of flame is very considerably higher. The results are extremely good as will be seen by reference to table I. This is partly because the power employed is large, and partly because the rate of cutting of the air with the flames is high, both being conducive to efficient working.

Of the foregoing description, Prof. S. P. Thompson made the following criticism: The authors had hardly appreciated the importance of the spontaneous further oxidation of the gases formed in the passage of the air through the flaming arcs. The gases, after they left the furnace were not treated with water or lime until they had been allowed to remain (and cool) a considerable time in large oxidation chambers. If that were not done a very large proportion of liquid formed in the water tanks would be nitrous, instead of nitric acid. It seemed to him that 900 kg. of nitric acid per kw-year was too high for the average commercial yield of that process. If he remembered rightly, this was an exceptional, not an average figure; the average figure being nearer 600 kilos. It was well that there should be no exaggeration, and he happened to know that in Norway the experts expressly took a lower figure, so as to have a margin of safety in their calculations. The large scale working of the new factory at Notodden had certainly shown a higher economical yield than that assumed in the estimates.

That the Birkeland-Eyde process might not be successful in this country is suggested by Dr. Frank as follows: The production of calcium nitrate $(Ca\ N\ O_3)_2 + H_2O$, prepared by dissolving CaO or $Ca\ CO_3$ in $(HNO_3)Ag_1$ by the Birkeland-Eyde process, seems to be developing exceedingly well in Norway. It should, however, be noticed, that this industry has not made much progress in any other land save Norway; but it should not be forgotten that it is only in this northern clime that electrical energy can be cheaply obtained on account of its unrivalled resources of water power.

The *Badische Aniline und Soda Fabrik* process is one of the newer ones, which promises to give results superior to those obtained by the Birkeland-Eyde process. The air is blown tangentially so as to circulate spirally around the quietly-burning arc. In some examples of this apparatus recently exhibited the tubes are of glass, coated on the inner periphery by a wire spiral, which is in metallic contact with a knob at the top of the tube. At the bottom of the tube, the wire spiral is separated only by a short distance from the other electrode, which is placed in the axis of the tube. When a 3000 volt supply is applied between the two electrodes a spark jumps across and the arc travels rapidly up the tube. If air is forced through the bottom, in a number of symmetrically placed tangential nozzles, the arc burns quietly in the axis of the tube, without touching the sides, and absorbs about four amperes at 3000 volts. The air charged with nitrous gases which leaves the top of the tube, gives up some of its heat in raising the temperature of the fresh air, about to enter the tube, to some 500 deg. C. and the rest is employed in steam generation. The cooled gas is then mixed with water to form nitric acid, which, after treatment with lime, results in the required manuring material. An experimental installation on these lines was opened in Christiansand (South Norway) in the spring of 1907, with a total power of 2000 h.p. Three ovens are at work, each with a length of flame of five meters and absorbing 600 h.p., alternating current of fifty cycles is employed, and the arc burns quietly and reliably.

The third and perhaps the most important process at the present time is the Cyanamide process of Caro and Frank, which has been briefly referred to above. The process appears to yield the best results per horse power expended and is described by Dr. Frank as follows:

The carbide coming from the electric furnaces is ground-charged into retorts made of fireproof material which are mounted in a furnace similar to gas-house furnaces. The nitrogen is then passed over the carbide at a temperature of from 800 deg. to 1000 deg. C. The carbide used is of the same quality and percentage as that employed for lighting purposes, and the nitrogen is obtained by fractional distillation of liquid air by the Linde system, or the so-called "copper" process in which air is passed through heated copper particles. The copper takes up the oxygen and the free nitrogen passes to the furnaces. The resulting copper oxide is reduced in the same apparatus by treatment with reducing gases or vapors, and the copper which is removed is then ready for a new cycle. In the Linde process the oxygen remaining after separation of the nitrogen may be utilized for any purposes. As soon as the carbide in the retorts is saturated with nitrogen, a fact which will be made apparent by the controlling gas meter coming to a standstill, the calcium cyanamide is extracted from the retort in the form of a hard cake and cooled while the air is excluded. It is then ground to a fine powder and is ready for use. Recently a new electric furnace has been developed for treating carbide with nitrogen and is being universally adopted by all the new cyanamide factories.

The calcium cyanamide obtained is only about 57 to 63 per cent. pure, and is known as lime nitrogen or nitrolim. It contains about 20 to 22 per cent. nitrogen, about the same as sulphate of ammonia. Most carbide works yield about two tons of carbide per kw-year, and two tons of carbide will combine with practically 500 kg. of nitrogen in the form of nitrolim; a power of 2 kw. is required per year for fixing one ton of nitrogen by the Caro and Frank process. In addition thereto about one-third of one horse power is required for grinding and all other separations.

At twenty dollars a kw-year then the cost of power to produce one ton of nitrogen would be forty-five dollars, and for one ton of nitrolim nine dollars. Comparing the Birkeland-Eyde process with the Caro and Frank cyanamide process, Dr. Frank pointed out that the works at Odden which produce 2500 tons of nitrogen only employ 5000 kw. to 6000 kw.; whereas from the statement of Mr. Eyde it appears that in the works at Notodden in Norway, for the preparation of an equivalent amount of nitrogen in the form of nitrate of calcium, 25,000 kw. are required. At twenty dollars a kw-year this would mean two hundred dollars for electric power per ton of nitrogen or twenty-five dollars per ton of calcium nitrate ($Ca\ [NO_3]_2\ 4\ H_2\ O$).

The figures on page 475 are derived from data given in papers by various authors and may not be accurate.

TABLE I

	Formula	Cost per Ton	Per Cent. N	Cost per Ton N
Sodium nitrate	$NaNO_3$	$40.00	19	$210
Ammonia sulphate	$(NH_4)S_2O_4$	57.80	22	260

TABLE II

	Formula	Cost of Production per Ton at $20 per Kw-year	Per Cent. N	Cost of Production per Ton of N at $20 per Kw-Year
Calcium cyanamide	$CaCN_2$ (Crude)	$9	21	$45
Calcium nitrate	$Ca(NO_3)_2 4H_2O$	25*	12	200*

In regard to the relative merits of cyanamide and nitrate of lime as a commercial product, Sylvanus P. Thompson expressed himself as follows: There was no doubt that the two successful processes today were the nitrate of lime process and the cyanamide process, but though both of them took nitrogen from the air, the products were of different character. Nitrate of lime has proved to be just as satisfactory for agricultural purposes as nitrate of soda, and, in the case of a heavy clay soil, the lime in it gave it a preference. Cyanamide, on the other hand, was akin to sulphate of ammonia rather than to nitrate of soda, and competed with the former rather than with the latter. Moreover, nitrate of lime had certain important applications in the coal tar color industry for which the cyanamide would not serve.

While the above figures would indicate that the cyanamide process is the more economical, the results of experiment do not seem to demonstrate that the product of this process is as generally satisfactory as that of the direct air process.

In practice it has often been found that some uncombined calcium carbide has remained in the nitrolim, and has proven offensive in generating acetylene upon becoming wet. Cyanamide manufacturers claim that this objection has been satisfactorily remedied and that the process is cheaper; but the fact remains that a good deal of capital has been, and constantly is being, invested in processes which effect a direct combination of oxygen and nitrogen from the air.

In *Zeit. f. Elektrochemie*, January 1, 1911, a review is given by F. Haber and A. Koenig of the present status of fixation of atmospheric nitrogen. The following table sums up the results obtained with the three successful processes in commercial operation; the process of the *Badische* Company (Dr. Schonherr) the process of Birkeland and Eyde, and the process of *Salpetersaure-Industrie* Company (Pauling).

	Grams HNO_3 per kw-hour	Concentration in per cents NO.
Badische Company	75	2.5
Birkeland and Eyde	70	2
Pauling	60	1 to 1.5

The table gives both the yield in grams HNO_3 per kilowatt-hour and the concentration in per cent. of NO, since both items are of fundamental commercial importance.

The comparison with theoretical figures is difficult. The commercial yield of the process of the *Badische* Company is about 63 per cent. of the theoretical value obtainable (without regeneration of heat), on the hypothesis that the oxidation of the nitrogen is a purely thermal process and that the temperature of the arc is 3800 deg. C. The authors give a very useful review of the various scientific investigations made in recent years on the mechanism of the oxidation of atmospheric nitrogen by electric discharges through the air.

It may be concluded that the fixation of atmospheric nitrogen opens a vast field for manufacturers of electrical apparatus. The total kilowatt capacity of electrical machinery already installed is very large, and with the refinement of existing processes and the development of new methods, it may be expected that there will be created an increasing demand for specialized electrical appliances. The subject of frequency and its influence on the process has not been closely examined as yet, and much research will have been prosecuted before a knowledge has been obtained of just what potentials fulfill the most nearly ideal requirements.

* Birkeland-Eyde process.

THE WATER POWER DEVELOPMENT AND TRANSMISSION SYSTEM OF THE CONNECTICUT RIVER POWER CO. AND CONNECTICUT RIVER TRANS. CO.

By J. B. Mahoney, Station Superintendent

The Connecticut river (from the Indian name "Quonekticut" meaning long river) has for its source the Connecticut Lakes in northern New Hampshire, with tributaries extending into the Province of Quebec, Canada. It flows in a southerly direction through the state of New Hampshire, and for about three quarters of the length of Vermont and New Hampshire its west shore forms the boundary line of these states. Just before it reaches the junction point of the states of Massachusetts, Vermont and New Hampshire, it turns abruptly on itself and flows in a northeasterly direction for about ½ mile, thence turning and continuing south through Massachusetts and Connecticut and discharging into Long Island Sound.

At this abrupt turn in the river and directly across from each other are situated the towns of Vernon, Vt., and Hinsdale, N. H. Here is located the site of the dam and power house of the Connecticut River Power Company. The immediate vicinity of both these towns is particularly rich in historic memories as the scene of many sharp conflicts between the early settlers and Indians. Within a short distance of the dam were located Fort Hinsdale on the east side of the river and Forts Dummer, Sartwell and Bridgman on the west. At different times all suffered from the attacks of the Indians and on several occasions were captured and destroyed, only to be rebuilt by the persistent and hardy settlers. Of particular note is the attack and capture of Fort Bridgman in 1755. The Indians having ambushed the men while working in the fields easily took the fort and carried off into Canada three families, among whom were Jemima Howe and her seven children, ranging from 6 months to 11 years in age. The story of this woman's sufferings graphically depicts the sturdy

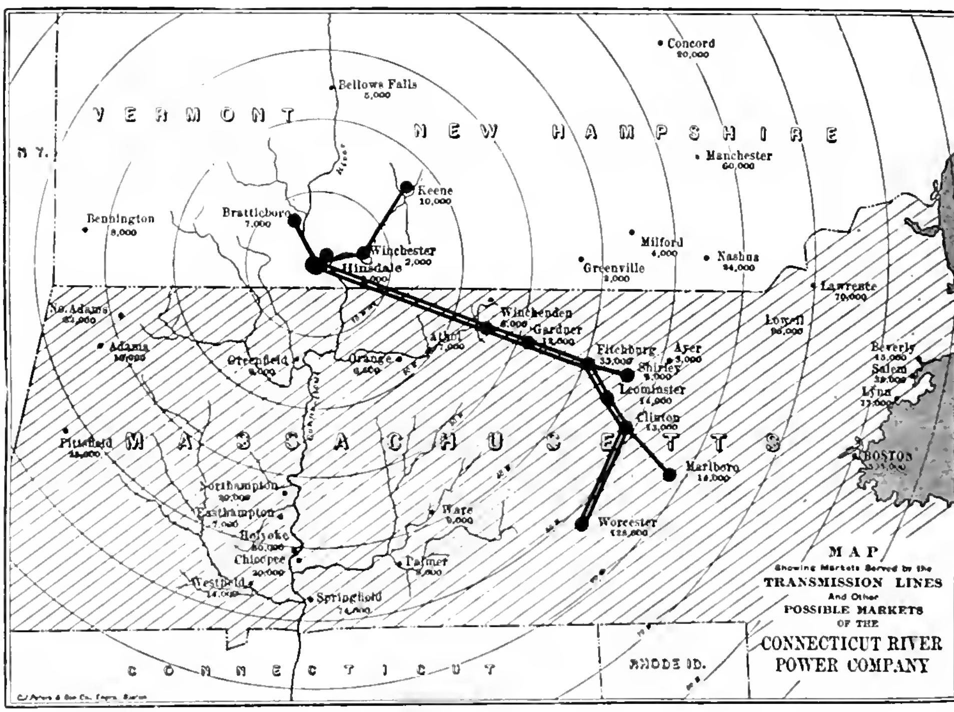


Fig. 1. Map Showing Transmission Lines of the Connecticut River Power Company

character and hardihood of these early settlers; for although her children, with the exception of the 6 months infant, who died from exposure on the march to Canada, were separated and distributed throughout the provinces, she succeeded in gathering them together after many years of effort and privation, and outlived them all.

Just before the river sweeps around the short curve previously mentioned, it breaks into quick water. It was long ago realized that this fall in the river, together with the immense water shed of nearly 6500 square miles and the proximity of Massachusetts with its numerous factories, offered an unparalleled site for an hydro-electric installation. In the years 1902 and 1903, a number of public spirited citizens of Brattleboro, six miles up the river, organized a popular subscription for the funds necessary to defray the expenses of an investigation to determine the feasibility of building a dam and power house on this site, and in the same years secured the necessary charters from the state of New Hampshire. Later they succeeded in interesting some Boston capital, and the year 1907 saw active work on the proposition well under way. In June, 1909, seven years after the matter was first agitated, power was first delivered.

The dam proper, which also forms the spillway, is of the ogee type, 600 feet long and built of reinforced concrete on solid rock foundation. For about two-thirds of its length it is hollow, thus providing for the necessary space required for flood gate gearing. These gates, of which there are ten, are motor operated and made of steel. Each gate is nine feet by seven feet and capable of discharging 2520 cu. ft. of water per second, or a grand total of 25,200 second feet, which, together with the capacity of the spillway, will take care of any floods without endangering properties bordering on the river. With water at the crest of the dam, a lake 16 miles long is formed, and with four feet of flashboards in position, the water is backed up about 30 miles.

The power house is locate' in the bed of the river and forms the connecting link between the dam proper and the west, or Vermont shore. The substructure is of reinforced concrete and the superstructure of brick with steel skeleton framework. There is one main floor, 216 feet by 55 feet,

Fig. 2. Spillway of Dam in Course of Construction Showing Location of the 10 Floodgates

on which are located the generators, exciters and switchboard. A gallery extends the full length of the building and on this are placed the high tension switches and busbar. Directly under this gallery and leading off the main floor are compartments in which are installed the transformers, consisting of four 5000 kw. and one 2500 kw. units.

A basement on the north side contains the thrust bearings, governor and thrust bearing pumps, and all necessary shafting for driving them. A second basement on the south side contains the 2300 volt busbars and switches, as well as a storage battery, transformer oil treating tanks, and storeroom.

On the east wall of the power house is located a log sluice for convenience in passing logs by the dam, the water passing through this sluiceway being controlled by means of a bear trap dam. The Connecticut is one of the largest logging rivers in the country and some extremely large drives have been made on it. This year the drive contains 15,000,000 feet of lumber.

Each generator has a normal capacity of 2500 kw. at 80 per cent. power-factor, and is wound for 2300 volts at 60 cycles; the speed of the generator being 133 r.p.m. The exciters are of 300 kw. capacity and deliver current at 110 volts. All units are of the vertical type and are of General Electric manufacture. There are a total of 8 generators and 2 exciters.

The waterwheels were manufactured by the S. Morgan Smith Co., each unit being made up of two 60 in. runners and one 57 in. runner. The two lower, or 60 in., runners are used in normal water conditions and develop the rated power of the generator under the prevailing head of 32 to 34 feet. These runners are regulated by a Type N Lombard governor, specially designed for this installation and capable of full gate travel in 1½ seconds. The upper, or 57 in. runner is controlled by means of a handwheel located on the main floor and is normally run idle. In times of flood conditions, when the effective head is reduced, these top runners are put in service, thus compensating for the reduction in head and equalizing the available power. The gates on all the wheels are of the wicket type.

The entire revolving element of each main unit is supported by a thrust bearing located in the thrust bearing chamber, between the generator and waterwheel. Each unit has an independent chain driven triplex pump, which pumps the oil direct from an individual settling tank to the thrust bearing. In addition to this, a common oil header is provided with an auxiliary pump driven mechanically from the exciters for purposes of starting and stopping. A second auxiliary pump is provided for emergency purposes. The thrust bearings are of very liberal design and support the revolving weight of some 40 tons without any undue heating of the oil, and no artificial means of cooling the oil is necessary.

A lignum vitae step block is located at the extreme lower end of the shafting to support the revolving element when at rest. As soon as the oil is turned on the thrust bearing, this step block is relieved. The only bearings besides these are the lignum vitae steady bearings in the waterwheel and two babbitted steady bearings in the generator. Lubrication is provided for the latter by means of an electrically driven pump which raises the oil from a settling tank in the thrust bearing room to an overhead tank located on the high tension gallery, whence it flows by gravity through a common header to the different bearings. A mechanically driven pump is also provided for emergency purposes.

The exciters are supported on bearings of the roller type lubricated from the same system as that which supplies the steady bearings of the generators.

The entrance of water to each wheel is controlled by means of two wicket gates and

Fig. 3. View of Dam and Power House from Vermont Side

one large steel gate. This latter gate is hinged on the bottom and opens upstream. Its operation is controlled by means of a chain which extends up to the main floor, where an electrically operated crane may be attached to it. The racks are placed in front of the gates and in front of these a concrete curtain wall 9 feet in depth is located. About 1500 feet north of the power house the shore line extends far out into the river, thus providing a natural canal for the station. This, together with the unusual depth of the pond in the immediate vicinity of the installation, has made anchor ice and ordinary rack troubles unknown quantities.

All transformers are of General Electric manufacture, and are of the three-phase, water-cooled type. The four 5000 kw. units are wound for 2300/66000 volts and are connected delta-Y with the neutral grounded. Suitable taps are brought out for intermediate voltages. The 2500 kw. unit is wound for 2300/31500 volts and is connected delta-delta, giving 19,100 volts for the Brattleboro and Keene lines. A permanent connection is made to one of the 5000 kw. units for use in case of a break down in the 2500 kw. transformer. The oil in these transformers is tested at stated intervals and unless it stands a predetermined voltage, it is treated in a special system installed in the 2300 volt chamber for the purpose.

The switchboard consist. of 19 slate panels, marine finished. A dummy busbar is mounted on it, giving in miniature all the station connections. This has worked out exceptionally well. A voltage regulator is installed on one end of the board and a storage battery panel on the other. Twenty-four relay contacts are contained in the voltage regulator, 12 for each exciter. It is therefore one of the largest so far manufactured by the General Electric Company. The storage battery is used for the switch signal lights and for operating the oil switches, which are all remote controlled. An emergency connection from the exciters is also provided for this purpose.

The general wiring scheme of the station is simple yet sufficiently flexible to permit of all desired combinations. As will be noted from the accompanying sketch, two generators and one 5000 kw. transformer comprise one complete unit capable of being isolated on any one line or busbar, or of being operated in parallel with the other units. This arrangement also permits of any generator being run on any transformer.

Each generator is provided with two K-4 non-automatic, electrically operated oil switches, so arranged that the machine can be operated either on the main 2300 volt transfer bus or on its own transformer. Between these switches and the transformer, an automatic H-3 switch is provided. K-10 switches of the automatic type are installed on the 66,000 volt side of the transformers as well as on the outgoing

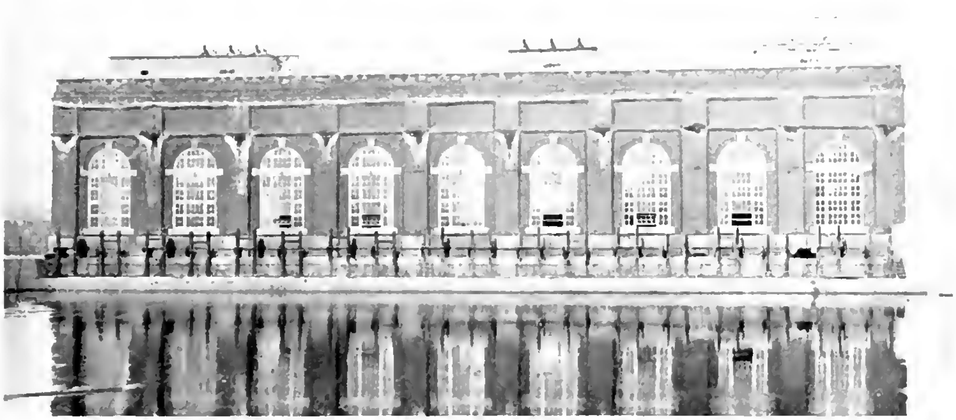


Fig. 4. North View of Power House Showing Racks and Head Gates

66,000 volt lines. Time limit relays of the inverse type control the K-10 switches, while the H-3 switches are provided with those of the definite type. The only apparatus on the 66,000 volt side of the station are the series relays for controlling the K-10 switches.

At present there are five lines extending from the station; two operating at 66,000 volts, two at 19,100 volts, and one at 2300 volts, the last supplying power and lights locally in the town of Vernon. All lines are protected by arresters of the electrolytic type suitably housed on the roof.

The first of the 19,100 volt lines runs direct to Brattleboro, a distance of six miles, where 300 h.p. is supplied to the Twin State Gas and Electric Company for street railway, power, and municipal purposes. A branch is taken from this line just as it enters Brattleboro and runs to the Estey Organ Works, one of the largest manufacturers of organs in the world. In this plant are installed 81 motors ranging in size from $\frac{1}{4}$ h.p. to 40 h.p. Both the individual and group drives are used with very satisfactory results. The average daily maximum demand is 175 h.p., with a power-factor of 85 per cent. A large cotton mill now under construction, known as the Fort Dummer Mills, will be put in operation this fall. A contract for 1000 h.p. has been closed with them. Besides these concerns, there are a number of other smaller manufacturers taking from 50 to 75 h.p. each.

The second 19,100 volt line extends directly across the river to New Hampshire and on to

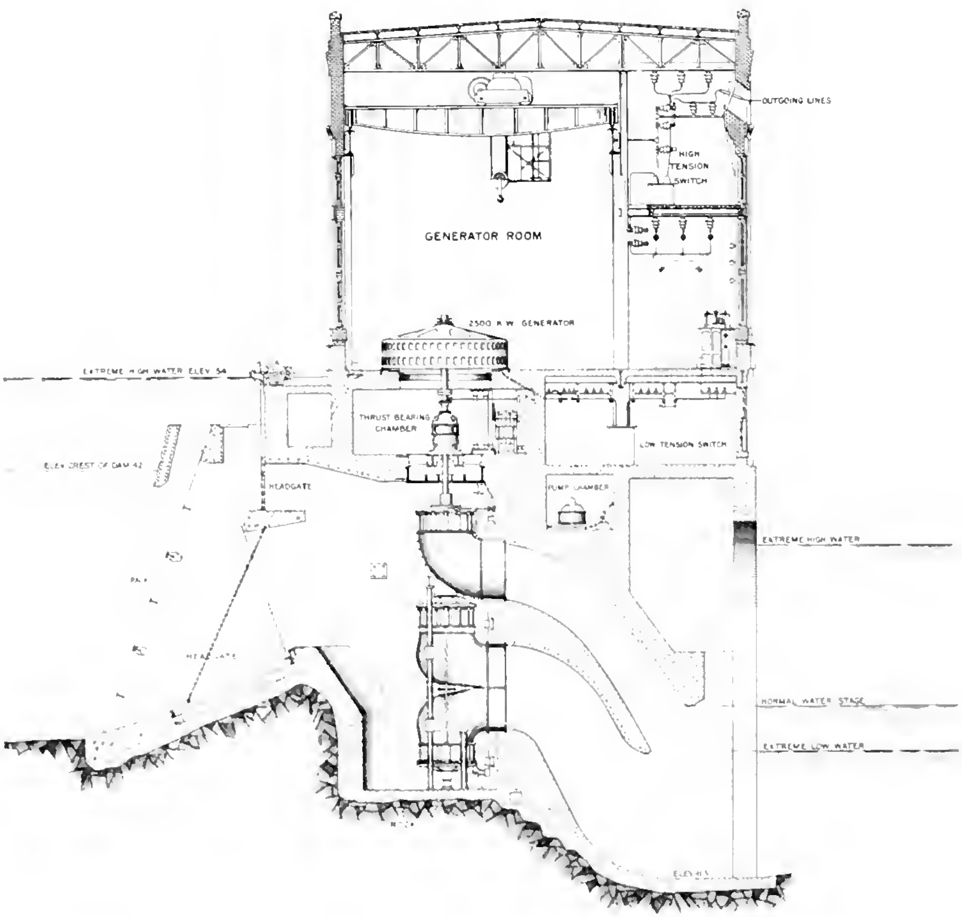


Fig. 5. Cross Section of Power House Showing Construction of Waterwheels and Location of Apparatus

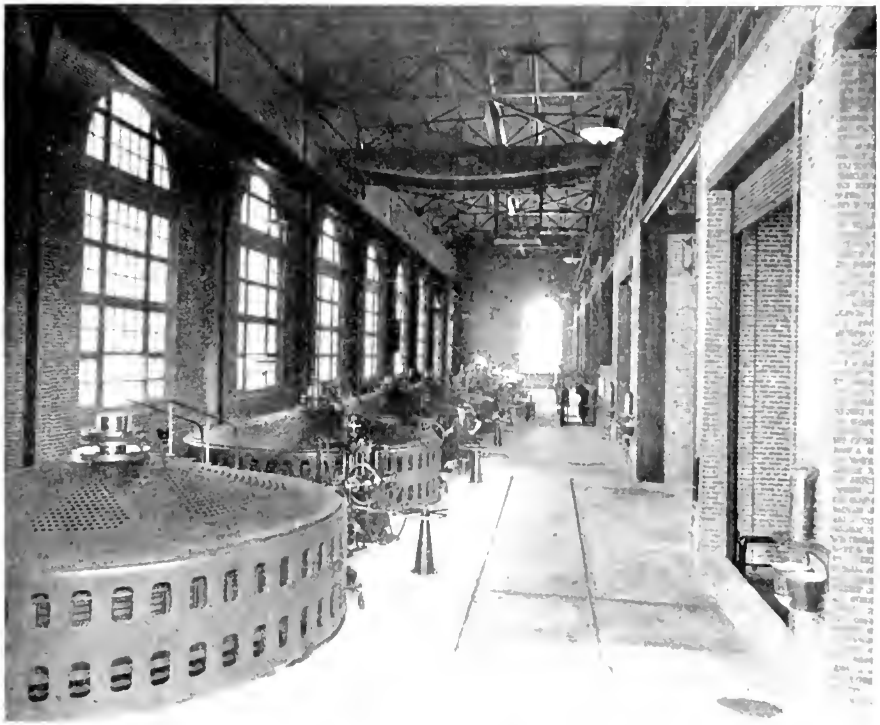


Fig. 6. View of Main Floor Showing the Eight 2500 Kw. Generators

Fig. 7. Thrust Bearing Chamber

Keene, a distance of about 20 miles. This line is not yet fully complete but is being pushed forward rapidly and will be in operation before the end of summer. A contract has been made with the Keene Gas and Electric Company for 500 kw. with privilege to increase this to 1500 kw. as required. This line is being built by the Keene Company who will also operate and maintain it.

The two 66,000 volt lines extend diagonally across the river from the roof of the power house—a distance of 1320 feet—and continue in a southeasterly direction across a corner of the state of New Hampshire on into Massachusetts, passing through the cities and towns of Hinsdale, Northfield, Warwick, Royalston, Winchendon, Gardner, Fitchburg, Leominster, Sterling, Clinton, West Boylston, Marlboro and into Worcester, a distance of 66 miles. The conductors are made up of No. 2 B.&S. copper cable carried on 35 lb. insulators supported on steel towers of the two circuit type built by the American Bridge Company. With the exception of the first span from the power house and a span of 1940 feet across the Wachusett reservoir in Clinton, the average spacing of the towers is 410 feet. There are a total of 885 towers on the main line exclusive of 36 more on a branch line running from the Fitchburg switch tower to the substation. Switch towers with suitable disconnecting switches are located about every ten miles, which brings them at Warwick, Royalston, Gardner, Fitchburg and Clinton. At each of these points patrolmen are stationed nearby who can quickly sectionalize the lines and localize the defect in case of trouble. A private telephone line made up of No. 4 copper clad steel wire extends the full distance of the transmission line and is tapped into every substation. This is also sectionalized at every switch tower. At every point on the system where a telephone instrument is installed, protective apparatus in the shape of an electrolytic arrester and drainage coil is also located. The service of the telephone system has been very satisfactory, very few cases of serious trouble having been experienced. A No. 5 copper clad steel ground wire supported on a central mast is carried the full length of the transmission line and grounded at every tower. Interruptions from lightning have been very scarce.

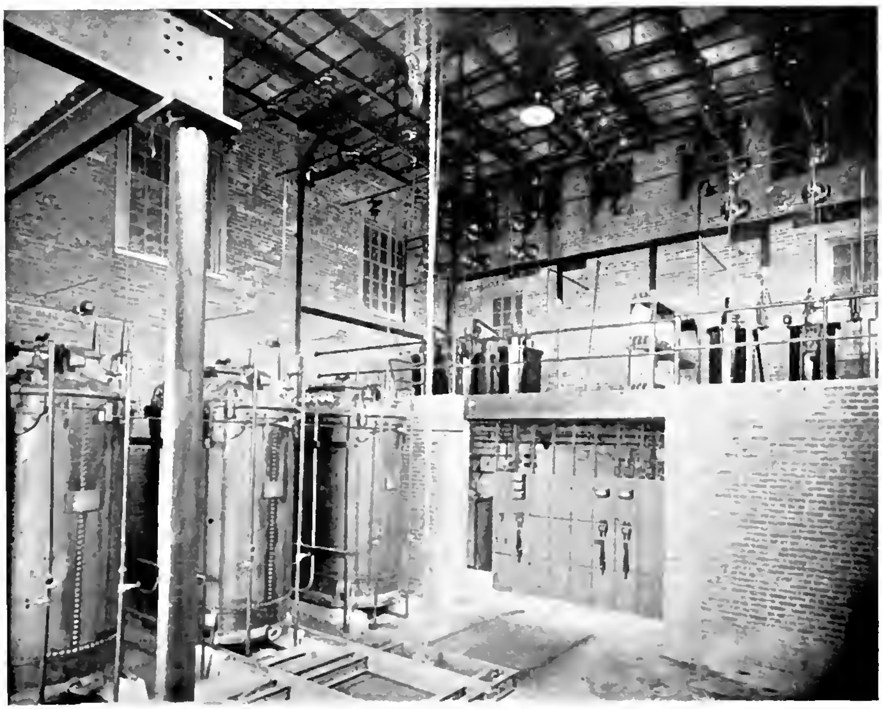


Fig. 8. Interior View of One of the Substations

At the Gardner switch tower the main line is tapped and the branch carried on wooden poles to the substation of the Gardner Electric Company. The present transformer capacity of this station is 1500 kw., current being transformed from 66,000 volts to 2300 and 6600 volts for street lighting and commercial purposes. There are also located here Diesel oil engines with a capacity of 750 h.p., which can be used by the Connecticut River Transmission Company, if desired, during low water periods.

At the Fitchburg substation are installed seven 1500 kw. transformers, six of which are connected in two banks of three each, the remaining transformer being held for emergency purposes. Both lines are brought from the junction tower just outside the city to the substation, where they pass through suitable air break switches and K-10 oil switches to the transformers, which reduce the potential to 6600 volts for local distribution. The customers at present supplied with Connecticut River energy are the Fitchburg Gas & Electric Company (1000 h.p.), three mills of the Parkhill Manufacturing Company (1920 h.p.), eight mills of the Crocker-Burbank Company (2200 h.p.), De Jonge Paper Company (900 h.p.), and the Falulah Paper Company (500 h.p.). It is of interest to note here that all the paper used in printing the "Saturday Evening Post" and "Ladies Home Journal" is manufactured in the Crocker-Burbank Mills.

At Clinton, the junction tower is located just outside of the substation. In this station are provided four 1500 kw. transformers, three of which are connected in one bank, with one spare unit for emergency. The voltage is reduced from 66,000 to 13,200 volts, at which potential it is supplied to the Lancaster Mills and the Marlboro Electric Company. The former consume 1000 h.p. while the latter require 800 h.p., which is used locally in Marlboro and the towns of Westboro, Northboro, Berlin, Southboro and Shrewsbury. At the Lancaster Mills two 1800 kw. synchronous motor-generator sets are installed, the motors of which operate at 13,200 volts, while the generators deliver current at 40 cycles, 600 volts. A steam plant of 4500 h.p. is also located at this point, and may be used by the Connecticut River Transmission Company whenever necessary. By running the motor-generator sets inversely, this plant can be operated in parallel with the rest of the system.

The Worcester substation is located in Greendale, a suburb of the city of Worcester. The equipment here consists of six 1500 kw. transformers connected in two banks of three, which lower the line pressure to 13,200 volts. One spare unit is provided for emergency. At the present time four overhead lines leave the station, one of which supplies the Osgood Bradley Car Company, Morgan Spring Company, Norton Grinding Company, and the Worcester Pressed Steel Car Company; another extending to the town of West Boylston, where energy is supplied for street lighting and miscellaneous purposes; while the remaining two circuits run into the city of Worcester to a terminal house on Brookfield street, where an underground cable system begins and where suitable protective apparatus and disconnecting switches are installed. From this terminal house two No. 0000 three-phase cables are carried underground to the North Works of the American Steel & Wire Company, a distance of ½ mile. A No. 0 three-phase cable extends from the North Works to the South Works of the Steel Company at Quinsigamond, a distance slightly over three miles. At the North Works the installation consists of two motor-generator sets, one of 500 kw. and a second of 800 kw. capacity. Both motors take energy at 13,200 volts and deliver direct current from the generators at 250 volts.

At the South Works there is an 800 kw. motor-generator installed, which takes current at 13,200 volts and delivers direct current at 250 volts. This machine is used for miscellaneous purposes. There is also an electric furnace which takes about 2000 h.p. This furnace is giving excellent results, the grade of steel being greatly superior to that of the basic furnaces, and the refining is effected in much less time.

At the Bradley Car Company there is a motor installation of about 1500 h.p., the motors ranging in size from 2 h.p. to 300 h.p. The average load is about 500 h.p.

The Norton Grinding Company has an aggregate motor installation of 415 h.p., the motors ranging in size from 7½ h.p. to 100 h.p. The average load runs about 200 h.p., with a maximum demand of 250 h.p.

In the plant of the Morgan Spring Company there are 18 motors, varying from 10 h.p. to 100 h.p. The average maximum demand is 150 h.p.

The Worcester Pressed Steel Car Company require 400 h.p. for their purposes.

In all of the Company's substations the main transmission lines enter through suitable air break and electrically operated automatic K-10 oil switches. The stations are supplied from both lines, which are paralleled with K-10 oil switches, these switches being equipped in each case with reverse current relays. Should a short circuit occur on either line, this paralleling switch would automatically cut that line out and leave the station operating on the other line. Heretofore different substations were run from different lines, the two lines being paralleled at the power house only. As a consequence it was found that during certain load conditions it was almost impossible to meet the voltage requirements of customers operating on different lines, and whenever a short circuit occurred on either line, all customers operating from that line were interrupted until the power was restored; or else they were transferred to the other circuit. The paralleling of the lines in all the stations has greatly improved the regulation of the system and reduced the danger of interruption to a minimum.

All incoming and outgoing lines are protected by electrolytic arresters, and at the transformer station of each customer arresters of the same type are installed. These are charged twice daily at stated periods.

Each substation is equipped with a storage battery for operating the oil switches. All transformers are of the water-cooled type, and for the sake of simplicity all the substations were designed as nearly alike as possible. Fireproof construction was followed throughout.

The company makes two classes of contracts, known as primary and secondary. Under the terms of a primary contract, the company guarantees to deliver the amount of power contracted for, while under those of a secondary contract, the right is reserved to cut off the supply of energy upon reasonable notice. The price of secondary power is, of course, less than that of primary, and in making primary contracts the company is keeping well within the low water capacity of the Connecticut River.

Reciprocal contracts have been made with the Lancaster Mills, American Steel & Wire Company, Marlboro Electric Company, Fitchburg Gas & Electric Company, Gardner Electric Company, De Jonge Paper Company, and Keene Gas & Electric Company, under the terms of which the plants of these concerns are held in readiness for operation and the company has the privilege of using them to turn energy back into its system. The advantage of such contracts is obvious, as they eliminate the necessity of a large investment in a steam auxiliary plant to guard against extreme low water conditions at Vernon.

The company maintains on the premises of all customers both integrating and graphic recording wattmeters which are read daily and calibrated monthly. It is thus enabled to closely follow the characteristics of each load individually.

There are in operation on the system at the present time some 4000 kw. in synchronous motors, which allows a power-factor of between 85 and 90 per cent. to be maintained at Vernon. With the addition of future customers, it is intended to install enough synchronous apparatus to hold the power-factor at this value.

The system was designed and installed by J. G. White and Company, of New York City.

A contract was recently made with the Metropolitan Water & Sewage Board, under the terms of which the Connecticut Company have agreed to take 5,000,000 kw-hrs. per year from them. They have just completed the installation of four 1000 kw. waterwheel driven units at their Wachusett reservoir in Clinton. Delivery of power began August 9, 1911, with very satisfactory results. The Wachusett reservoir is connected with receiving reservoirs just outside of the city of Boston and the energy purchased by the Connecticut River Transmission Company is taken from the water while it is being delivered to these reservoirs. Inasmuch as the Wachusett reservoir is drawn on to the greatest extent during the summer months, when the Connecticut river is low, it will prove a very valuable auxiliary to the Connecticut Company. The contract, however, permits of calling on this power whenever it is required.

The Chace-Harriman interests, who are the controlling factors in the Connecticut River Companies, have at the present time developments under way on the Deerfield River near Shelburne Falls, Mass., which will be operated in conjunction with the present system and will double the present output.

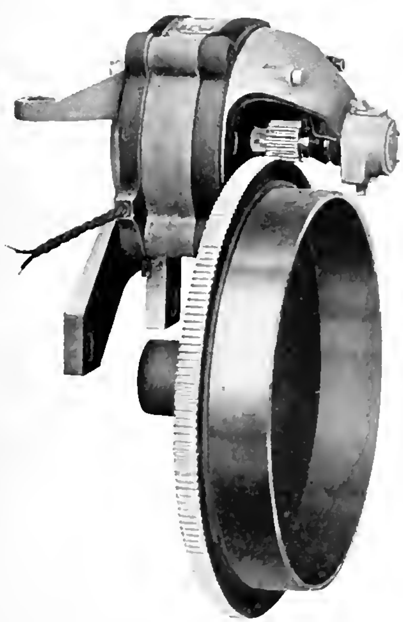
ALTERNATING CURRENT MOTORS FOR DRIVING LINOTYPE MACHINES

By J. B. Wiard

One of the most interesting and important developments in the line of printing machinery, and one which has a very marked influence on newspaper and other publications, is that of the linotype. A great many attempts were made to set type mechanically before a commercially successful machine was finally brought out.

The machine as finally built is necessarily intricate in its design, and does not lend itself readily to the application of electric motors. This is primarily because of the slow speed of its main driving shaft. While the amount of power involved is quite small, the satisfactory application of a motor is difficult. The riveted frame construction is particularly adapted to cases of this kind, on account of its small size per unit of capacity.

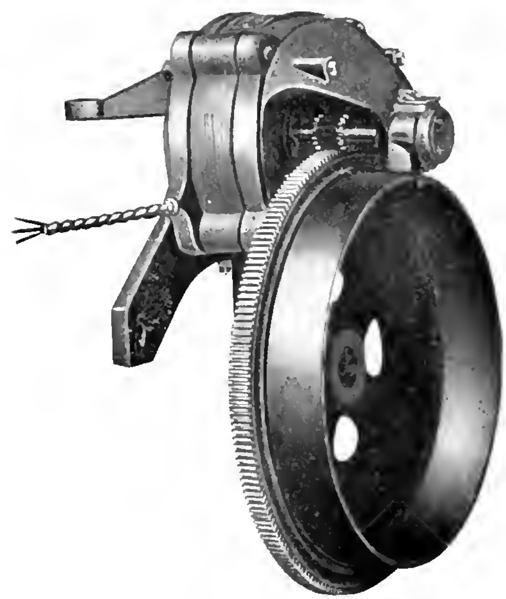
The motor which has been recently developed for the direct application of linotype



4 H.P. Single-Phase Direct Connected Linotype Motor

is so constructed that it can be assembled on the machine without doing any fitting beyond the capabilities of an ordinary mechanic. As the care of the linotype machine itself requires an attendant whose ability is much above the average, this application can be made without the services of a special construction man.

The torque demand of the linotype is very variable. The distributing mechanism



4 H.P. Three-Phase Direct Connected Linotype Motor

operates continuously, and requires a very small amount of power. It is only when the line of matrices is complete, and the cam motion is set in operation preparatory to casting the line of type, that there is any considerable torque demanded of the motor. Of course the fly-wheel effect of the motor armature geared directly to the main shaft of the linotype is of particular advantage during this momentary heavy torque demand. A comparatively small starting torque is required, as the machine is set in motion before the cam motion, requiring the major portion of the power, is tripped.

The motor, which is shown in the accompanying illustrations, is so designed that it can be wound for all commercial frequencies, phases and voltages. The polyphase machine is provided with a distributed polyphase field winding, and is started and operates in the ordinary manner.

The single-phase machine is provided with a split phase winding consisting of two sections, only one of which is active when the motor has attained its full speed. The motor armature is arranged to slide laterally in its bearings a short distance, its core being displaced from the field in the starting position. Two brushes resting on a collector ring complete the circuit of the starting section of the motor winding. Upon closing the switch the armature is strongly repelled, and therefore held displaced from the field by reason of comparatively large currents developed in its squirrel cage winding. As soon as the speed has reached a value which corresponds to the production of comparatively low armature currents, the core is drawn magnetically into its field; the pinion which is in mesh with the large gear slides with the armature into its running position; and the collector ring above referred to passes from underneath the brushes which are in circuit with the starting winding, and opens the starting circuit by reason of the brushes resting on a drum composed of non-conducting material. The collector ring and non-conducting drum referred to are cone shaped, so that the brushes by reason of their tension force the armature out of the field as soon as the main circuit is opened.

The motor is therefore an automatic self-contained single-phase motor, whose starting winding is opened in the running position without the use of a centrifugal device. The design is extremely simple and particularly effective where the starting torque required is small, as in the present case.

Mechanically these motors follow the same general lines as the standard riveted frame construction, the bearing castings being modified to suit the requirements of this particular application. The bearings are of the oil ring type, having ample oil well capacity. The large gear shown in the illustration is supplied with each outfit, the outside surface of the pulley carrying the belt which operates the distributing mechanism, and the inside surface being designed to engage with the friction clutch which controls the cam shaft. All motors are provided with cotton fabric pinions, so that noise is reduced to a minimum.

It will be noted that the leads are brought out through flexible steel armored conduit. This conduit is supplied in such a length that it can pass from the motor to the key desk of the linotype, where the motor switch is usually installed.

THE PRINTING EQUIPMENT OF THE RIVERSIDE PRESS

By W. D. Bearce

The Houghton-Mifflin Company, whose plant located at Cambridge, Mass., is popularly known as the "Riverside Press," have recently made extensive additions to their establishment in the shape of a large one-story building for housing a large part of their printing equipment including several new presses. The building not only presents the most pleasing appearance, but is designed to utilize to the utmost the natural lighting facilities.

Each of the twenty-two presses now operating in this building is provided with an individual motor and controller arranged for speed reduction of 50 per cent. Advantage has been taken of the flexibility of individual motor drive in the location of the presses, so that a minimum of labor is required to supply stock to the feeding board, and to remove the finished product.

All of these motors are of the three-phase 60 cycle induction type operating at 550 volts, and are equipped with wound rotors and slip rings for the insertion of external resistance for speed variation. The controllers on the smaller motors are of the

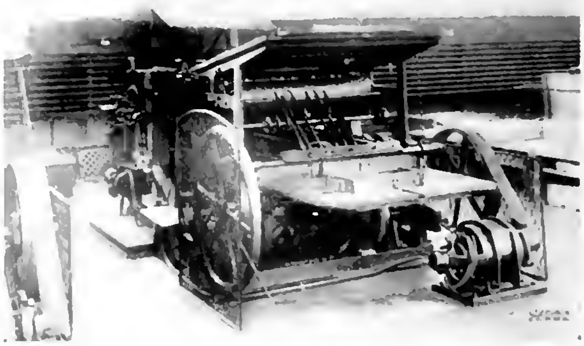


Fig. 1. Hoe No. 4 Stop Cylinder Press Showing Manner of Mounting CR-167 Speed Controller

dial type especially designed for printing-press control, while the larger presses are provided with drum-type controllers and separately located grid resistances. On account of the short belt centers and the comparatively large ratio between motor pulley and press pulley each motor is equipped with a belt-tightening device in order to increase the bearing surface on the driving pulley.

The work produced by this company comprises both bound volumes and pamphlets, but much of the printing work is intended for standard editions of text books, popular novels and work of a similar nature. The *Atlantic Monthly* is also printed in this establishment. The average run, in most cases, is below 50,000 copies; so that a large proportion of the time required for running off an edition is spent in preparing the press for the run. An appreciable saving in energy is therefore effected by the use of individual motors, which require power only when they are actually doing work.

The illustration shown herewith includes several types and sizes of flat-bed presses driven by variable speed induction motors, ranging in size from 2 to 7½ h.p. The majority of these presses were originally included in the old equipment and were recently provided with individual motors. The installation, therefore, indicates the ease with which group driven presses may be changed over from steam engine to electric drive.

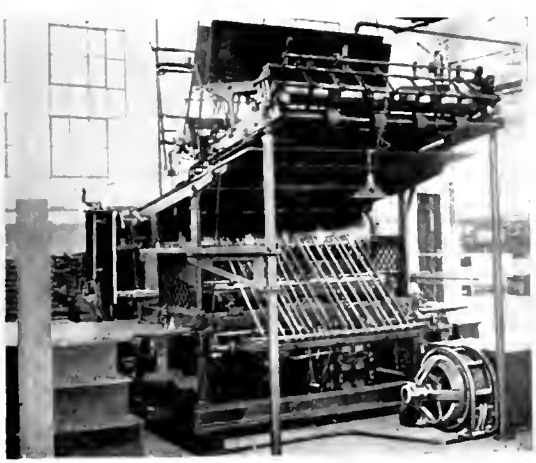


Fig. 2. No. 9 Hoe Press Driven by 7 1-2 H.P. Motor

Fig. 1 shows a small stop cylinder press, known as Hoe No. 4, driven by a 2 h.p. motor. Speed reduction i obtained, as in all of these motors, by the insertion of resistance in the rotor circuit. The amount of speed change is governed by a dial-type controller mounted at the left, within reach of the operator's hand. By use of this

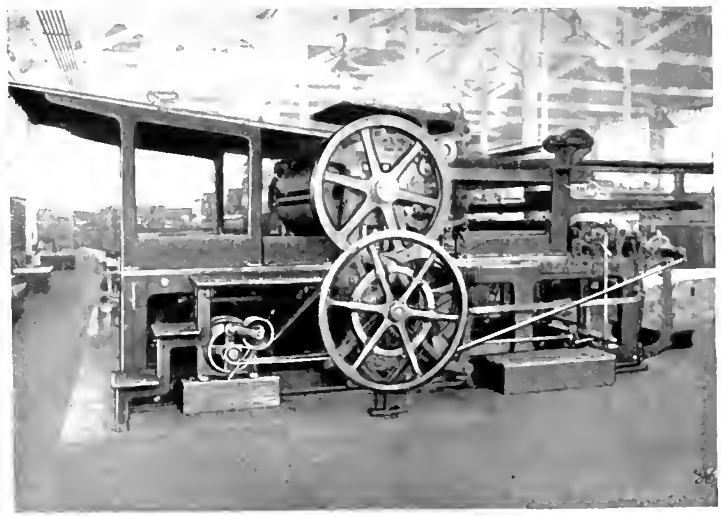


Fig. 3. Hoe Press Arranged for Front Delivery

controller the press can be notched along during the make-ready, or can be operated at any speed between 800 and 1400 impressions per hour. Twelve of these presses, in three sizes and driven by 2, 3 and 5 h.p. motors, are employed chiefly in printing straight book work, where smaller sheets are used than on the large-sized presses. Some of these presses are also employed for printing colored inserts, small pamphlets and similar work.

Fig. 2 shows one of the larger presses known as Hoe No. 9 driven by a 7½ h.p. motor and equipped with a drum-type controller. The motor is installed under the delivery table and therefore occupies no useful space.

Fig. 3 illustrates one of the most recent types of Hoe press arranged for "front delivery." With this type, stock is fed from the back and is delivered at the front in the center of the room.

Fig. 4 shows a front view of two new Miehle presses equipped with Cross feeders. These are driven by 5 h.p. motors operating at 1800 r.p.m., and are equipped with drum-type controllers.

One of the most recent safety appliances designed for the protection of apparatus has been installed in connection with one of the above presses. Briefly, this consists of an oil switch (Fig. 5) for opening the motor circuit, operated by a mechanical trip in case the paper is not properly taken care of. This switch may also be reset by the foot levers shown in the illustration; the switch is closed by one of these levers before starting the motor, and is opened by a spring under compression released by the tripping mechanism. The automatic protection afforded by this contrivance has been so satisfactory that these switches are to be installed on all of the larger presses.

Fig. 4. Miehle Press Equipped With Cross Feeders and Driven by 5 H.P. Motor

The rough service demanded by printing machinery of this type, on account of the rapid reversals of the heavy bed of the press has been most satisfactorily met by the polyphase induction motor. This motor is further adapted to printing requirements by reason of its variable speed characteristics. It has also been shown that the uniform speed, maintained by individual motor drive, allows a larger number of impressions per hour to be made than with a group of machines, driven by steam engines or other prime movers.

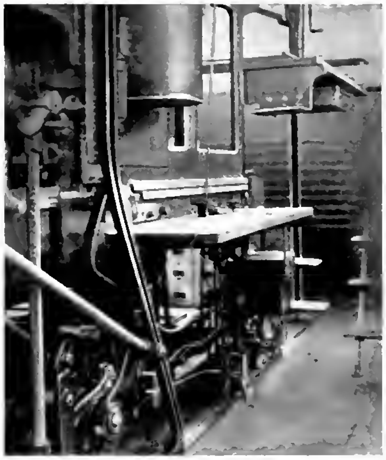


Fig. 5. Device for Opening Motor Circuit When Paper Fails to Feed Properly

In other parts of this plant several motor drives are used, some of these being employed for the operation of gathering and folding as well as for monotype machines and factory elevators. The press-room is lighted throughout by luminous arc and incandescent lamps which may be seen in several of the illustrations. The entire electrical equipment, consisting of motors, controlling apparatus and arc lamps was supplied by the General Electric Company.

The accompanying table gives the principal data concerning this installation.

	Number of Presses	Impressions per Hour	Size Bed	H.P.	Speed	Controller
Hoe No. 4	1	800 1400	26 x34″	2	900	Dial
Hoe No. 5	2	800 1500	29 x42″	3	1200	Dial
Hoe No. 6	5	800 1500	32 x47″	3	1200	Dial
Hoe No. 7	5	900 1400	36¼x51″	5	1200	Dial
Hoe No. 8	2	1000 1500	38¼x55″	5	600	Drum
Hoe No. 9 (old)	1	1100 1400	47½x61″	7½	600	Drum
Hoe No. 9	1	1000 1800	42 x60″	5	1800	Dial
Miehle No. 0000	3	1000 1800	48 x62″	5	1800	Dial
Miehle No. 00000	2	850 1800	48 x65″	5	1800	Drum

Total number of motors	22
Dial-type controllers	17
Drum-type controllers	5

ALTERNATING CURRENT APPARATUS TROUBLES

PART V. BY D. S. MARTIN AND T. S. EDEN

SYNCHRONOUS MOTORS

In considering troubles which may be met with in the operation of synchronous motors, it may be well to bear in mind that motors of this type have two distinct fields of utility. The fact that synchronous motors run at constant speed at all loads renders their use desirable in many industrial applications; but apart from this, their ability to draw from the supply a leading or lagging current as desired, depending on their field excitation, has led to their installation in many instances as power-factor regulators or synchronous condensers. Operating characteristics in a motor which will render it unsuitable for power applications may not be necessarily classed as defects if the machine be used simply to float on the line as a condenser. In many cases, naturally, synchronous motors are installed to fulfill the double purpose, that is to say, are employed for furnishing power in cases where the induction motor might be preferable on some grounds, but in which the synchronous motor is selected on account of its beneficial condenser effect.

Since the great majority of synchronous motors built at the present time are of the polyphase type, we shall in this article pay no attention to single-phase machines. We do not propose here to discuss parallel operation of synchronous motors, as the subject of parallel operation of all synchronous machinery has been fully dealt with in Part IV of this series of articles. In this respect it is impossible to consider motors as distinct from generators, since the conditions affecting satisfactory parallel operation are concerned not only with the motors, but also with the prime movers, generators and feeder cables. All of these factors receive due consideration in the article referred to.

The remaining operating troubles of synchronous motors which we shall consider in this article are in connection with the failure of a motor to start, failure to develop required torque, and overheating.

FAILURE TO START

Broadly speaking, synchronous motors have poor starting characteristics, and a number of different methods are at the present time in use for overcoming their weakness in this respect. Practically any polyphase alternating current generator may be started up as a motor by applying full voltage to the armature circuit leaving the field open. The rotating field in the stationary armature induces a field in the pole pieces of the rotating element, and the interaction of these two fields is sufficient to start the motor with a small torque. The starting current under such conditions, however, is excessive, being anything from 1½ times to 3 or more times full load current, and since this represents a load on the line of very low power-factor, considerable derangement of the system may result. Some method is usually adopted for reducing this current. Due precautions have also to be taken to limit the voltage which is induced in the field windings of the revolving element, which may sometimes reach an excessive amount.

Methods of Starting Synchronous Motors

1. A voltage-reducing auto-transformer may be used to reduce the applied armature voltage at starting. Such auto-transformers are provided with 3 or 4 taps, and test is made on the motor to determine which tap can be most advantageously used to suit the particular load and supply conditions under which the motor will operate. With a good design of motor and a properly selected tap, the starting current from the line may be limited to the full load value, although the torque will be comparatively low.

2. In the majority of modern designs, the revolving field of the motor is provided with a special squirrel cage winding in order to improve the starting torque. The action of the motor at starting is similar to that which takes place in the induction motor, in that the starting torque is produced by the interaction of the field in the primary, due to the impressed voltage, and the field in the secondary (or rotor), due to the induced voltage in the squirrel cage winding. This auxiliary squirrel cage winding consists of a number of bars laid in slots in the pole faces and short circuited by two end rings. Various metals and alloys are employed to provide a high torque and high resistance auxiliary winding, and a well designed motor so equipped will start from the line with about 1½ times full load current and will develop about 30 per cent. full load torque. This

Erratum: July REVIEW, page 335, 2d paragraph. Should read:—the connection must be such as to place a *S* pole of the commutating field ahead of a *N* pole of the main field, i.e., *beyond it in the direction of rotation.*

auxiliary winding, known as the amortisseur winding, has also a beneficial effect on the stability of the motor. Further reference to this matter is made in Part IV of this series of articles, which considers the amortisseur winding as applied to alternating machinery in general.

3. The above method of starting, viz., employing an auxiliary squirrel cage winding, is the most satisfactory in practically all synchronous motor installations; but in certain instances where motors of very large capacity are used where the effect on the line would be considerable, an auxiliary starting motor is employed for bringing the synchronous machine up to speed. This is usually of the induction type, and since the duty is usually of a very intermittent nature (confined to starting up the set at infrequent intervals), it may be considerably underrated for its full load torque, and should preferably be of the high torque, high slip, slip-ring type.

In some instances the direct current generator which is used for supplying excitation voltage to the motor is used also as a starting motor. This obviously is only feasible where the exciter is either belted or direct-connected to its motor; and in such cases must be designed of considerably greater capacity than would be the case if it were to serve simply for excitation purposes.

4. In power and mining applications where alternating current transmission is used in conjunction with direct current motors, motor-generator sets are extensively employed, consisting of an alternating current motor and a direct current generator. Synchronous motors have preference over induction motors in such applications on account of their constant speed property as well as their condenser effect; and in starting, the sets may be run up to speed either from the a.c. end or the d.c. end. If a direct current supply is available the generator may be used to motor from this supply and the synchronous machine thrown on to the busbars when synchronous speed has been reached.

5. In cases where a synchronous motor is used for power purposes, e.g., driving shafting, or any drive in which a considerable starting torque is required, a friction clutch, or some equivalent device, is necessary to enable the motor to start light and to take over its load only when synchronous speed has been reached. Some such arrangement should be adopted whether the motor is self-starting or provided with a separate starting induction motor. Self-starting synchronous motors are built for starting up moderate loads, such as grinders in pulp mills, centrifugal pumps, or fans.

Methods Which May be Tried Out in Overcoming Starting Troubles

A knowledge of the various methods by means of which a synchronous motor may be started is often of service in handling cases where a motor refuses to start, as this is sometimes not due to defects in the motor itself. In cases where a motor takes excessive starting current and an auto transformer is not available, the necessary reduction of the applied voltage may be performed by using an ordinary 2-winding transformer with low-voltage taps. The transformer or auto-transformer method of starting up is satisfactory in certain conditions, but in cases where there is not much spare power behind the source of supply, i.e., where the alternator is not a great deal larger than the motor, then starting up by this means, i.e., by switching on primary voltage with field open, presents a difficulty owing to the wide range of regulation of the alternator at low power-factors. The power-factor when starting in this way is exceedingly low, and the inherent regulation of the alternator may be as much as 30 or 40 per cent. under conditions such as might be met with in this case. This means starting up on falling volts; and since the torque falls away as the square of the volts, it may be impossible to get the motor up to synchronous speed. In such conditions a good plan which has been successfully tried out in emergencies, is to obtain the necessary reduction of applied voltage, by inserting a non-inductive resistance in series with the line. Water rheostats are often advantageously used in this manner, as besides limiting the starting current their effect on the power-factor of the system is not so harmful as that of an inductive resistance. One tub is connected in series with each phase and the plates adjusted in the water as required.

In cases where a motor used with an auto-transformer is found to consume an excessive starting current, voltage readings should be taken of the auto transformer taps. If it is found that reducing the voltage, to such a value as would limit the starting current sufficiently, thereby prevents the motor starting at all, it will probably be found necessary to provide a starting winding on the rotor.

In cases where no friction clutch is employed and the motor has to start against a definite load, say 35 to 40 per cent. of its full load value, the amortisseur winding may be incapable of providing sufficient torque, and it will in such cases be necessary to provide a separate starting motor to turn over the initial load.

In some cases where the motor is the sole load on the generator supplying it, a satisfactory method of starting up has been found in paralleling the two armatures before the generator is started from rest. In this case the motor will come slowly up to speed with the generator and lock into step. The method may be found useful in cases where with full voltage applied the motor takes excessive starting current.

As a matter of interest we may mention the case of the starting up of high speed synchronous motors of the turbo-generator type used inverted for driving high speed machinery, such as turbine pumps, etc., and running at a speed of 2400 or 3000 r.p.m. In such cases, which are rarely met with, it is impossible to start by means of the induction method as used for other machines, i.e., the method in which the starting torque is provided by producing eddy currents in the pole faces; as in these synchronous motors of the high speed type, the revolving field structure is usually provided with laminated poles in order to eliminate eddy currents as far as possible, and there are therefore no pole faces in this sense of the term. A method which has been used in such cases is to provide a short-circuiting switch to short-circuit the field at starting. Voltage should be applied to the stator, the necessary reduction being obtained with auto-transformer, transformer, or water rheostats as before. With the short-circuiting switch closed, induced currents will then be set up in the field winding, with the result that the revolving field structure will tend to follow the rotating magnetic field produced by the stator. When the machine is up to speed as far as it will go, the short-circuiting switch should be withdrawn and excitation switched on to the field system. The motor will then synchronize itself and pull into step as in the case of the other machines when started as described above.

Cases have been known in connection with systems in which the synchronous motor represented only a small portion of the entire load, and hence in which heavy starting current was of little consequence, where an auto transformer was used to raise, instead of lower, the impressed volts at starting, in order to enable the motor to develop a starting torque of something over half its full load value.

Defects in Motor or Auxiliaries

Failure of a motor to start, due to lack of proper starting auxiliaries, is generally due to a design based upon incomplete knowledge of all the existing local conditions as regards load, generator capacity, etc. There are, however, defects in the motor itself and in its starting auxiliaries which may be responsible for its failure to start. If a separate starting motor is employed, the necessary steps should be taken to see that this is operating properly. Where the synchronous motor constitutes part of a motor-generator set driving a direct current generator, and where the direct current generator is used for starting from the direct current end, these precautionary steps usually consist in tracing through the armature circuit, including the starting resistance, brush connections, terminal board and series field (if any) to see if the circuit is continuous, and secondly, in determining whether the field is capable of building up. Detailed reference to this subject may be found in text books on the operation of direct current motors.

Where a small auxiliary induction motor is used for starting the synchronous motor, this should be disconnected from the latter, if possible, in order to run it up on its own light load. Where the starting motor has few poles compared with the synchronous motor and is geared thereto, disconnecting in this manner will usually be possible by sliding the motor pinion out of engagement with the gear wheel on the main shaft.

Where the motor is found to take an excessive current when starting on light load, attention should be paid to the bearings of the machine, as if these are not running easily, sufficient braking may be put on the motor to prevent its starting up satisfactorily. Cases have been known where stray currents in the shaft and pillow blocks brought about a pitting of the bearing liners; and this, besides causing overheating of the bearings when running, resulted in putting a comparatively heavy load on the motor at starting.

Sometimes the failure of a motor to start may be found to be due to the open-circuiting of one phase. This may occur either in the switchboard wiring, in the cable connections between switchboard and auto-transformer, in the auto-transformer, in the connections to the motor, or in one of the phases of the motor itself. Such a condition may be detected by a humming noise in the machine; and by feeling the outside of the winding insulation with the hand it may easily be detected whether all phases are carrying current or whether one of them is open-circuited. This advice is somewhat dangerous to give to an inexperienced operator, and some judgment should be exercised as to whether the accessibility of the stator end windings makes it feasible without risk of fouling the rotor. Such open-circuit of one phase prevents the motor from starting: in the case of Y wound armatures, the stator is left on single-phase and thus, though the field due to the applied voltage is still a rotating one, it constitutes all the field there is and reaches its zero point twice in every cycle.

A short-circuited phase may also act with the same effect. On most synchronous motor circuits ammeters are provided in each phase, and it is possible to determine from these whether a phase is short-circuited or open-circuited. If a phase becomes grounded within the machine on a three-phase circuit with grounded neutral, this is equivalent to a short-circuit of one phase in whole or in part. Such a condition sets up a heavy circulating current in the short circuited portion of the winding, usually sufficient to burn out the affected coils. The point where the current is going to ground can usually be located through the fact that at this point the greatest amount of heat will be generated, as an arc is usually formed between the copper and side, or bottom, of the stator slot.

FAILURE OF MOTOR TO DEVELOP FULL LOAD TORQUE AFTER ATTAINING SYNCHRONOUS SPEED

While the ability of a self-starting synchronous motor to start depends on the field induced in the pole-pieces by the applied primary rotating field, the torque which the motor must develop on load is provided by the normal field on the revolving element under full excitation. When the motor has come up to speed, failure to carry its load will point to a defect in the field circuit. The first point to receive attention should be the exciter, and a voltmeter held across the slip rings will show whether the exciter is giving its full voltage. If this is found to be correct, the trouble may be due to an open-circuit in the field winding or in the field rheostat, or a short circuit or reversal of one or more field spools.

Probably a majority of all the troubles met with in operating synchronous motors are due to breakdowns in the field circuit, caused by the excessive induced voltage at starting. The field winding at starting plays the part of an open-circuited secondary of a transformer, and the voltage induced in it depends on the ratio of armature turns to field turns. The question is therefore one of design, viz., to limit the induced volts between field turns to as low a value as possible and allow for sufficient insulation accordingly. If the breakdown point is reached, the trouble may first occur in one of several places. The voltage may jump between turns, from coil to pole, between collector rings, or between the field leads. Where the fault occurs at the collector rings, the trouble may be overcome by placing pads of wood, pressboard or other insulating material, between the rings. In many cases where the trouble through excessive induced voltage is persistent, the only remedy will be to rewind the field, employing heavier insulation on coils, between rings, etc.

Mention should here be made of the importance of the discharge switch and resistance, supplied for limiting the induced voltage when the field circuit is broken. If these precautions with regard to opening the field are neglected and the field circuit is suddenly ruptured, a very high voltage may be induced sufficient to break down the insulation between field turns, short-circuiting two or more turns, and possibly breaking the continuity of the field circuit in cases where the copper is burned right through.

OVERHEATING

In mentioning the question of overheating of synchronous motors, we desire to avoid going over any of the ground already covered in our remarks on alternating current generators. (See August REVIEW.) With regard to defects in the motor winding, those remarks apply equally to synchronous motors as to generators; and the methods specified in that article for locating defects in the winding circuits of the machines are equally applicable in the present case. It may be as well, however, to add a word on a tendency which is frequently shown in the handling of synchronous motors, i.e., the tendency to over-rate their capacity for providing a leading current, for counterbalancing the effect of heavy inductive loads in other parts of the system. As far as the motor is itself concerned, the most economical point of operation is at unity power-factor, i.e., with minimum armature current. In cases where a heavy inductive load has to be compensated for, the excitation is sometimes increased far beyond the point of safety. The question is simply one of design, i.e., when the machine is built the windings are designed for a given current capacity, whether energy current or wattless current, and sufficient allowance is made in the design for taking care of over-excitation at any given load. When the motor is operating on any given load, over-excitation increases the armature current, at first slowly, but much more rapidly at low leading power-factors. It must be borne in mind that there is a limit to which this over-excitation can safely be carried, both as regards field and armature heating, even though the mechanical load which the motor is carrying be comparatively light.

THE STANDARDIZATION AND CARE OF INSTRUMENTS

By A. L. Ellis

It is not proposed here to consider all the instruments, or even the most important, used in the various branches of modern scientific investigation. For instance, a volume or two could be written on the standardization and care of the bolometer, capable of measuring the radiation from the distant stars; and several papers as long as this one could be devoted to the calibration and care of a glass liter flask used by the chemist. Even the two-foot rule used by the carpenter and sold in any hardware store in the country for the small sum of 10 cents, involves in its manufacture problems affecting its accuracy, of which the user little dreams. In the two-foot rule we see the rough and ready standard of the artisan; in the bolometer, the delicate standard of the physicist. Both are standards and both are calibrated by reference in terms of a standard of a higher order of precision The term "standard" is, therefore, a relative one.

I have thought it best to confine my remarks to electrical instruments commonly used, calling attention to the methods of standardization, and the necessity for care in handling suggested by long experience in the laboratory of a large manufacturing company. Even though the subject is thus limited, it is still so broad that I must treat standardization very meagrely in order that we may give to the more important subject, the care of instruments, that consideration which is its due.

Probably the most common electrical measurement today is the measurement of power. We may be concerned with the energy expended in a group of incandescent lamps, a motor circuit or one of the great distribution systems. In any case, the watt-meter is almost universally used. The watt-hour meter is used to measure the total energy, and the indicating wattmeter the instantaneous power delivered. Watt-hour meters may be divided into two groups, those designed for alternating current, and those designed primarily for use on direct current circuits, the latter very often operating very well on alternating circuits feeding non-inductive loads. The indicating wattmeters may also be divided into two classes, viz., switchboard instruments and portable instruments. The switchboard instruments are based upon the same theoretical principles that evolved the portable type, but are designed to give approximate indications of the power delivered, extreme accuracy being of secondary importance as compared with legibility of scale when viewed from a distance, and ability to withstand the trying conditions attending their location on the average switchboard. The portable instruments comprise our working standard; which may, in turn, be divided into three groups, voltmeters, ammeters and wattmeters, and each of these into two classes, viz., rough-and-ready instruments, and instruments of precision. We will only consider the latter.

The portable wattmeter serves as a standard when checking or re-calibrating the watt-hour meter, switchboard wattmeter and the rough-and-ready portable instruments. The portable wattmeter is calibrated by comparing it with a non-portable working standard of the laboratory, or it may be compared directly with the primary laboratory standards. The former method is to be preferred, as will be explained later.

The working standard referred to preferably takes the form of a transfer instrument, i.e.

one which, because of its design, can be calibrated on direct current by comparison with the primary standards, and subsequently used on alternating current without change of calibration. In design the working instrument may be a Siemens' electro-dynamometer of the indicating type, carefully mounted in the magnetic meridian, or of the astatic reflecting type. It is very important, in either case, that the instruments be of reliable make and carefully investigated, to make certain that no serious errors are introduced when calibrated on direct current and then used on alternating current.

It is best to compare the portable alternating current instruments, and particularly the wattmeter, with the transfer working standards in preference to the primary standards, because, by so doing, one is sure that accidental short circuits cannot exist in the windings without discovery, and that disturbances due to self-induction of the circuits within the instrument will be taken into account, should they be of appreciable magnitude. The same remarks apply to the standardization of portable voltmeters and ammeters of the alternating current type. Direct current portable instruments are standardized by direct comparison with the primary standards, multiple or sub-multiple copies of same, by means of the potentiometer and Wheatstone bridge.

The primary standards of a laboratory are the volt (in the form of a standard cell), the ohm (in the form of a well-aged metal resistance standard) and the ampere (in the form of the silver voltameter). The silver voltameter, while capable of great refinement, is very difficult to use, requiring an operator of great manipulative skill, while it is also very slow-working; so that most laboratories, if not all, prefer to use the volt and ohm standard, and derive the ampere by Ohm's law with the aid of the potentiometer.

We will now turn our attention to the care of portable instruments and other testing equipment, to be found where electrical measurements are frequently made.

The instruments in such cases are placed in the care of a department equipped with suitable standards, whose duty it is to keep them in working order and furnish the testing department with data concerning the accuracy of each individual instrument. This department is known as the standardizing laboratory.

The standardizing laboratory at Lynn has the care of approximately 5,000 testing instruments, one-half of which number are portable. The majority of the latter pass through the hands of the laboratory at least once in two weeks for examination and verification of the calibration. These instruments are used in the various departments where the degree of accuracy required varies from approximate results only, to the accurate calibration of meters and instruments. When such a large number of instruments are in use it is not surprising to find that a great many are damaged, due to accidents in test, careless handling, etc., and also that we should be called upon to investigate discrepancies in results. We have kept a careful record of the reason for repairs and discrepancies in results; and, as a consequence, I wish to point out the following simple precautions, which, if observed when making tests, will reduce the possibility of damage to the instruments to a minimum, and the probability of an accurate test will be greatly enhanced. The following points are applicable to instruments in general.

Handle instruments carefully. When moving them around be careful to lay them down gently, to avoid damaging the fine points of the pivots or the polished surface of the jewel. The greater number of so-called "sticky" instruments have been reduced to this condition because some one has thoughtlessly set them down as he would a hammer or a monkey wrench.

Have as much respect for an instrument in its carrying case as out of it.

When connected to the circuit, arrange the leads so that the instrument cannot be pulled off the table.

Never place an instrument on a bench or other support which is subject to vibration from adjacent machinery or other source.

It should be borne in mind that all instruments, when calibrated in the laboratory, are connected in circuit just long enough to obtain the reading; also that the losses in the instrument produce an increase in temperature. Therefore, in order to obtain the best results, it is always advisable to duplicate, as far as possible, the condition under which the instrument was calibrated. To accomplish this, when using a voltmeter, never leave the push button closed longer than is absolutely necessary.

When using an alternating current ammeter or a direct current ammeter having an external shunt, always provide a switch for short-circuiting the instrument. Keep the switch closed as much as possible, and make sure that it is performing its office by removing one of the leads from the ammeter. The object of the switch is to protect the shunt and the instrument in case of overload, such as sudden short-circuiting or an intentional increase in current. If the current from the shunt is in excess of its rated capacity, which it could easily be, the instrument could be damaged by burning out the coils or by bending the pointer. This can be avoided by removing one of the leads from the instrument, and this precaution should therefore always be taken to insure protection of the meter. This is an additional safeguard to providing the short-circuiting switch, and insures protection of the meter in the event of the switch not properly short-circuiting the shunt owing to faulty contact. When using a wattmeter, provide a short-circuiting switch and keep the push button open as much as possible; also when measuring inductive loads, be very careful that the current through the instrument does not exceed the current limit mentioned in the certificate accompanying the instrument or marked upon the scale itself.

When using astatic instruments of the electro-magnet type, see that they have been connected to a circuit at approximately the exciting voltage marked on the instrument for at least one hour before taking readings. This is necessary on account of the heat developed in the magnetizing windings, it being essential that all parts of the instrument shall have reached a steady temperature value before readings are taken.

Be sure that the current and potential are within the limits of the instrument you are about to use.

Instruments carrying currents should never be placed nearer together than 18 inches on centers, unless they are of the shielded type.

Avoid, with great care, placing a permanent magnet type of instrument within the influence of strong fields of any kind, for the magnet will almost certainly be spoiled and the readings consequently rendered inaccurate.

Form a habit of twisting together all leads used in connecting up all instruments, and thereby avoid the variable errors produced by strong fields from the leads themselves, which sometimes prove very troublesome if this habit is not cultivated.

When connecting up apparatus for test, always arrange the leads so that they are non-inductive, as far as possible. This condition is fulfilled by the use of twin cable, twisting the leads together, or by placing them side by side. The matter of stray fields from leads is a most important factor when large currents are used because instruments designed for large currents, particularly alternating current instruments, have comparatively few turns of wire upon their torque producing coils. Therefore the effect produced by a single wire placed a given distance from an instrument will be five times greater on a 25 ampere instrument than that produced on a 5 ampere instrument, the instrument measuring the current through the leads in each case.

Do not attempt to take readings from an instrument when placed on a bench directly over the iron supports, or over a drawer containing iron tools, or upon a packing case the contents of which are unknown.

Avoid placing unshielded types of permanent magnet instruments closely together; keep them at least 18 inches apart, as the stray field from the magnet of one will affect the indication of the other.

Rheostats, dimmers, reactive coils and circuit breakers are good stray field producers and, therefore, should always be open to suspicion.

When measurements are being made with direct current and the stray field cannot be eliminated, astatic instruments, or shielded instruments should be used. If these cannot be obtained, quite accurate results can be obtained by means of the average of two readings, the second reading being taken after the instrument has been turned 180 degrees from its original position. In case of alternating current, the effect or absence of stray fields should always be ascertained by taking reversed readings, i.e. by reversing the flow of energy through the instrument by reversing the leads at the instrument itself. Where more than one instrument is used in a test, the reversed readings should be obtained by reversing one instrument at a time, in order to include in the readings the effect produced by the stray fields from the instruments as a group.

In cases where low voltage circuits are to be measured, always ascertain whether or not the voltage is approximately what it is supposed to be, by connecting first to the high scale of the voltmeter, and thereby avoid the possibility of burning out the instrument.

Never leave a low reading voltmeter connected to the circuit.

When making resistance measurements on alternating current apparatus, always disconnect the direct current instruments as soon as readings have been taken. When measuring the resistance (by drop method) of any inductive circuit, such as a transformer or shunt field of a dynamo, never break the circuit without previously disconnecting the instruments, as the inductive "kick," due to the collapsing of the magnetic lines of force, is very apt to break the needle of the voltmeter.

When it becomes necessary to use a multiplier in connection with a wattmeter or voltmeter in order to adapt it to the potential of the circuit, the following precautions should be taken: examine the multiplier carefully in order to ascertain whether or not it has been adjusted to the instrument about to be used. In any case, do not take it for granted that the value marked upon the box is the correct resistance, but first measure the resistance upon any Wheatstone bridge. If the result agrees within one per cent., the resistance marked upon the case may be taken to be the correct one. This precaution is necessary because a multiplier may have been overloaded and still show no sign, by its external appearance, of internal damage.

Where multipliers are provided with more than two binding posts, be sure, when using, that one of the leads is on the zero post and the other where it should be.

When using wattmeters on circuits of 500 volts and upwards, always protect the moving element by connecting the correct potential post (depending on the type of meter employed) to one of the current posts by means of a fuse wire. Either current post may be used; but if the one connected direct to the load is chosen, the indication of the wattmeter will include the watts lost in its own potential circuit.

In order to increase the range of a given direct current ammeter, external shunts have been provided, the instrument taking the form of a low voltage voltmeter. There are two classes of shunts in use; the universal type, which may be used interchangeably with any number of instruments, and the combination shunt, which may be used only in connection with the instrument to which it has been adjusted. The scales of the instrument to be used with universal shunts are marked with two sets of divisions and corresponding numbers, one set of 100 and the other set of 150 divisions.

The current flowing through a shunt of almost any full load capacity can readily be determined, by the reading on one scale or the other and the use of a simple constant. All instruments adjusted for use with either type of shunt are supplied with suitable leads, and positively no other leads must be used. If the nature of the test requires longer or shorter leads than the standard, such leads should be made up in the laboratory.

Take care to avoid errors due to stray fields, and do not place the instrument too near the shunt.

After taking the reading, disconnect one side of the instrument from the shunt.

When connecting up, be sure that the lead tips are clean and bright and free from oil, as well as the metal parts of the binding posts. See that binding posts make good contact with lead terminals, but do not use unnecessary force. When using shunts and instruments each having more than one pair of binding posts, see that the leads are connected to the proper terminals. When using combination shunts, be sure that the identification marks upon the instrument and the shunt agree.

When making tests upon high voltage circuits, one of the greatest sources of error is that produced by "static," which causes the instrument to appear sticky, or causes the needle to deflect above or below zero before the circuit has been completed. This source of error can usually be eliminated by connecting one binding post to the metal cover by means of a fine wire, and, in addition, covering the bench beneath the instrument for about 18 in. square with tin foil and connecting this to the cover. Under no circumstances should a sheet of copper, iron or brass be used for this purpose, or any metal having an appreciable thickness.

The above remedy can be applied, with safety to the instrument, to ammeters only, as in cases where voltmeters or wattmeters are used in connection with multipliers, should the wrong binding post be connected to the cover and the static effect, in consequence, not be removed, the instrument is very liable to be burned out by the needle swinging against the cover.

Do not remove the base or cover from any instrument, as in doing so particles of dirt and lint, which are floating in the air in large quantities in the testing room, are almost certain to get into the instrument, causing it to become sticky. Several hours of close examination may be required before the cause of the trouble can be found.

The electro-static voltmeters used on high potential testing sets are not instruments of precision and cannot be relied upon for an accuracy better than 5 per cent.; yet their calibration is practically constant within this limit, provided the needle stands at zero when disconnected from the source of potential. If the needle does not stand at zero, the error may be due to two causes, either the needle has been bent or the instrument is not level. Raise the glass front and place a level in the center of the base (if there should be no leveling device connected with the instrument), and re-level the instrument. If the needle is thought to be bent, no attempt should be made to straighten it, but notification should be made to the laboratory, who will determine whether or not the instrument is to be corrected by bending the needle.

The best range of resistance measurements with Wheatstone bridges used in the Testing department is from 10 to 10,000 ohms. The tops of the bridges should be kept scrupulously clean. When the bridge is adjusted, the plugs are made to fit the taper holes as closely as is possible, in order that the plug resistance may be a minimum. Therefore, when using a bridge, do not force the plug into the hole and keep twisting it, as this only serves to destroy the fitting of the plug by wearing away the brass, which, falling between the blocks, is liable to reduce the apparent resistance of the coil by short-circuiting it, and at the same time greatly increasing the plug resistance as a whole. Place the plug in the hole squarely and firmly, then lock it by a slight twist.

Do not touch the metal parts of the bridge top or the plugs with the fingers, as the grease therefrom can increase the plug resistance to twenty times its original value. The spaces between the blocks should be frequently cleaned, by drawing a clean cloth between them, care being taken to force a sufficient amount of it down between them, to fill up the space made by under-cutting the blocks where they join the rubber top.

If, during a test, the galvanometer should be set swinging violently, it can be brought quickly to rest by closing the lower contacts of the galvanometer key, and thus shortening the time required to obtain a balance.

Do not attempt to increase the sensibility of a bridge set by using too many batteries, as the heating of the bridge coils will result in large errors produced by thermal currents. Two dry cells will give good results for most purposes up to 2,000 or 3,000 ohms, beyond which three, or at most four, cells may be used.

THE DIARY OF A TEST MAN

IX. A CASE OF DIFFICULTY IN PARALLELING SYNCHRONOUS MOTOR-GENERATOR SETS

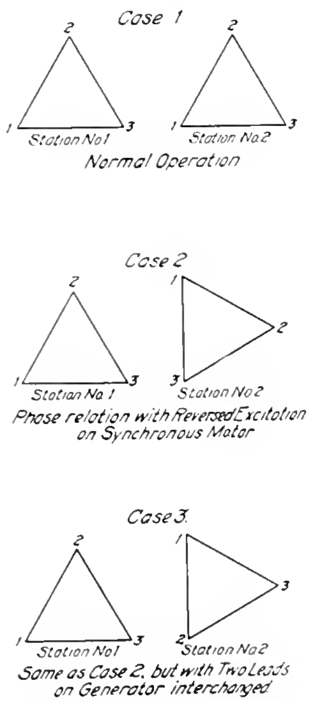
Synchronous motor-generator sets are often used for changing alternating current supply at one frequency, such as 25, into current at some other frequency, such as 60, more suitable for lighting or other class of service.

The particular case under consideration was in connection with motor-generator sets of which the motors were 40 cycle and the generators 60 cycle machines; the peculiar difficulty occurring in the midst of making a transfer from an old, over-crowded power house to a new substation. The power house and substation were several hundred feet apart, but the special conditions causing the difficulty would give the same results if the two stations were a number of miles apart.

It is pretty well understood by those who have had anything to do with frequency changer sets, that certain special attention must be paid to connections of both armatures and fields of the different sets, so that the same definite and fixed relation as regards phase difference and polarity between alternating current of one frequency and of the other frequency shall be alike for all the different sets designed for parallel connection. This is a quite different condition from requirements for parallel operation of alternating current generators in the same or different stations, where it is merely necessary to make sure that leads from the several generators are connected up with proper regard for phase rotation.

The particular sets under consideration, working between 40 and 60 cycles, were provided with double-pole, double-throw field reversing switches on the 60 cycle generators, as a little study will show that to reverse the field on the 40 cycle motor, causing the motor to shift in reference to some fixed time standard by one pole pitch, would cause the 60 cycle generator to shift in reference to the same standard by 1.5 of its pole pitch. In other words, the electromotive force from the 60 cycle generator would be 90 deg. out of phase with the electromotive force from the 60 cycle generator of another set in which the motor field had not been reversed.

The trouble experienced was due to taking out some temporary exciter wiring in the new substation in the day time when part of the sets could be shut down. The permanent wiring between exciter and switchboard interchanged the leads, giving polarity on the exciter busbars opposite from polarity existing while the temporary connections were in use.



Vector Diagrams Showing Phase Relations of 60 Cycle Generators for Normal Parallel Operation and for the two Cases Referred to in Text

With ordinary alternating current generators, this would cause no trouble, provided all the synchronous motor-generator sets were supplied from this same exciter bus; but on attempting to parallel the two stations (the excitation being reversed in one) in time to pick up the evening load, it was found that the 60 cycle phase relations could not be made right. After some lost time, during which the load on the machines in service was steadily increasing, the engineer in charge concluded that the trouble was due to some reversal in the generator leads, and interchanged two of these. This naturally made what was already a bad matter worse, since the change of leads gave reversed phase rotation, so that parallel connection was quite impossible. The machines carrying the load were at this juncture pretty well overloaded, and as the cause of the trouble was still a mystery, it was hastily decided to break some connections and divide the load, leaving part of the circuits on the old station and part on the new substation. In the haste to make this change, the fact that phase rotation had been reversed on one of the sets was overlooked. It resulted that the circuit connected to this machine supplied one of the newspapers, and in a very few minutes the telephone rang, the newspaper office in great excitement reporting that the printing press could not be started, as it was trying to run backwards! Rather than interrupt the circuit to correct the polarity, it was deemed best to change connections at the printing press motor, leaving the circuit on reversed phase rotation for the night, there being no other important motors connected to this circuit.

Matters having been arranged so that no customers were without power or light, there was time to give the matter some consideration, and it was soon realized that the trouble was in the excitation.* VECTOR

X. UNUSUAL CAUSE OF SHORT-CIRCUIT ON TRANSMISSION LINE

At the Calumet and Hecla Mining Company, Calumet, Michigan, during the past spring, there was experienced a short-circuit, or rather, a series of short-circuits, from a very peculiar cause.

Fig. 1 shows the layout of the buildings around the substation. It will be noted that there are two stacks connected to a boiler-house which operates hoisting engines. It will also be noted that there was a slight wind in the direction indicated by the arrow.

A short time previous to the trouble, it had been necessary to use the forced draft under the boilers in the boiler-house, and the larger of the two stacks having accumulated considerable soot, caught fire and burned out. The flying soot drifted slowly out and fell, covering pretty thoroughly the area within the dotted line. Soon after this occurrence, warmer weather was experienced, and the snow, which covered the cross arms and banked up against the insulators on the transmission line, melted very slightly. Later, a slow mist set in, and before long, the 13,200 volt line flashed over at one of the poles. This flash-over was followed by others, at various other poles, until the whole mine was

* Those who are interested in studying further the question of parallel operation of synchronous motor-generator sets may consult Transactions A.I.E.E., Volumes XXV, 1906, "Some Features Affecting the Parallel Operation of Synchronous Motor-Generator Sets," by J. B. Taylor.

shut down. The lines were finally cleared by disconnecting the feeders and bringing up the voltage on the incoming line until there was another flash-over. This process was repeated until the trouble was burned out. In all, some three hours were required—the longest shut-down ever experienced at the mine, in fact, more than the total time of shut-down in the five years of electrical operation.

In order to determine whether the soot was responsible for the trouble, the electrical engineer, Mr. Bosson, tried the following experiment:

An ordinary porcelain dish was filled with clean water, and the two sides of a 110 volt lighting circuit were placed on opposite sides of the dish and well into the water. There was no effect with the clear water. Now some of the soot from the stack was dropped into the water and stirred until it began to dissolve; immediately there was a flash analogous to the short-circuit which occurred on the transmission line. It seemed evident

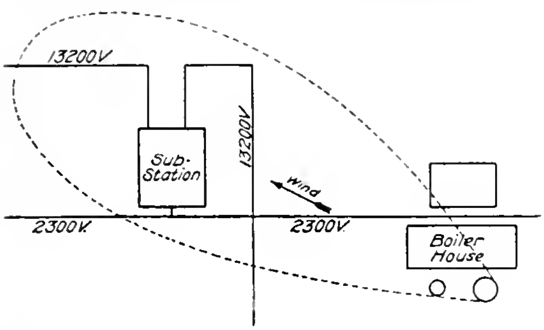


Fig. 1

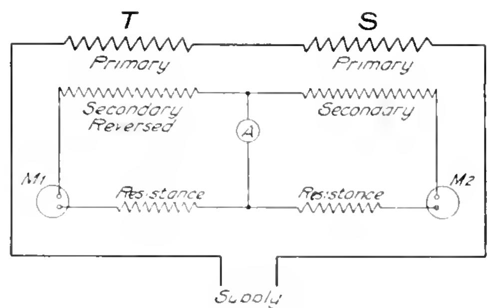
that the snow had bridged between the lines, and that as long as it was dry or frozen hard, the soot had no effect; but that when the snow melted and the soot was dissolved in the water thus formed, the resistance was so reduced that a short-circuit took place.

C. C. ADAMS

XI. TESTING RATIO OF A CURRENT TRANSFORMER

The following description relates to the method for obtaining the ratio of a current transformer which is probably well known to the majority of electrical engineers, but of which I can find no mention in back numbers of the GENERAL ELECTRIC REVIEW.

Referring to the diagram, T is the transformer whose ratio is to be determined, while S is a known standard of the same ratio as the name plate ratio of T. The primaries of these two transformers are joined in series and excited from the line; their secondaries are also joined in series, bucking instead of boosting. If the ratio of T were exactly



equal to the ratio of S, then the voltage across the secondary of each would be exactly the same, and there would consequently be no exchange of current between the secondaries. If, however, there is any difference in the ratio, this will show itself in an out-of-balance current between the two. Meter A is used to measure this current, while the function of M_1 and M_2 is to indicate whether T has a greater or less ratio than S. If the reading on M_1 is less than that on M_2, then the ratio of the transformer T (which is responsible for the reading on M_1) is greater than that of S; and the percentage of A to M_2 gives the per cent. error in the ratio of T.

Suppose the normal current of T is 5 amperes, secondary readings should be taken with current of 2.5 amperes and 5 amperes in M_2. Great care must be taken in protecting the meter A from excessive current, in the case of considerable error in the ratio of transformer T. It is therefore usual to insert a further ammeter in series with A having a maximum reading of, say, 2 amperes; when excitation is applied, A should be short circuited, and if it is found that the reading on the second ammeter in series with A is excessively small (less than .1 ampere), the circuit through A may be opened and the out-of-balance current read. The meter A is a specially constructed instrument having a full scale deflection of not more than, say, 1.5 amperes; an error in the transformer ratio of one per cent. with 5 amperes flowing in the secondary, would mean an out-of-balance current of .05 amperes in A, and meter A must therefore be capable of reading very small amounts.

G. E. R.

ARC LAMP CONFERENCE AT LYNN

The annual conference of the arc lamp specialists of the General Electric Company was held at the Lynn factory, September the 7th, 8th and 9th. The business in hand included the discussion of many papers on various phases of G.E. arc lamp activity, as well as inspection of work in the factory. The delegates consisted of representatives of the Engineering and Sales Departments, at headquarters and in the field, while members of the Consulting Engineering and Patent Departments and the Publication Bureau were also present.

Table Decoration with Miniature Boulevard Luminous Magnetite Arc Lamps

Throughout the conference the luminous magnetite arc lamp received great prominence; its design was thoroughly discussed, its good points fully brought out, and a concrete illustration of boulevard lighting by the latest type of luminous arcs actually provided in the grounds of the River Works, where a number of the lamps on ornamental poles were spaced along the sides of the roadway at 50 foot intervals. A more detailed description of this lamp will be given in the December arc lamp issue of the Review; but for the present we desire only to give a brief description of the very excellent scheme of dinner-table illumination which was adopted at the Suntaug Inn, at the break-up dinner at the close of the conference, and which provided a beautiful illustration of what the luminous lamp may look like.

At this dinner the example of boulevard lighting at the River Works was faithfully reproduced. Down the length of the dining room ran one long table, seating 36 guests. Opposite each cover was an exact miniature reproduction of the boulevard lamp, duly wired off the lighting supply. The pillar of the lamp was made of cast bronze, finished in "verde antique" as in the original and supported on a circular white base made from moulded asbestos compound. At the top of the pillar, 8 in. from the surface of the table was the lamp itself, consisting of a specially prepared tungsten filament in a frosted bulb. Each of the two parallel circuits had 18 lamps in series on the 110 volt house supply, each lamp taking about 6 volts 7½ watts. The dinner table is shown in the accompanying illustration.

The effect of all these lamps was exceedingly pleasing; the decoration combining excellent taste with great ingenuity of design and a maximum of symbolic effect. Each lamp was provided with its own junction box, by means of which it could be detached from the mains, and each guest who was present was allowed to take away his own lamp. There is certainly no doubt that they can perform a very useful purpose in showing in a realistic manner exactly what the latest type of luminous lamp looks like. Most likely a great number of the miniature lamps will now be turned out in order that they may do their own missionary work in a scheme of self-recommendation.

A special type luminous lamp for ornamental street lighting has been developed to meet the increased demand for an ornamental unit, embodying high candle-power with high illuminating efficiency and low maintenance cost; and it seems to have been a happy inspiration that gave birth to the Suntaug dinner lamp, which can furnish proof that, at least as regards artistic effect, the goods have been produced.

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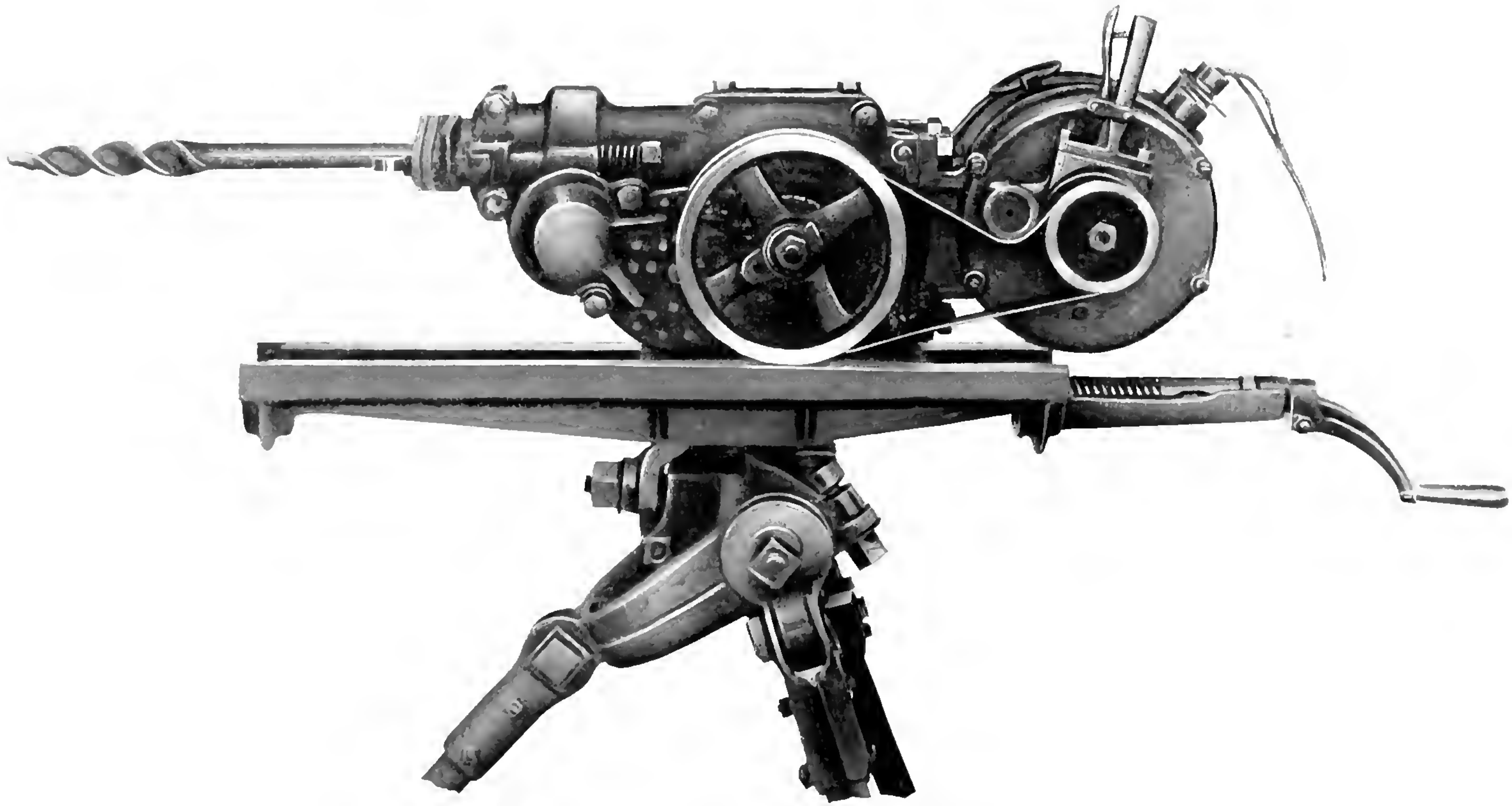

Electric Rock Drill

"Electricity in Mining"—page 540

GENERAL ELECTRIC REVIEW

ELECTRICITY IN MINING

We are increasing the size of this month's REVIEW somewhat in order to admit of the inclusion of a paper on Electricity in Mining, presented by Mr. D. B. Rushmore at the American Mining Congress, held at Chicago October 24 to 28, 1911.

In spite of the comparatively small amount of space which the facts and argument occupy, this paper will be found to constitute a very complete summary of the position, in 1911, of electricity as applied to the mining industry. A brief introduction serves to convey some concrete idea of the magnitude of the industry in the United States, and to emphasize the fact that the system of motive power for mining in the future must be such as to reduce the cost of production while increasing the safety of the individual engaged in the mine. Having shown how electricity is capable of meeting these requirements, the author proceeds to review the position in greater detail. The method adopted throughout the paper is to make a general survey of current electrical practice in the mining industry, together with an argument and discussion of the various reasons which have been responsible for setting the standard; and, based upon this, to draw general conclusions as to the practice which may be adopted in any case of new development, with a view to obtaining the most satisfactory and economical service. As pointed out more than once in the paper, however, it is impossible always to lay down hard-and-fast rules, or even general recommendations, without a more or less detailed acquaintance with any local peculiarities which may exist. On these lines, the various systems of the generation and transmission of electrical power, as applicable to mining centers, are reviewed; after which attention is given to the various power-consuming devices, and the extent of their application at the present time. This subject is divided under the heading of hoisting, pumping, haulage, drilling, coal-cutting, rock-crushers, breakers and tipples, electro-magnetic ore separators, dredging, lighting, and telephone and signalling systems.

The publication of this paper does not break the continuity of the paper by Mr. John Liston on Electricity in Coal Mines, the third instalment of which is also published in this issue.

EQUIVALENT LOAD TESTS ON LARGE ALTERNATING CURRENT GENERATORS

In the testing of large alternating current generators, it is frequently impossible to obtain either sufficient rheostatic capacity on which to load the machine, or a prime mover sufficiently great to drive the generator at its full output for the required time. In any case, even where these facilities are available, a great waste of power must ensue; and to obviate this condition there have been proposed during the last few years a number of different methods for carrying out an "equivalent load" test, the object in all cases being to realize as far as possible actual load conditions with regard to the heating of the various parts, by allowing the passage, through the electrical and magnetic circuits of the machine, of the same amount of energy as would be expended in the form of internal losses if the generator were running on load. Many of these methods are in the nature of an approximation; but others may be capable, in the hands of experienced designers, of providing sufficiently accurate data to give a reliable indication of the temperature which would be reached if the generator were running under normal load.

In the *Electrical World* of April 22, 1905, a new "equivalent load" method for testing the heating of large generators was proposed by Messrs. H. M. Hobart and F. Punga. This was based upon the common practice of open-circuit short-circuit runs, but with the main idea of equivalent loss further developed in order to reproduce more exactly actual conditions. Instead of giving the machine its full duration open-circuit run until constant temperature was reached, then shutting down, taking the temperatures and running on short-circuit, the authors proposed to run the generator alternately on open-circuit over-excitation and short-circuit under-excitation, each condition lasting only for a matter of a few minutes. The purpose was to reproduce the iron loss during the open-circuit periods, and the copper loss during the short-circuit periods; and the amount of over-excitation for the former condition was adjusted to such a value that, during the course of one hour, the aggregate of all the kilowatt-minutes iron loss in all the open-circuit periods would be equivalent to the actual number of kilowatt-minutes which would be lost if the machine were running under normal voltage for a period of one hour. Similarly, the under-excitation for the short-circuit periods was adjusted to such a value that, during the course of one hour, the aggregate of all the kilowatt-minutes copper loss in all the short-circuit periods would be equivalent to the actual number of kilowatt-minutes which would be lost if the machine were running under normal current for a period of one hour. If the machine continues to operate alternately with these two methods of connections during the entire heat test, then evidently it is possible to consume per hour an amount of energy in friction loss, iron loss, and copper loss equivalent to the amount of energy which would be consumed per hour in the different parts during normal operation. The article pointed out that the single indefinite feature related to the I^2R loss due to the field excitation current; but the authors, however, proceeded to describe a graphical method for determining the correct ratio of the under-excitation and over-excitation periods, such as would reproduce the equivalent amount of kilowatt-minutes lost in the field winding.

We are now able to publish a further contribution from Mr. Hobart in which this idea is developed still further by applying it to a machine which has actually been built, whose losses have been tested and are therefore known. He divides each hour into four periods of 15 minutes, and each of these periods is further sub-divided into open-circuit and short-circuit periods, with excitation such as will give the correct number of kilowatt-minutes lost per hour. If this first tentative adjustment fails to reproduce the correct value of equivalent field heating, it is a simple matter, as pointed out in the article, to select a further sub-division; and no complicated calculation is required in order to hit upon the correct length of short-circuit and open-circuit periods to reproduce the equivalent heating of actual conditions.

A leading article, published in the issue of the *Electrical World* to which we have referred, dealt with this method of testing large generators; and after observing that the method appeared to show many advantages, pointed out that it would be very interesting to have it thoroughly tested and reported upon. It does not appear that a great deal has been done in this direction up to the present time; so that the figures which appear on page 508, comparing the heating by this method with the heating of a similar machine running under full load, should prove of considerable interest.

It will be noticed that there is very little difference between the results obtained in the two tests. On the other hand, we have also seen figures showing the heating on another machine, as indicated by the Hobart-Punga method, the separate open-circuit and short-circuit test, zero power-factor method, and actual full-load run, in which the difference between the various results obtained is somewhat more noticeable, and the heating by the Hobart-Punga test is considerably less than that given by the other methods. This we imagine may well be due to a delay (more or less necessary) in making the frequent change-overs from open-circuit to short-circuit conditions, and *vice versa*. Where these occur on the average once every 7½ minutes, it is easy to realize that a few seconds one way or the other every time may make all the difference in the results; and in order that accurate readings may be obtained, it is essential that this "cooling" interval be reduced to a minimum.

A careful perusal of the description of the test will show that, since it may be arranged to expend internally in the machine exactly the required number of kilowatts-minutes per hour, the Hobart-Punga method cannot give other than correct results if the adjustments are correctly made, the time intervals correctly proportioned, and *an instantaneous change-over effected every time.*

A METHOD FOR TESTING THE HEATING OF LARGE ALTERNATORS

By H. M. Hobart, M. Inst. C. E.

Consulting Engineer with General Electric Company

The following is a description of a method of testing the heating of large alternators, which is especially applicable to machines of the design employed for large water-wheel and steam turbine-driven units, where some "equivalent load test" is necessary, and where it is desired also to reproduce as far as possible full load conditions.

The method consists in operating the machine alternately open-circuited over-excited, and short-circuited under-excited. The excitations for these two connections are so selected that during the entire test, the amount of energy dissipated as heat in each part of the machine is identical with the amount of energy which would have been dissipated as heat in each of these parts, had the machine been carrying its rated load during the entire test. Since the connections are changed every few minutes from the open-circuit arrangement to the short-circuit arrangement, the heat capacity of the machine will insure a rise of temperature of as smooth a character as that which would be obtained if the heat test were made by operating the machine at its rated load.

FIRST EXAMPLE

I can best explain the application of the method by making the necessary calculations for a particular machine. I have selected a 9000 kw., 13,200 volt, 25 cycle machine running at 750 r.p.m., upon which the losses have been tested, and are therefore known.

Rated output at unity power-factor	9,000 kw.
Terminal pressure	13,200 volts
Pressure per phase	7,600 volts

$$\text{Full load current} = \frac{9{,}000{,}000}{3 \times 7600} = 395 \text{ amperes}$$

Core loss	85,000 watts
Armature I^2R loss	27,300 watts
Field I^2R loss	28,000 watts

Let us divide the hour into four complete cycles of operation, each cycle occupying 15 minutes. We may consider one of these intervals of 15 minutes and divide it into two parts. The appropriate length of each of these two parts is determined by two or three trial assumptions.

First Assumption

Operate the machine over-excited for 8.5 minutes. Operate the machine on short-circuit for 6.5 minutes.

Over-excited period of 8.5 minutes:

During each hour there will be four of the over-excited periods. Consequently, the machine will be operated over-excited for $(4 \times 8.5) = 34.0$ minutes out of each hour. We must, during these 34 minutes, dissipate as much energy in core loss as would, during operation at rated load, be dissipated in core loss in 60 minutes. Thus instead of the normal core loss of 85,000 watts, we must, for these 34 minutes, have a core loss of

$$\frac{60}{34} \times 85{,}000 = 150{,}000 \text{ watts.}$$

From the core-loss curve we find that a core loss of 150,000 watts corresponds to a pressure of 16,100 volts; and from the no-load saturation curve, we find that a pressure of 16,100 volts requires, on open-circuit, an excitation of 38,000 ampere-turns.

Thus for the 8.5 minute periods of over-excitation, we must maintain the excitation at 38,000 ampere-turns.

Short-Circuit period of 6.5 minutes:

The total time of short-circuit-running during each hour is $(4 \times 6.5) = 26.0$ minutes.

During normal operation at full load, the armature I^2R loss amounts to 27,300 watts per hour (since the full load I^2R loss is 27,300 watts). In order that there shall, in 26 minutes, be the same total dissipation of energy as heat in the armature conductors as occurs in 60 minutes of operation at rated load, the armature I^2R loss must, for the 26 minutes, be maintained at:

$$\frac{60.0}{26.0} \times 27{,}300 = 63{,}000 \text{ watts.}$$

Since full load current of 395 amperes is accompanied by an armature I^2R loss of 27,300 watts, we must, during the short-circuit test, maintain the armature current at a strength of

$$\frac{63{,}000}{27{,}300} \times 395 = 600 \text{ amperes.}$$

From the short-circuit curve we find that the corresponding field excitation is 25,500 ampere-turns.

Thus for the excitations during the two periods, we have obtained the two following values:

I During open-circuit, 38,000 ampere-turns.

II- During short-circuit, 25,500 ampere-turns.

But up to this point we have not taken the field loss into consideration. For normal running (9000 kw. and unity power-factor), the field loss is 28,000 watts, and the excitation under these conditions is: 32,500 ampere-turns.

The field loss during the open-circuit period will be

$$\left(\frac{38,000}{32,500}\right)^2 \times 28,000 = 38,000 \text{ watts.}$$

During the short-circuit period the field loss will be

$$\left(\frac{25,500}{32,500}\right)^2 \times 28,000 = 17,200 \text{ watts.}$$

During one hour, the loss in the field will be made up of two components:

Open-circuit period:

$$\frac{34}{60} \times 38,000 = 21,700 \text{ watt-hrs.}$$

Short-circuit period:

$$\frac{26}{60} \times 17,200 = 7,450 \text{ watt-hrs.}$$

$$21700 + 7450 = 29,150 \text{ watt-hrs.}$$

Loss during one hour = 29150 watt-hrs.

For normal operation the field loss is 28,000 watts; consequently, the above result is a little too high. If it is considered essential to have it *just* right, then we may accomplish this by modifying the durations of the two periods, i.e., the open-circuit period and the short-circuit period. Thus let us make a second trial assumption as to the durations of these two periods.

Second Assumption

Operate the machine over-excited for 8.7 min.

Operate the machine on short-circuit for 6.3 min.

In the following table, I have placed in parallel vertical columns, the steps in the calculations corresponding to the first and second assumptions.

Thus we see that the results obtained by the second assumption give us just the same losses per hour in core, armature circuits and field circuit, as would be obtained in operating the machine at its rated load. But the energy required in testing the machine by this method is only that represented by these three losses, *plus* friction and windage, and *plus* the losses in the rheostat for controlling the field strength. In a machine of the size employed in this example, all these losses together do not exceeed three per cent. of the rated capacity of the machine. We thus obtain the advantage of reproducing, so far as *heating* is concerned, the precise conditions of a full load test, with the small consumption of energy corresponding to the internal losses in the machine.

	1st. Assumption	2nd Assumption
Duration of over-exc. period	8.5 min.	8.7 min.
Duration of short-circ. period	6.5 min.	6.3 min.
Core loss during over-exc. period	150,000 watts	146,000 watts
Field I^2R loss during over-exc. period	38,000 watts	35,300 watts
Pressure during over-exc. period	16,100 volts	15,750 volts
Excitation during over-exc. period	38,000 amp.-turns	35,500 amp.-turns
Arm. current during short-circ. period	600 amps.	610 amps
Arm. I^2R loss during short-circ. period	63,000 watts	65,500 watts
Excitation during short-circ. period	25,500 amp.-turns	26,700 amp.-turns
Total duration of over-exc. period (per hour)	34.0 min.	34.8 min.
Total duration of short-circ. period (per hour)	26.0 min.	25.2 min.
Field loss during over-exc. period (per hour)	21,700 watt-hrs.	20,500 watt-hrs.
Field loss during short-circ. period (per hour)	7,450 watt-hrs.	7,500 watt-hrs.
Total field loss per hour	29,150 watt-hrs.	28,000 watt-hrs.

SECOND EXAMPLE

In accordance with the method previously explained, the following calculations and experimental heating tests were made on a second generator, this being a 2500 kw., 1800 r.p.m., 2300 volt machine. As no core loss test was made on the machine in question, the following losses derived from test records describing duplicate machines were assumed as being sufficiently accurate for our purpose.

Full Load Losses:

Core loss	49,000 watts
Armature I^2R loss	8,300 watts
Field I^2R loss	13,400 watts

The system of dividing the hour into four cycles, as previously described, was maintained, but the following subdivision of time was made:

Operate machine over-excited for 10 min.
Operate machine on short-circuit for 5 min.
Hence:

$4 \times 10 = 40$ min. of operation over-excited per hour.

$4 \times 5 = 20$ min. of operation on short-circuit per hour.

For Core Loss: (operation over-excited)

49,000 watts = rate of loss at normal load.

$\frac{60}{40} \times 49{,}000 = 73{,}500$ watts

= rate of loss required for test.

From the curves we have: 73,500 watts core loss corresponds to 2720 volts armature, or 118.6 per cent. normal volts, and requires 168 amperes field.

For Armature I^2R Loss: (operation on short-circuit)

8300 watts = rate of loss at normal load.

$60/20 \times 8300 = 24{,}900$ watts

= rate of loss required for test.

628 amps = normal load current.

$\frac{24{,}900}{8300} \times 628 = 1090$ amps. required for rate of 24,900 watts.

$(1090 \div 628)100 = 173.5$ per cent. normal amps.

From the short-circuit curve: 1090 amps. armature requires 120 amps. field.

For Field I^2R Loss:

Take 0.6 ohms as resistance of field.

$168^2 \times 0.6 = 17{,}000$ watts

= rate of loss during over-excitation.

$40/60 \times 17{,}000 = 11{,}320$ watt-hrs. loss on over-excitation (40 min.)

$120^2 \times 0.6 = 8650$ watts

= rate of loss on short-circuit (20 min.)

$20/60 \times 8650 = 2880$ watt-hrs. loss on short-circuit.

$11{,}320 + 2880 = 14{,}200$ watt-hrs. total field loss.

But, 13,400 watt-hrs. = field loss during same length of time under rated load.

$(14{,}200 \div 13{,}400)100 = 106$ per cent. loss in field.

This increased loss in the field has been allowed for two reasons: First, to allow for operation of the machine at a power-factor less than unity, and, second, because the division of time is convenient (10 and 5 minutes).

Loss Curves

The curves on Figs. 1 and 2 show the losses in the machines for one hour, Fig. 1 referring to the first machine we considered, and Fig. 2 relating to the second. These curves do not show all the losses, as the

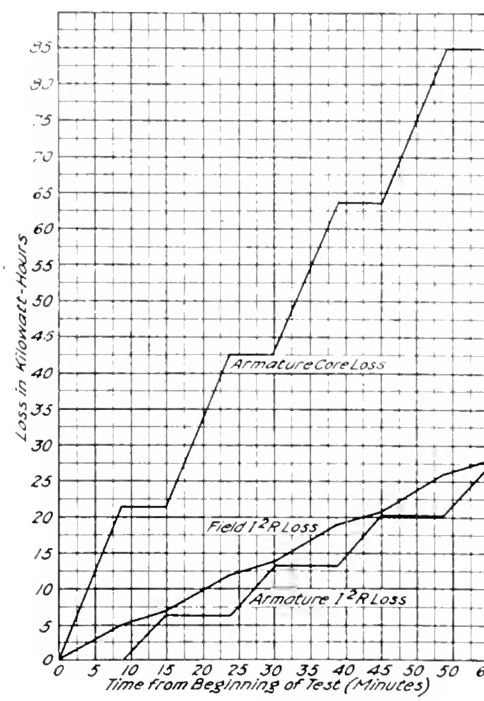

Fig 1. Calculated Loss Curves for Alternator (First Example)

friction and windage loss, which may amount to as much as 2 per cent. of the total capacity of the machine, and the dielectric loss due to voltage stresses on the insulation, are not given. It is evident, however, that the friction loss is the same in this case as it would be in the case of a load test. On a high voltage machine, the dielectric loss at open-circuit might be higher than under normal voltage, but the fact that it would be zero at short-circuit should bring this down to about the right amount.

Comparative Results

In the following table the results of this run are shown giving the degrees rise on various parts of the machine, also the degrees

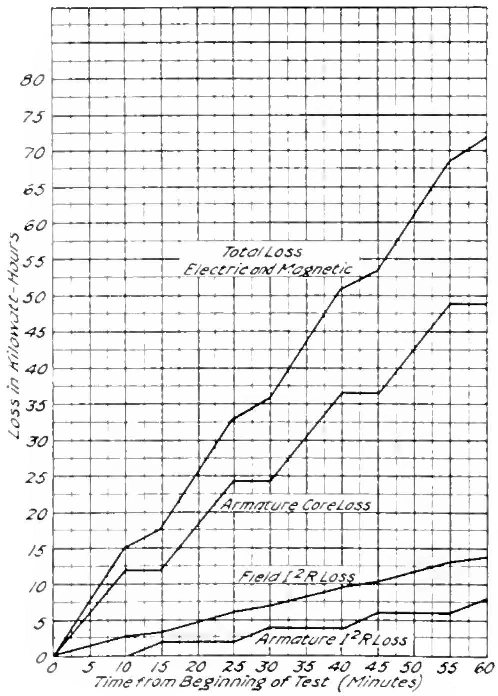

Fig. 2. Calculated Loss Curves Alternator (Second Example)

DEGREES RISE

	Open Circuit Short Circuit Test	Full Load Test
Laminations	30	29
Armature core, center	30	35
Armature coil, by res.	20	36
Rev. field, by res.	32	35

rise obtained on a machine of the same capacity (but different voltage) when fully loaded.

Fig. 3 gives a sketch of the connections as used in this test with the following directions for operation. With S3 and S2 open, and S1 closed, set R1 to a position such that the alternator voltage is 118.2 per cent. of the normal value, i.e., 2720 volts; this gives the open-circuit condition. With S3 closed, S1 open and S2 closed, set R2 to a position such that the short-circuit current is 173.5 per cent. of normal value, i.e., 1090 amps. This gives the short-circuit condition. Run on open-circuit for *10* minutes, then change over to short-circuit and run for *5* minutes. Alternate these periods continually until temperatures are constant. The change-over must in all cases be effected instantaneously, for, with intervals each of but a few minutes duration, the loss of only a few seconds occasions an appreciable percentage error.

It may be of interest to mention that I once applied this method to the testing of a small continuous electricity generator.

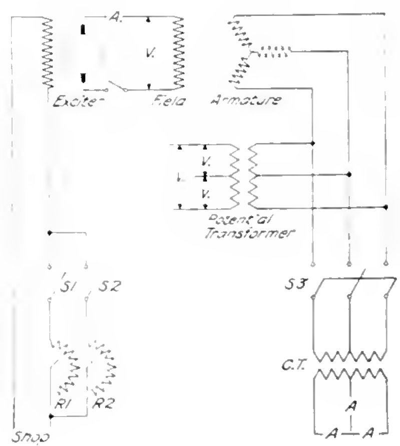

Fig. 3

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ALTERNATING CURRENT APPARATUS TROUBLES

Part VI. By W. Brooke

INDUCTION MOTORS

The following remarks with regard to the localizing and remedy of induction motor troubles are intended to apply to single-phase and polyphase machines of the squirrel cage and slip ring type, since these are the types most commonly employed in industrial service. The Form L motor, with polar wound rotor and internal starting resistance, and the RI repulsion induction motor, are not included in the scope of this article.

The operating troubles for convenience are grouped under the following headings:

(1) Starting.
(2) Overheating of Stator.
(3) Overheating of Rotor.
(4) Sparking at Brushes and Pitting of Collector Rings.

STARTING

The failure of a motor to start may be due to:

Cause 1. No Voltage at Motor Terminals

Some defect in the connections between the service switch and the motor terminals may result in absence of voltage at the latter. All the connections should therefore be carefully traced out. In the case of a squirrel cage motor, such inspection will include whatever device is employed for reducing the applied voltage, whether an auto-transformer or Y-△ starting switch. Lamps in series may be used for looking for an open circuit.

Cause 2. Low Voltage

This may be due to overloaded generators or transformers, in which case it will sometimes be impossible to start the motor until the line volts are raised to the correct value. In the case of a squirrel cage motor with auto-transformer starter, a wrong tap in the latter may result in applying insufficient voltage to the motor terminals with the starter handle in the first position. The cover of the starter should be removed and fresh auto-transformer connection made to see if the motor will start up on the next higher tap. In certain industrial applications where heavy starting torque is essential, and where the starting torque of the motor installed is at best only just sufficient for the requirements, it is essential that the generator voltage be maintained at the normal figure, and in some cases the line voltage is actually raised at starting to help the motor over the heavy-torque period, although this course is not recommended. It should be remembered in this connection that with line volts low the torque of the motor at starting falls away as the square of the volts.

A case was once known in connection with a squirrel cage motor, where the auto transformer connections were brought out in such a way that, with the starting handle in the first position, full voltage was applied to the motor; while, when the handle was pushed over to the running position, a 60 per cent. tap was connected in, with a consequently reduced torque on the motor. If the cause of any starting trouble is suspected to be in this direction, a simple test is to cut the auto-transformer out of circuit altogether and note whether the same effect is still produced.

Cause 3. Defects in Stator Winding

Defects in the stator winding will apply equally to slip ring and squirrel cage machines. In the case of single-phase machines, an open-circuit will render all of the stator winding inoperative. In the case of two-phase machines, an open-circuit in one phase also leaves the motor with zero starting torque. If the motor were brought up to speed mechanically, it would then continue to operate and would deliver single-phase output (i.e., 50 per cent. of full two-phase rating). In order therefore to determine whether the cause of the trouble lies here, it is often a good plan to give the rotor some mechanical assistance to see whether it shows any inclination to turn in either direction. If the rotor will not move from rest unaided, but shows a tendency to come up to speed when assisted mechanically, this will suggest an open-circuit in one stator phase; and the usual methods should be tried out to prove whether this is the case. If the stator circuit is broken, there will be no rotating stator flux, and hence no inclination of the rotor to turn in either direction.

With three-phase Y-wound machines, an open circuit in one phase will leave the motor with single-phase excitation and consequently without starting torque, as in the case of two-phase machines. If brought up to speed, such a machine will continue to operate, developing single-phase power.

In the case of three-phase delta wound machines, an open circuit in one phase winding will result in an open circuited delta, excited with three-phase current. Such a winding will produce a rotating magnetic field and consequently develop a starting torque, although of smaller value than normal three-phase torque. However, if the normal starting torque is just sufficient to start the load, the motor will most likely refuse to start when suffering from this defect.

In a three-phase delta wound machine with one of the leads from the terminal board to the junction of the winding parted or disconnected, the motor will receive only single-phase excitation, with the result that no starting torque will be produced. As before, the motor will operate with single-phase output if mechanically brought up to speed.

In order to detect which is the open-circuited coil, it is necessary to strip the insulation off the ends of all the coils and test out with a voltmeter from the main terminals of the machine. As this entails considerable trouble and delay, resort should not be made to this procedure until it is proved that the open-circuit does not occur in the line connections, but is actually in one of the stator phases.

A short-circuited coil in the stator will usually not prevent the machine from starting, unless it happens that its starting capacity for the particular local conditions is already taxed to its limit.

Two grounds in the windings of one motor may be sufficient to prevent the motor starting, since their effect is to short-circuit a portion of the whole winding. A ground may be tested for with lamps between the motor terminals and the frame, and it is usually not difficult to locate the ground, since charring of the teeth in the core is usually caused where the current is going to ground.

Cause 4. Defects in Rotor or Secondary Circuit of Motor

Burnt-out coils in the rotor of a slip ring motor may prevent the machine from starting, depending on the amount of starting capacity which the machine has in hand for the particular starting load. Such burn-outs are usually easily located on inspecting the rotor. Trouble in the rotor circuit is usually confined to wound rotor machines, and cases of burnt out bars in squirrel cage secondaries are of very rare occurrence.

Starting troubles in the case of slip ring machines may often be traced to the controller, resistance, starting rheostat or collector rings. The secondary connections should therefore be carefully inspected to see that there is no break in the continuity of the rotor circuit. Possibly the amount of starting resistance may be too high, and a few tests may be made in short-circuiting some of the units in the starting resistance. Care should be given to the collector rings and brush rigging. If the acceleration is violent and jerky, it may be that the grading of the various resistance steps is incorrect; and this may be ascertained either by resistance measurements and calculation, or, where a controller and separate grid resistances are employed, by re-grouping some of the resistance units. Excessive brush contact resistance may prevent the motor from starting. The rings should therefore be kept clean and smooth, and the brushes bedded true to the surface of the collector.

Cause 5. Excessive Load at Starting

Failure to start may often be due to the fact that the load to which the machine is connected is too heavy for the motor to turn over unassisted. Such a question as this involves the original design of the motor, laid out or not laid out to meet the particular conditions, and frequently the only remedy is to install a new machine.

Starting of Single-Phase Motors

Starting troubles are probably more frequently met with in connection with single-phase machines than with polyphase. Single-phase machines of the squirrel cage type are usually started up by means of a starting box having extra contacts, to which is connected a reactive coil which sets up a lagging current and thereby produces a second phase. Currents from this phase are utilized in the stator of the induction motor on a winding corresponding to a second winding on a two-phase machine, as without this second winding, no revolving field could be set up, and hence the machine would not turn from rest unaided. If the motor takes a heavy current and makes no apparent effort to turn, make sure that there is only belt load on the machine, and that the armature turns freely on being assisted round by hand, or with a bar. It should be noted whether it is any more difficult to turn by hand in the backward or forward direction when the current is on; if it is easier to turn in one direction than the other, then it is obvious that the starting circuit is not open, and the circuit should be examined for badly-made connections which might produce a high resistance in the starting circuit. If there appears to be no starting effort on the motor, then the starting box should be examined to see that the reactive coil is in circuit. This can easily be determined by noting whether or not the core of the reactive coil vibrates when excited, by holding a pencil on the core.

Starting of High Tension Slip Ring Motors

In machines having stators wound for high voltages (up to say 10,000 volts) it is customary to install charging resistances, for the purpose of gradually applying the pressure to the stator, so as to prevent static discharges occurring due to the rapid rise of flux. These charging resistances consist of a form of liquid starter, which inserts a high resistance in each phase and keeps down the pressure on the windings to a fairly low value when switching on. By cutting out resistance, the potential is allowed to rise gradually, and this then avoids the necessity of throwing on the very high voltage, which might result in breaking down the insulation of the machine. A case of this description occurred on the starting motor of a synchronous motor-generator set which was taking power from a 3300 volt circuit. The stator of this starting motor was switched directly on to the line by an oil-switch on the main switchboard, which was interlocked with the other switchgear, and the rotor circuit was left open by the three-phase regulator. Each time this motor was switched on to the line, a spark would invariably jump from one or another of the coil connections to the frame. Eventually the machine broke down and had to be rewound, this evidently being due to the cause which has been mentioned above. When the machine was repaired, the three-phase regulator was arranged so as to be always closing the rotor circuit, though through sufficient resistance to ensure that the machine would not turn until the regulator was moved round to a step of lower resistance, when it would then accelerate, the regulator in this case being used for synchronizing. By closing the rotor circuit in this manner, it acted more like a discharge resistance on the shunt field of a generator.

OVERHEATING OF STATOR

Cause 1. Motor Running on Load with Line Volts Low

Most induction motors will usually operate satisfactorily on any circuit of the same frequency as that for which they are designed, provided the voltage is within 10 per cent. of their rated voltage. The maximum output, however, varies as the square of the voltage; and if the line voltage is reduced below the normal value, it must be remembered that the breakdown value of the motor torque will be considerably reduced and the machine will not continue to run on the same load with the same heating as guaranteed for full voltage. The only remedy therefore for trouble of this nature is to bring up the line volts, or reduce the motor load.

Cause 2. Too Frequent Starting Service

In most motor installations, the starting torque is the determining feature with regard to the type of motor which is selected. If the machine has to turn over a load at starting corresponding to 60 h.p. and the normal load is only 30 h.p., a 30 h.p. slip ring motor may be selected for the work. But the ability of the machine to stand this service depends on the number of starts which will be normally made per hour, and if the starting is frequent, possibly a 40 h.p. or 50 h.p. motor would be insufficient. This point should be particularly watched when first setting the motor to its work; as it is not unusual, when making a trial of the driven apparatus which the motor has to operate, for the user to forget that the motor cannot perform its overload starting at frequent intervals, and it will therefore become overheated. Trouble from this source is not so common when once the motor and the driven machinery have been put into regular service.

Cause 3. Unintentional Overloading

Mechanical faults, causing the rotor to bind on the stator may be responsible for overloading of the machine. Under this heading would come badly worn bearing liners and obstructions on the rotor periphery. Air-gap clearances should be checked with feelers, and to remedy the trouble may require new bearing linings and re-turning up of the shaft.

Cause 4. Normal Load at Reduced Speeds

Overloading is sometimes caused, in the case of slip ring machines, by endeavoring to run them at their full load output on the last notches of the starting resistance. It should be remembered that a motor is fully loaded, as far as is determined by heating, when it carries the same current at all speeds, i.e., when its horse power decreases exactly in proportion to its speed (which, of course, assumes a constant torque). For instance a variable speed 20 h.p. motor (secondary control) is rated to give 20 h.p. at full speed; if in service it is made to do 20 h.p. at half speed, then its windings will be correspondingly overloaded and general over-heating will result. The remedy for this is to replace the motor with a larger machine.

Cause 5. Ventilation Passages Obstructed

To avoid overheating of the windings through obstruction of the ventilation passages (stator air-ducts and stator winding) it is advisable to make a habit of cleaning out the machine periodically. A compressed air-blower may be used to expel all dust, dirt and other foreign matter from the coils, ducts, etc.; but a vacuum cleaner is preferable, as the danger of accentuating the trouble, instead of removing the cause, is obviated.

Cause 6. Defects in the Stator Winding

A short-circuited coil in the stator will cause overheating; and this may be found by examining the stator winding with the hand, and noting if any particular coil is hotter than the rest: this trouble usually manifests itself by the presence of a burning smell which is later followed by smoke. The defective coil should be removed and replaced. There should be no difficulty in finding it, as it will probably show up due to its scorched appearance, and will be hotter than the rest. If there is any doubt as to the exact location of the coil, the motor should be run a little longer under load until the fault shows up properly. The short may have occurred between the incoming and outgoing leads and not actually in the coil itself, though by the time the short-circuit manifests itself, the coil will probably have perished due to the overheating, and can be repaired only by replacing it by a new one. A short-circuited coil does not usually cause any trouble whilst running, although if it is not detected and remedied, it may lead to further trouble in the machine in some other direction.

It may occur that when a three-phase machine is running on the line, overheating may be developed on one phase; so that, when the windings are examined with the hand, it may be found that all coils belonging to one group or phase are much hotter than the rest. This would be detected by a burning smell followed by smoke issuing from the windings, or may first attract attention by hot air issuing from the air ducts in the stator. In order to locate the trouble, measure the voltage across the terminals of each phase of the stator, and note if they are unbalanced. If this appears to be the case, it will point to the possibility of one of the phases having become disconnected from some part of the stator, either between the motor and the line, or between the motor terminals and the winding itself; as the effect of this would be that, for a given amount of work that the motor was steadily doing, the current would be considerably over normal in the overheated winding due to the phases being split, i.e., the machine would be running on single-phase. Proof of this would be further obtained by shutting down the machine and trying to start up again; if the trouble was as here anticipated, then the machine would fail to start on single-phase.

Cause 7. Defects in the Rotor Winding

Loose connections in the rotor circuit, whether the machine be squirrel cage or wound rotor, may have the effect of introducing a high secondary resistance. For the former type of machine, the secondary bars should be closely inspected. Any defective soldering should be re-soldered; any loose nuts should be tightened. For slip ring machines, the connections to the starting rheostat or to the controller and resistance box should be carefully gone over.

OVERHEATING OF ROTOR

Cause 1. Short Circuit in Rotor Winding

As a matter of interest, a case may be quoted which occurred some time ago in a factory, which, while uncommon, illustrates the overheating and general distress which may be caused by a short-circuit of one or more coils in the rotor. This short occurred through the winding being grounded in two places. The motor in question was found to be emitting hot air through the stator air ducts although the stator winding itself seemed cool enough. One set of the slip ring brushes was sparking badly, resulting in pitting of that slip ring, while the other rings were in fairly decent order. The motor was shut down, the bad ring cleaned up, and new brushes put on it, with the same result again. The motor was shut down again and the rotor winding was found to be very hot locally. On switching on to start again, a buzzing noise was heard followed by an arc inside the rotor; and on closer examination two of the leads between the slip rings and the rotor end-winding were found to be in contact with the armature spider (this had been caused by the centrifugal force pressing them to a portion of the spider and bursting the insulation of the conductor behind and earthing; the conductors appeared almost as if they had been hit on to a sharp metal part with a hammer). The winding was thus grounded at two points, causing a short on two phases, and the heavy out of balance current was returning through one slip ring and through the resistance and the other rings together. The current density on the bad brushes was therefore so high as to cause sparking and damage the slip rings.

In any case of this description where two points are grounded inside the rotor, these points must be found and re-insulated. If the faults are inside the rotor winding, then the best method to find them is to untape all the coil connections, and, connecting a source of supply to one pair of slip rings and putting on about half the load current, the drop should be measured by a low-reading voltmeter between each coil connection and the shaft. The readings will be found to gradually decrease when approaching the grounded point, and will again increase on the other side of the same. A continuous current is preferable to use in this test if available, although an alternating current may be used if necessary. When grounds develop in the rotor, they usually appear on the sides or the top portion of the slots, and manifest themselves by fusing a portion of the teeth.

Cause 2. Open Circuit in Rotor

This usually manifests itself by over-heating of the rotor winding and the emission of hot air from the ducts. If the motor were under load, the speed would drop considerably, on account of the fact that the rotor would be running on single-phase, so that only a portion of its winding would be operative. A certain indication of an open-circuit of one rotor phase is given by the fact that the rotor, when the machine is started from rest, locks at half speed, and will not run up above this point. The cause of trouble in this case may be in the rotor winding of the machine, or it may be external to the motor altogether, and might be found in the starting and controlling gear.

The fault should be located by measuring the voltage between the slip rings; if any zero readings are obtained, then the fault is evidently inside the machine, and the circuits should then be rung through with a bell and the fault located by this means. Assuming, however, that readings are obtained between each pair of slip rings, then the fault is external to the machine and the voltage should be measured between the lines connecting between the slip rings and the external gear to which they are connected. It would then be found that the readings between two of the lines would be zero if one phase were open. By this means the locality of the fault may be traced, and it may possibly be found that a lead has become disconnected.

SPARKING OF BRUSHES AND PITTING OF SLIP RINGS

When machines are overloaded trouble is sometimes experienced with the slip rings in that the brushes spark, owing to the high current density in them; this causes the rings to become pitted, and the brushes to wear away rapidly.

Most machines are arranged to have a little end-play in the rotor, so that the rings oscillate past the brushes and prevent the latter wearing grooves in the rings. If grooves are allowed to be worn in the rings, and the rotor develops a little end-play, the brushes chatter, make bad contact, and pit the rings. If these points are attended to, not much difficulty will arise. If the rings become eccentric the rotor should be taken out and mounted in the lathe, and the rings turned true. The rings should periodically be cleaned with sandpaper; and new brushes should always be bedded true to the rings. As pointed out above, under starting troubles, excessive brush contact resistance may prevent the motor from starting; while it may also cause excessive drop in speed, inability to carry rated load, and overheating of the collector rings.

A MOTOR-OPERATED SHEET BAR MILL

By B. E. Semple

Chicago Office, General Electric Company

The Indiana Steel Company started work on the immense steel plant at Gary, Indiana, in April, 1906, on a site which at that time presented an almost barren waste of sandy country. On the twenty-third of July, 1908, the first cargo of iron ore was received, and the Gary Harbor was officially opened. Since that date a number of different mills have been finished and placed in regular production, the list comprising a rail mill, billet mill, axle mill, plate mill and five merchant mills. In June, 1911, the 18 in. continuous sheet bar mill was completed and placed in regular production.

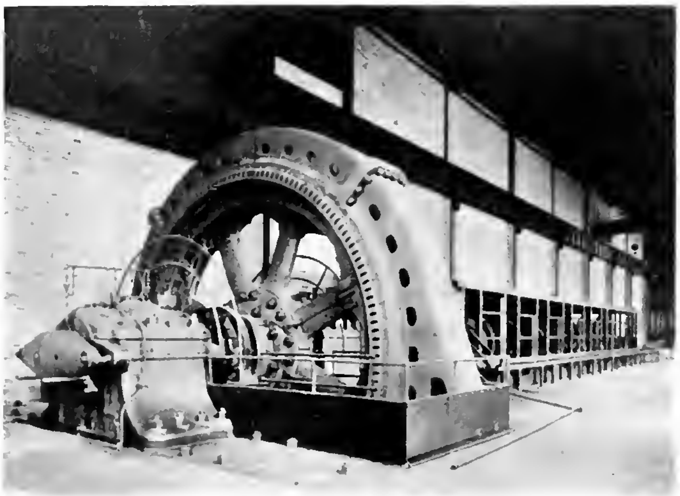


Fig. 1. 6000 H P. 3-Phase Induction Motor Driving Sheet Bar Mill

These several mills have their main rolls driven by 25-cycle, 6600 volt, three-phase induction motors, the total horse-power in motors for this purpose being 73,350; the entire plant, including the new coke oven department, uses something more than 120,000 h.p. in electric motors of either alternating or direct current types.

The sheet bar mill is driven by a 6000 h.p., 83.3 r.p.m., 6600 volt, three-phase, 25 cycle, slip ring type induction motor, manufactured and installed by the General Electric Company, this motor being almost an exact duplicate of six others previously installed. The mill has eight stands of two high rolls which are connected to a single drive shaft through bevel gears. The drive shaft is in turn connected to the motor shaft through a flexible coupling, the coupling being furnished as a part of the motor equipment.

Fig. 1 shows the motor with the drive shaft and gearing arrangement; the shafts carrying the gears pass through the wall in the background to their respective roll stands. The motor is of the same massive construction as the six others in the plant, and differs only in construction by having a slightly different rotor winding, in that this winding is held in place against the action of centrifugal force by clamps, instead of wire bands around the rotor circumference outside of the slots.

In the rolling operation of this mill, the work demanded of the motor is continuous in character, when steel is in the rolls, for periods of too long a duration to make a flywheel of any value in absorbing portions of the load. The motors of this same rating in other mills throughout the plant have a very large flywheel effect in their revolving elements; this is of vast assistance in the saving of power, as the work is of an intermittent nature, the steel being in the rolls for only short periods at a time. The rotor of the sheet bar mill motor was, therefore, not provided with the heavy steel segments bolted to the rotor spokes as were the other motors; but provision was nevertheless made in the manufacture of the rotor to admit of the addition of these segments at any future time if found necessary. In the illustration the machined surfaces on the rotor spokes for the reception of the segments can readily be seen.

Fig. 2 shows the primary and secondary control equipment for the motor. The incoming 6600 volt line can be seen coming from above to the disconnecting switches directly in front of which is located the main line motor-operated Form H-3 oil switch. In front of the main line switch are the reversing and direct current switches, while in front of them the panel containing the indicating and recording instruments is located; the master controller is located directly at the right of the instrument panel. On the extreme right in front are the secondary contactors, with the secondary resistance in the background. The control equipment is located about eight feet to the left of the motor, the motor and control being in the same room entirely separated from the mill proper by a brick wall. This arrangement assists in bringing about cleanliness, and keeps the mill operators away from the electrical equipment.

The motor is started by the electrical attendant at the beginning of the rolling period, and is allowed to run continuously at constant speed until the rolling period is over, at which time the electrical attendant shuts it down. Direct current at 250 volts is employed in operating the control equipment, and also for providing a dynamic braking effect on the revolving element of the motor, for the purpose of bringing it to a stop quickly in case of necessity.

The three blades of the disconnecting switch are operated simultaneously by one handwheel which is interlocked with the oil switch on the 250 volt direct current circuit in such a manner that the disconnecting switches must be open before the direct current switch can be closed and direct current admitted to the stator winding for dynamic braking purposes; this precludes the possibility of getting the 6000 volt alternating current system and the 250 volt direct current system together. Suitable interlocks also prevent operating the reversing switches while the main line oil switch is closed; the motor normally operates in one direction and is only reversed in emergencies.

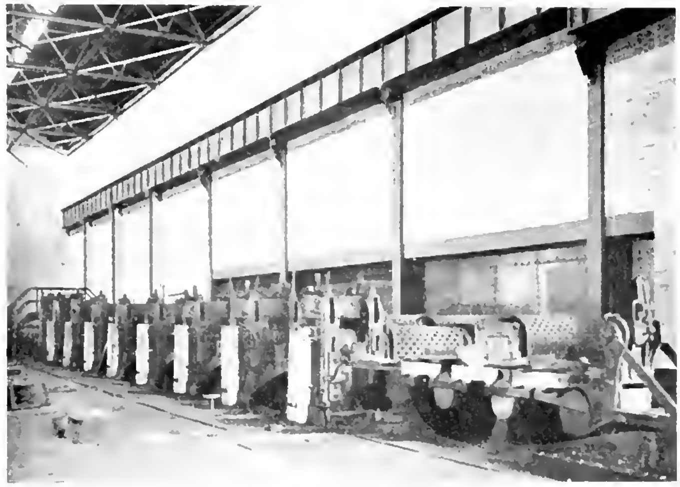


Fig. 3. Sheet Bar Mill, Showing Eight Stands of Rolls, Steam Flying Shear and Crop Shear

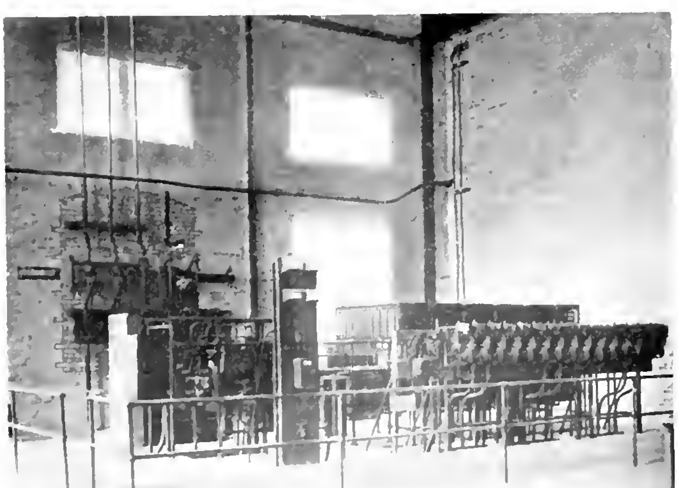


Fig. 2. Primary and Secondary Control Equipment for 6000 H.P. Motor

The main line switch is automatic on overloads, and also opens automatically in the event of failure of alternating or direct current, either separately or simultaneously.

In using direct current for dynamic braking, a predetermined resistance is placed in series with the stator winding to limit the current to approximately full load alternating current value. The control equipment is extremely simple and entirely fool proof and can be operated by any person of ordinary intelligence.

Fig. 3 shows the eight stands of rolls in the mill proper, with the steam flying shear at the right and the crop shear at the left. Steel is served to these rolls from the billet mill over a transfer table at the extreme left of the illustration, in pieces $4\frac{1}{2}$ in. by $7\frac{1}{2}$ in. and not longer than eighty feet. The steel first passes the crop shear, thence through eight stands of rolls, being rolled down to $\frac{3}{8}$ in. by 8 in., after which it passes through the steam flying shear where it is cut into 30 foot lengths. It then passes through the pinch rolls to the cooling beds. The mill is capable of adjustment for rolling sheet bars up to $1\frac{1}{2}$ in. thick if desired.

Pass	Teeth in Pinion	Teeth in Gear	Roll Speed r.p.m.
1	18	90	16.3
2	22	85	21.1
3	28	81	28.2
4	36	75	39.1
5	44	65	55.2
6	52	56	75.7
7	61	40	124
8	65	41	129

In the motor room (Fig. 1) the reductions from the drive shaft to the roll shafts are as given in adjoining table.

The pinions and gears are of cast steel with cut teeth.

The sheet bar mill has a capacity for rolling approximately 120 tons per hour, its product being sent to the new plant of the American Sheet and Tin Plate Company, located just west of, and adjacent to the Indiana Steel Company's Works.

THREE-PHASE VECTOR REPRESENTATION*

By L. F. Blume

In the vector representation of three-phase alternating current problems, too great emphasis can not be laid upon the facts,

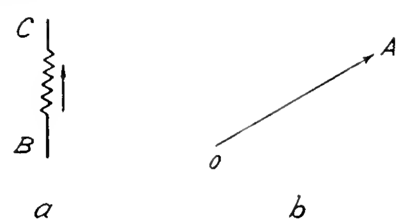


Fig. 1

first, that a vector completely represents a simple alternating quantity; and second, upon the applicability of Kirchhoff's laws.

In applying vectors to three-phase problems it must be remembered that the simple vector with its arrow and the conventional mechanism of rotation does not completely give the phenomena occurring in the circuit. There is still left to be decided the positive direction of current or electromotive force for which the vector stands. For example, in Fig. 1 vector *OA* represents to a certain scale the current flowing in the circuit *BC*, but until it is decided which is the positive direction of flow in that circuit, the representation is not complete. An arrow placed along the circuit is useful to indicate the direction of positive flow. Now, when the projections of the vector *OA* on the vertical axis are positive, the current flows from *B* to *C*, when the projection of the vector becomes negative, the current is flowing from C to B.

In ordinary single-phase problems, no confusion arises by neglecting to choose the positive directions, but in all polyphase problems, the failure in its proper selection for every part of the circuit will lead to confusion in the vector diagram, and consequently an inability to use it for a complete solution of the problems in hand.

The full understanding of Kirchhoff's two laws will also go a great way towards simplifying polyphase vector problems. The first law states that the vector sum of all the currents flowing towards a common point equals zero, when all the positive directions are taken either towards or away from that point. For example, in Fig. 2 there are represented four current carrying wires meeting at *O*. The positive directions, as indicated by the arrows, are all towards *O*. Kirchhoff's law, $\Sigma I = O$, is stated vectorially by the fact that the vectors *a*, *b*, *c* and *d*, when their

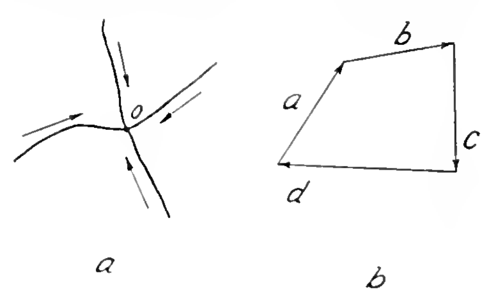


Fig. 2

arrows are all in the same direction, must form a closed figure.

Kirchhoff's law for electromotive forces states that in any closed circuit, irrespective of

*A paper presented to the Pittsfield Section, A.I.E.E.

that to which it may be connected, the vector sum of all the electromotive forces, including the electromotive forces due to resistance and inductance is equal to zero, provided the positive values are all taken in the same direction. For example, in Fig. 3a, circuit *abcd* has electromotive forces between the points *a* and *b*, *b* and *c*, *d* and *a*. The positive directions given by the arrows in the circuit are all clockwise. Then Kirchhoff's law requires that the vectors representing the electromotive forces in the circuit form a closed polygon when the vector arrows are all in the same direction.

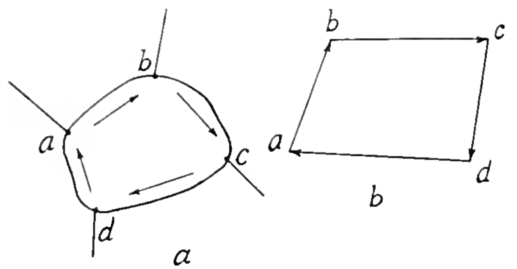


Fig. 3

In three-phase balanced circuits it has become conventional to represent electromotive forces or currents by either of two diagrams, given in Fig. 4. Fig. 4a gives three equal vectors, drawn from a common point *O* and spaced 120 deg. apart, with the arrows either away or towards the common point. Fig. 4b consists of a triangle with the arrows either all clockwise or all counter-clockwise. These figures equally well represent balanced three-phase values; but it should always be kept clear' in mind when this representation is used, that a very definite choice of signs is implied. These are given in Fig. 5. In the three-phase line represented by Fig. 5a the positive directions of current are all towards the right, as indicated by the arrows *A*, *B* and *C*, or the reverse. In the Y circuit, Fig. 5b, the positive directions are either all towards the neutral or all away from it, and in the delta circuit, Fig. 5c, the positive directions are either all clockwise or all counter-clockwise. Any other choice than those given will involve a corresponding change of the vector diagram if the same physical fact (balanced three-phase conditions) is to be represented.

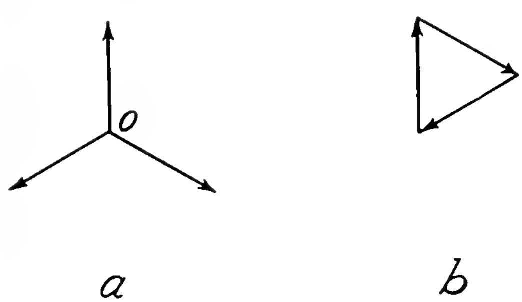


Fig. 4

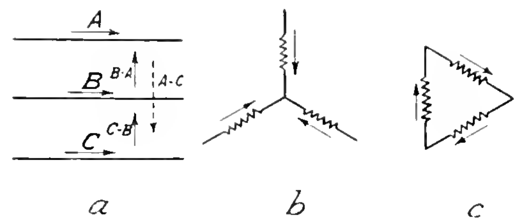


Fig. 5

As an illustration of the use of the proper choice of positive directions in three-phase circuits, the example given in Fig. 6 of the relation between line and phase currents of a delta connected system shows how the vector relation of the different portions of the circuit can be obtained. The three-phase currents flowing in the delta circuit, Fig. 6a equal and 120 deg. apart, are conventionally represented by the three vectors *a*, *b*, *c* in the vector diagram Fig. 6b, together with the arrows *a*, *b*, *c* in Fig. 6a, showing the positive directions. Choosing the positive direction for the line currents, as extending away from the delta, there is obtained from Kirchhoff's law the condition that the current in line I is the vector difference of currents in phases *a* and *b*. Similarly lines II and III will carry currents *b-c* and *c-a*, respectively. Referring to the vector diagram it will be seen that the vector difference of *a* and *b* is given by the vector *a-b*, which is the side of the triangle *ABC*. The direction of this vector is towards the apex *A*. In the same manner the other two sides of the triangle *ABC* represent the currents in lines II and III, and the directions are such as to make all the vectors forming the sides of the triangle point in the same direction, that is, counter-clockwise. It can therefore be concluded that the line currents are equal to the vector difference of the phase currents in a delta system, and that when the phase currents are represented by vectors drawn outward from a common point O, the line currents will be represented by the triangle formed by joining the extremities of the vectors.

Similarly, Fig. 7 shows the relation between the line voltages and the phase voltages of a Y connected system. The vectors a, b and c

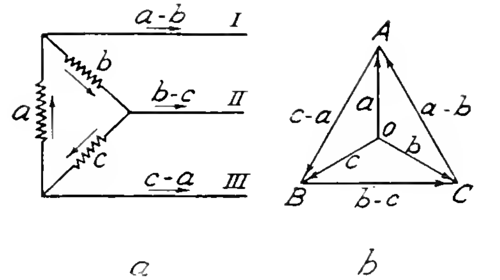


Fig. 6

represent the three voltages between neutral and line of the Y connected circuit when the positive directions are all away from the neutral and when the positive directions of the line voltages are given by the arrows I, II and III. Applying Kirchhoff's law of voltages to the three circuits, the voltage from line A to line C is evidently equal to the vector difference of c and a, c-a. Similarly the voltage between lines B and A and lines C and B are equal to a-b and b-c respectively. From the vector diagram we see that these

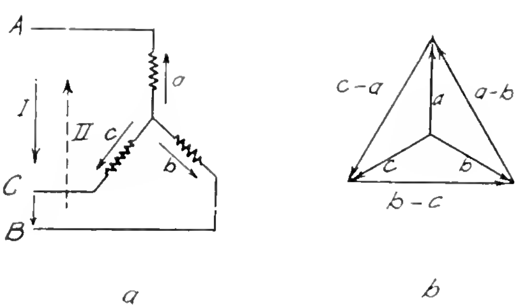


Fig. 7

vector differences are given by the sides of the triangles formed by joining the extremities of the vectors a, b, c.

No better example of the aid which the proper choice of positive directions give to three-phase problems can be shown, than that of the flux relations in three-phase shell type transformers. Taking first the case when the winding on the middle leg is not reversed; Fig. 8b represents by means of the vectors a, b and c, the three fluxes in one-half of the central portion of the core. Since the middle winding is not reversed these vectors will hold only when the positive directions in the central portions are all in the same direction, as given in Fig. 8a by the arrows a, b, c.

The problem is to find the amount of the flux in the portions d and e of the magnetic circuit. Assume for this portion of the core, the positive direction given in Fig. 8a. By the application of Kirchhoff's law to the junction points, we obtain the vector equations $a-b=d$ and $b-c=e$. Applying these equations to the vector diagram, we see that vectors d and e are displaced 30 deg. from vectors a and b respectively, and are equal in value to 1.73 times the value of a. Now, take the case when the winding of the middle phase is reversed. It is evident that for the same vector representation (vectors 120 deg. apart) the positive direction of the flux in the middle leg will have to be reversed. This is shown in Fig. 9a by the fact that now arrow b is opposed to arrows a and c. Kirchhoff's law gives the vector equations $a+b=d$ and $-(b+c)=e$. Applying these equations to the vector diagram it follows that the fluxes in the portions d and e of the magnetic circuit are represented by the vectors d and $-e$, which are 60 deg. displaced in phase from vectors a, b and c respectively, and equal in value to them.

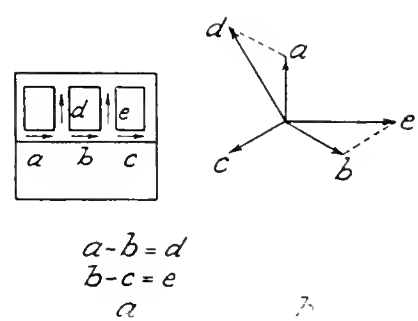


Fig. 8

It therefore appears that by a reversal of the winding on the middle phase in a three-phase shell type transformer the area of that part of the magnetic circuit which is common to two phases can be made equal to that of the individual phases instead of 1.73 times that value.

Properties of Triangles

Triangles play such a prominent part in three-phase problems that it becomes exceedingly helpful to know some of their general properties. Of greatest importance is the fact that the lines drawn from the vertices

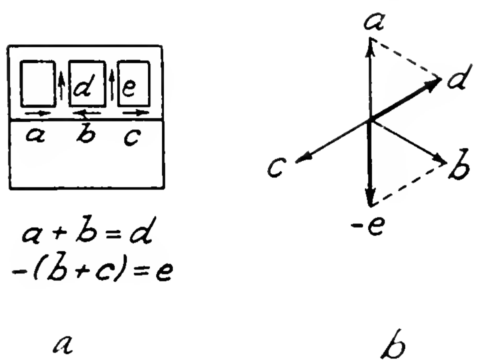


Fig. 9

of a triangle to the middle of the opposite sides intersect in a common point and this point divides the three medial lines, thus drawn, each into two parts equal to $\frac{1}{3}$ and $\frac{2}{3}$ of their total lengths respectively. Thus, in Fig. 10 the medial lines of the triangle ABC intersect at O and the portions OA, OB and OC are each $\frac{2}{3}$ of the lengths of the medial lines.

For convenience, in what follows the lines OA, OB and OC will be called the medial lines of a triangle and the point O the center.

Another property of triangles which is useful in three-phase problems is seen in that

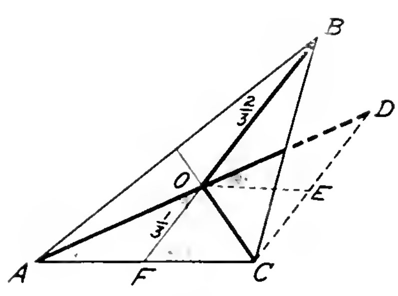


Fig. 10

the medial lines OA, OB and OC will form a closed triangle, COD, Fig. 10, if they are shifted to the positions OD and CD, parallel to OA and OB respectively.

Proof

From C draw a line parallel to OB, intersecting the extension of OA at D.

Draw the line OE parallel to AF.

Angle DOE = Angle AOF

Angle OED = Angle AFO

$\therefore$ Triangle AOF = triangle ODE

and $AO = OD$

$CD = OB$

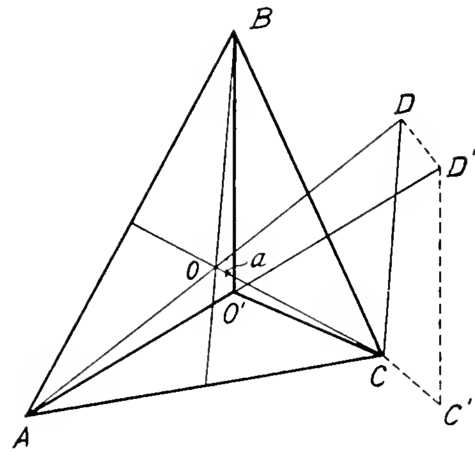


Fig. 11

And moreover the medial lines are the only lines that can be drawn from a common point to the vertices of a triangle that are capable of forming a closed triangle. For taking any other point O', Fig. 11, distant a from O, and attempting to construct a triangle from $O'A$ $O'B$ and $O'C$, it is evident by similar triangle $DD' = 2\ OO'$ and parallel: $CC' = 3\ OO'$ and parallel. Hence, when a three sided figure $CO'D'C'$ is formed by lines parallel and equal to $O'A$, $O'B$, $O'C$, the figure is open by an amount CC' equal to $3\ OO'$ and parallel to it.

If from a triangle ABC, Fig. 12, a new triangle is formed by shifting the apex B to the point D, thus obtaining ADC, the center O' of the new triangle will be found shifted with respect to the center O of the old triangle, an amount equal to $\frac{1}{3}$ the shift of the apex BD and parallel in direction: For from the figure we have

$$\frac{EO}{EB} = \frac{EO'}{ED} = \frac{OO'}{BD}$$

In handling three-phase vector diagrams it will often be found very convenient, for the purpose of simplifying the diagram, to make one vector represent more than one quantity. Fig. 13 illustrates how this may be done. The diagram, Fig. 13a, represents a current I to a certain scale, say one inch =10 amperes, and a voltage E to the scale of one inch=50 volts; with a phase angle θ between them.

The physical values can be equally well represented by one vector, as shown in Fig. 13b.

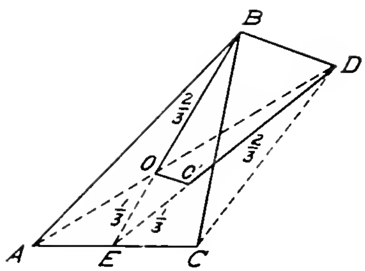


Fig. 12

In this the current is represented to the scale of one inch=10 amperes; and the voltage to a scale of one inch=100 volts. It is necessary, however, to remember that for the voltage representation the vector is displaced by an angle θ. The use of this scheme will be seen in its application to the three-phase problems which follow.

Problem 1

To determine the division of load between transformers connected delta delta one transformer having an impedance different from

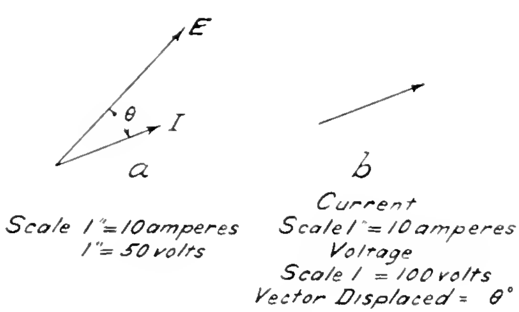


Fig. 13

the other two; assuming balanced three-phase load.

By applying Kirchhoff's laws to the delta transformer circuits, Fig. 14, we have for the primary side,

$$\Sigma \text{ Applied volts} = 0$$

and for the secondary (in primary equivalent volts)

$$\Sigma \text{ Terminal volts} = 0$$

By subtracting the second equation from the first there is obtained

$$I_1Z_1 + I_2Z_2 + I_3Z_3 = 0$$

which means that the three vectors representing the drops in the respective transformers must form a closed triangle.

Fig. 15*a* gives the vector representation of the three currents I_1 I_2 I_3, flowing in the

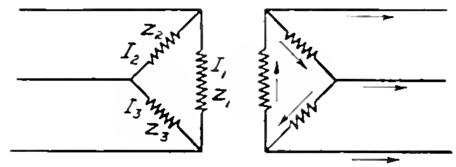


Fig. 14

transformers, drawn to scale. It should be noted that these are arbitrarily chosen so as to be unequal and not 120 deg. apart.

Fig. 15*b* gives the impedance diagrams (in ohms) of the three transformers drawn to scale, having the resistance components in the same phase. In this diagram Z_2 and Z_3 are equal while Z_1 is larger, having greater resistance and greater reactance and a different phase angle.

Now, as explained above, Fig. 15*a* can be made to represent impedance voltage drop also by using another scale and subjecting the diagram to an angular displacement, provided all the vectors are treated alike. Thus, the vector representing the current I_2 can also be made to represent the impedance I_2Z_2. The vectors I_1 and I_3 now represent, by this new scale, the products I_1Z_2 and I_3Z_2 respectively, and the diagram as a whole has been displaced by angle θ.

In the same way the impedance diagram Fig. 15b can be changed to a voltage drop diagram by the use of a new scale. In this case we will let the vector Z_1 also represent the product I_1Z_1. The whole diagram is correspondingly changed, Z_2 representing the product I_1Z_2.

Since I_1Z_2 is common to both figures the two diagrams can be joined by superimposing the two vectors representing I_1Z_2. We thus have Fig. 16, in which we have changed I_3Z_2 to I_3Z_3, which is allowable since Z_2 equals Z_3. In this, we now have a current diagram representing the three currents I_1, I_2 and I_3 to a certain scale and a voltage diagram representing the three voltage drops I_1Z_1, I_2Z_2 and I_3Z_3 to a certain scale. It should be borne in mind that the voltage vectors are displaced with respect to the current vectors by an angle θ.

Now, since the vector sum $I_1Z_1+I_2Z_2+I_3Z_3 =0$, as was shown above, the vectors representing these values, *OD*, *OC* and *OA*, must be capable of forming a closed triangle, or in other words, they are the medial lines of some triangle. Fig. 17 is obtained from Fig. 16 by joining the extremities of the vectors, thus forming the triangle *ABC* and

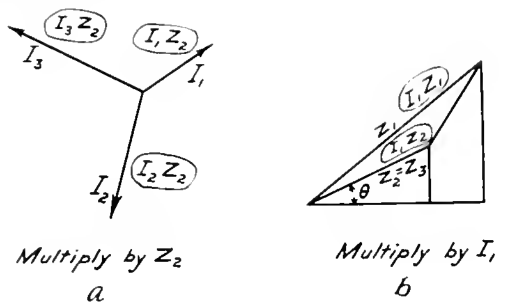


Fig. 15

ADC. From the foregoing it is evident, first, that the point *O* is the intersection of the medial lines of triangle *ADC*; and second, that *O* is distant from *N*, the intersection of the medial lines of triangles *ABC*, by an amount equal to $\frac{1}{3}$ *BD* and parallel to it.

We have now a means of locating the point *N* for any particular case with respect to the impedance triangles, and of constructing therefrom the triangle *ABC*. The following geometrical solution will now be evident.

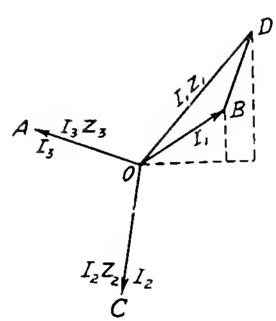


Fig. 16

In Fig. 17 the right triangle *OEB* represents the impedance triangle of the two similar transformers, and *OGD* the impedance triangle of the third transformer drawn to the same scale. This impedance is expressed in equivalent ohms primary. Draw *BD* and locate point *N* so that $ON = \frac{1}{3}$ *BD* and parallel to it. With *N* as a center construct the circle *ACB* and the inscribed equalateral triangle and draw *OC* and *OB*. Then *OA*, *OB* and *OC* represent the phase currents in the three transformers, both in magnitude and in phase relation. The line currents are represented by *AB*, *BC* and *CA*.

Problem 2

Another problem of considerable interest, which lends itself readily to vector solution, is the determination of the exciting current

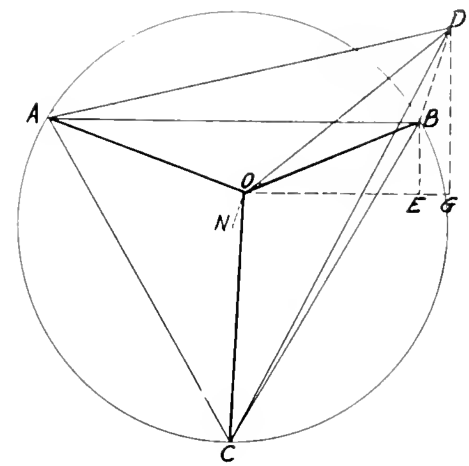


Fig. 17

in three-phase core type transformers, in which, on account of the unsymmetrical arrangement of the cores, the exciting currents are different in the different phases. If we neglect the higher harmonics these currents can be readily found in the following manner.

The usual arrangement of three-phase cores is given in Fig. 18a. A glance at this figure will show that a core of this type consists of three magnetic paths, the dividing lines of which are represented by the dotted lines. Taking for the positive directions of fluxes those indicated by the arrows, by Kirchhoff's law the vector sum of these fluxes equals zero. They will be equal and 120 deg. apart, if the impressed electromotive forces are equal and 120 deg. apart. The vector diagram of these fluxes is given in Fig. 18b, where *OA*, *OB* and *OC* are respectively the fluxes in legs *A*, *B* and *C*. The point *O* is the intersection of the medial lines of triangle *ABC*. Assume that the cross sections are equal and that the ratio of the length of an outside leg to the length of the middle leg is *r*. The magnetomotive force required for each leg can be readily calculated. It will lead the flux by the same angle in each case, and since its value will be proportional to the length of the path, for the outside leg it will therefore be *r* times as great as for the middle. If we let *OA* and *OC* represent the magnetomotive forces required by the two outside legs, with the understanding that there is a phase displacement between them and the fluxes, the magnetomotive force

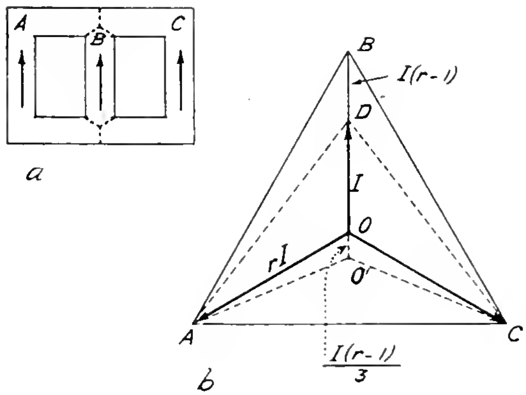


Fig. 18

required for the middle leg will be represented by the vector OD, where OD is equal to $OC\times\frac{1}{r}$.

The three-phase core consists of three complete magnetic circuits AB, BC and AC. The total magnetomotive force required in each circuit is therefore the vector difference of two of the individual magnetomotive forces described above; the vector differences being required instead of the vector sums, because the arrows representing positive direction are opposed to each other. The magnetomotive forces required for the three circuits are therefore represented by the sides of the triangle ADC, where

$$DA = OA - OD$$
$$CD = OD - OC$$
$$AC = OC - OA$$

The actual current flowing in each phase can now be determined if the electrical characteristics of the circuit are known. Thus assuming for the positive direction of currents that which will produce a flux in the direction of the arrows, Fig. 18a, it is evident that for each magnetic circuit the vector difference of the actual exciting currents must be proportional to DA, CD and AC respectively. A scale can now be chosen so that the sides of the triangle ADC will represent these vector differences. Hence the actual exciting current for the separate phases can be represented by lines drawn from vertices A, D and C to a common point. The location of this point will depend upon the electrical characteristics of the windings.

For example, the simplest case is that of open delta excitation in which the current in one of the legs is zero. Take the case with zero excitation in phase A. Evidently the common point must be at A, and AD and AC are the values of the exciting currents in the other two phases.

If the windings are connected Y then the vector sum of these currents must be zero and the common point must be located at the intersection O' of the medial lines of the triangle ADC. From the properties of triangles, the distance O' from O can readily be determined in terms of the ratio of the lengths of the magnetic paths.

If the windings are connected delta, the consideration that the vector sums of the two impressed electromotive forces and the counter electromotive forces equal zero necessitates that the vector sum of the impedance drops (open circuit impedance) must equal zero. Assuming that the ohmic impedances of the three legs are equal, it follows that the vector sum of the exciting currents must equal zero. This result is the same as was obtained above for the Y connection.

Hence, it may be concluded that for all three-phase excitations the value of the exciting currents per phase can be obtained from the ratios of the lengths of the magnetic paths. Letting the apparent exciting current in the middle leg be I (by apparent exciting current is meant the value calculated from the magnetomotive forces in the middle leg), then for the outside leg it will be rI; the neutral shift will be $\frac{1}{3}(r-1)I$, and the actual exciting current on the middle leg

$$I+\frac{1}{3}(r-1)I$$

or

$$\frac{1}{3}(2+r)I$$

and for the outside legs the actual exciting current becomes

$$\frac{1}{3}I\sqrt{7r^2+r+1}$$

The phase angle θ of the exciting current on the middle phase will be the same as that obtained with similar excitation on single-phase transformers.

For one outside phase, this angle will be increased, and for the other outside phase, decreased by the angle OAO', which is

$$30° - cos^{-1}\frac{1.5\sqrt{3}}{\sqrt{7r^2+r+1}}$$

These equations are obtained directly from Fig. 18.

AN ELECTRICALLY OPERATED COAL DOCK

DOCK NO. 7 OF THE PITTSBURG COAL CO., RICE'S POINT, DULUTH, MINN.

By R. H. McLain

One of the largest and most modern coal docks at the head of the Great Lakes is that of the Pittsburg Coal Co. at Rice's Point, Duluth, Minn. This dock is used during the summer to unload coal from boats which have brought it from the East. The coal is loaded on cars for shipment to the Northwest. About one-half of the coal is loaded directly into cars, the remainder being stored on the dock and then loaded into cars for winter shipment.

The coal is carried from place to place around the dock in huge self-filling buckets. The highly advanced state of the hoisting machinery and of the electrical apparatus, by which this bucket is handled, have combined to provide facilities for handling coal that were not dreamed of until electricity entered the field as a motive power. The fundamental requirement in this work, from an engineering standpoint, is to provide suitable means for delivering concentrated mechanical forces of enormous values intermittently at points scattered over a large area. This requirement has been admirably met by installing huge hoisting engines to which buckets are attached on trolley cars. These cars are installed on elevated railways, and these elevated railways or bridges are so installed on other railways that the bridges, as a whole, can move in a direction at right angles to the motion of the trolley

Figs. 1 and 2. Coal Bridge Equipment of the Pittsburg Coal Dock & Wharf Co., Rice's Point, Duluth, Minn. Three Bridges Equipped with Three 225 H.P. Hoist Motors and Magnetic Control, Six 112 H.P. Rack Motors and Magnetic Control, and Three 112 H.P. Bridge Moving Motors with Drum Control. All Motors Wound for 440 Volts cars. The trolley cars, hoisting engine, and bridges are all propelled by electric motors. A simple electrical transmission system, such as is ordinarily used in city street-car service, thus makes the full power of the hoisting engines readily available at any point in the area covered by the bridges.

From the above it will be seen that the general scheme of operation of a coal bridge does not differ very much from that of an ordinary shop crane. However, the rapidity with which the coal must be handled, and the vast area over which it must be stored, introduces problems which must be solved in a radically different manner from that of the shop crane.

A general view of the dock is shown in Figs. 1 and 2. The present length of the dock is 1250 ft., width 761 ft., and the depth of the coal about 40 ft. This provides a storage capacity for about 825,000 tons of bituminous coal. This area is covered with tracks for carrying a three-span bridge. There are three double-span bridges, about 576 ft. long, each equipped with a trolley, next to the dock face, and one single-span bridge about 300 ft. long, at the rear of the dock. This single-span bridge can be aligned with any one of the three double-span bridges and can be operated with them, thus making a single bridge 876 ft. long. This single-span bridge can be used also for transferring a trolley car from one double-span to another in case of break down. There is at present being added another single-span bridge, equipped with crane trolley at the rear of the dock.

There are three man trolleys, each equipped with a self-filling grab bucket, having a volume of 230 cu. yds. and a capacity of about $5\frac{1}{2}$ tons. Each of these bridge cranes when taking coal from a modern 10,000 ton boat, having hatches spaced 12 ft. centers, and depositing the same at the tenth panel of the span nearest the boat, will have a capacity of about 260 *net* tons per hour for the entire cargo. When handling coal from the boat to the center of the second or middle span, the capacity will be 200 tons per hour for the entire cargo; and when handling coal to near the center of the third span, the capacity will be about 150 *net* tons per hour for the entire cargo. This does not, of course, show the maximum rate at which one of these cranes can unload coal, because in unloading a boat a large amount of time is wasted in cleaning up; therefore, when taking coal from the top of the boat, these bridges can operate something like 20 per cent. faster than the figures given above. An idea of the enormous capacity for this plant is easily obtained when it is realized that the three bridges working simultaneously on a 10,000 ton boat, and when depositing coal into hopper at the front of the bridge, can unload the entire cargo in about twelve hours.

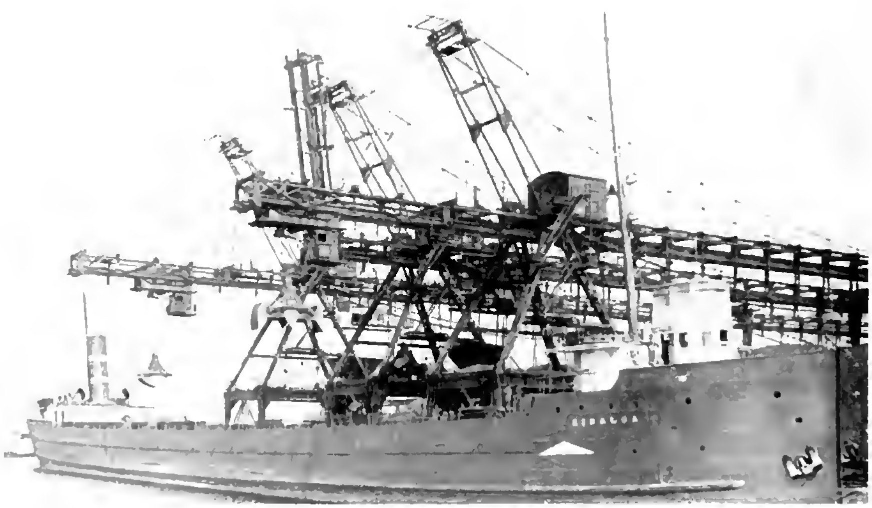


Fig. 3. Nearer View of Coal Bridge

Each of the double-span bridges is provided with one 112 h.p., intermittent rated, variable speed induction motor for propelling the bridge along the dock, and for raising and lowering the apron which extends out over the boat. The single-span bridge is equipped with a 52 h.p., intermittent rated, variable speed induction motor for propelling the bridge along the dock. When the single-span bridge is coupled to one of the double-span bridges, the two can be propelled as one bridge under the control of one controller. The hoisting engines on the trolley are equipped with one 225 h.p., intermittent rated, variable speed induction motor. Each trolley is propelled by two 112 h.p., intermittent rated, variable speed induction motors. These ratings are entirely nominal and the motors have reserve capacity beyond these values. In fact, the motors were chosen specifically for the work which is to be done rather than in accordance with the manufacturer's rating. These motors are controlled by magnetically-operated switches or contactors which are so constructed that they can easily handle the large currents to the motor, while the contactors are governed by a small master-controller in the hands of the operator.

It can readily be seen that the cost of such a dock and of operating it depends, in its last analysis, upon the relation of weight of the trolley car with its equipment to the weight of coal carried each trip, and also to the speed at which these trips are made. Hence, it is in the design of this trolley that the greatest demands are made on the ingenuity and the experience of the manufacturer. Every pound must be taken off the trolley that possibly can be, because the weight of the whole bridge structure is directly in proportion to the weight of the trolley, and also because the power consumption varies almost directly with the weight which must be moved. The two most essential things on the trolley are the coal bucket and the electrical equipment; the remainder of the trolley may be said to be built to support these parts. The motors in this case are of a well ventilated type and have a skeleton frame; this is all conducive to lightness. However, in the matter of trimming weight, experience is the only safe guide.

In addition to the facilities for handling bituminous coal, this company has an anthracite house which is capable of storing 60,000 tons of coal, and which contains elevators, screens, conveyors, etc. for handling this coal at the rate of 150 tons per hour. Coal for the anthracite house is unloaded from the boats by the bridges, and is dumped into a tunnel through which it is drawn by a screw-conveyor into the house. The screens, conveyors, elevators, etc. in this house

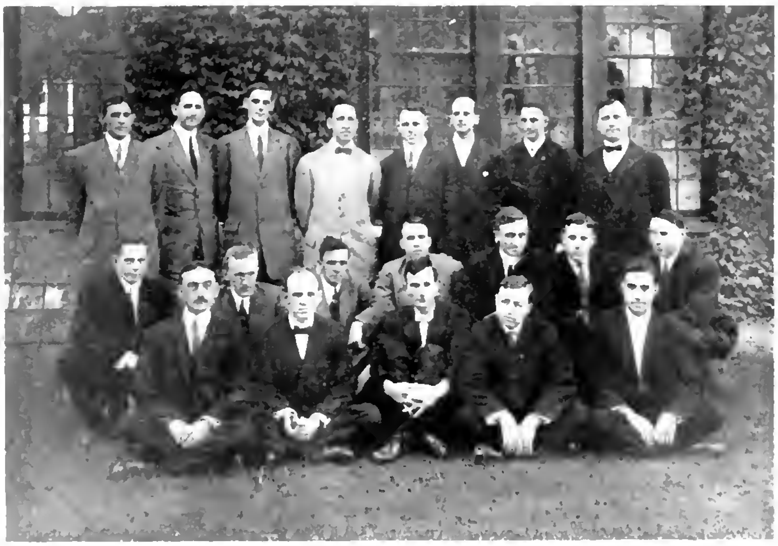
Fig. 4. Interior of Substation Showing 250 Kw., 13200-480 Volt Transformer and Switchboard

require a total of ten induction motors of the squirrel cage type whose combined rating is $123\frac{1}{2}$ h.p.

Electric power for this dock is furnished by the Great Northern Power Co. at 13,200 volts, 25 cycle, 3-phase. This power is transmitted underground to a small substation located at one corner of the dock. This substation, inside view of which is shown in Fig. 4, contains three 250 kw. transformers for reducing the potential to 480 volts. The substation also contains a modern equipment of electrolytic lightning arresters, and a switchboard, which contains an automatic oil-switch, an ammeter, a voltmeter, an integrating and a graphic recording wattmeter, for supplying power to the three bridges, as well as a small separate panel for supplying power to the anthracite house. The bridges and the hoisting machinery for this dock were built by the Brown Hoisting Machinery Co.

SECOND ANNUAL MEETING OF SWITCHBOARD SPECIALISTS

The pronounced success which General Electric Company switchboards have achieved in service may be in great part attributed to the close co-operation which exists between the factory designing engineers and the switchboard specialists maintained by the General Electric Company at its various district offices. Each of these divisions of activity is mutually dependent on and assisted by the other.



Front Row, Left to Right: I. M. Cushing, Boston; C. C. Adams, Chicago; G. R. Langley, Peterboro, Can.; O B Rinehard, Ft. Wayne Works; H. E. Harkness, Cincinnati. Second Row: A B Lawrence, G A Elder, E. B. Merriam, Schenectady; F. E. Hause, Sprague Works; J. J. Gaffey, Schenectady; H. M. Sliter, New York; D. S. Morgan, Schenectady Third Row: E H. Tiffany, New York; H. L. Smith, Schenectady; G. O Bason, New York; F W. Paterson, San Francisco; H H Bodge, Boston; J. J Kline, Ft Wayne Works; W H. Heinz, Chicago; Saul Lavine, Pittsburg

The engineers are responsible for the apparatus itself, its design, quality and behaviour under actual working conditions, while the specialists concern themselves with its proper application. They see that its selection and arrangement are such as to secure the needed results for the least outlay to the purchaser. The specialist must therefore be well informed, he must be able to discover the essential points on any switchboard situation from an analysis of the known factors or conditions, to recommend to the prospective purchaser just what is needed to meet his requirements, or to lend valuable assistance to his engineer.

This is especially true as regards the switchboard, since in its make-up there enter so many appliances and so many diversified uses. Features of safety, convenience and economy must all have reasonable consideration, and in large developments particularly it may be necessary to exercise an unusual degree of knowledge and ingenuity to obtain the best selection and arrangement of apparatus to fulfill the needs of the installation. Meter and instrument combinations, bus arrangements, sizes of oil switches, instantaneous or time limit operation of relays, etc., may all need expert consideration.

To accomplish as much as possible along these lines, the second annual meeting of switchboard specialists of the General Electric Company was held at Schenectady, N. Y., September 11th to 14th inclusive, and at Lynn, Mass., September 15th and 16th. The specialists came direct from the problems that have been presented to them for solution during the year, with recollections of various difficulties that had arisen and had been overcome. They reported on the trend of new developments, how the various switchboard appliances had been behaving in actual service, and went to a great deal of detail to explain how the purchaser could best be taken care of. As a matter of fact, the last was the real reason for the meeting and the dominant note of every session. The main question was, "How can we most benefit the purchaser; how can we find out his needs and meet them?"

With this end in view, the morning sessions were devoted to shop trips under the leadership of factory engineers, in course of which, new apparatus was described in detail. The afternoons were spent in discussions of this apparatus, as to what new appliances should be placed in production, and in answering questions which had been handed in in advance or were raised during the meeting. The free interchange of ideas, the informal discussion of switchboard problems by specialists from all over the country, and the different points of view presented, undoubtedly were of great benefit to all concerned and helped to gain the desired end.

THE GROWTH OF THE ELECTRIC VEHICLE* INDUSTRY

By P. D. Wagoner, President, General Vehicle Company

The rapid expansion of the gasolene pleasure car business has overshadowed that of the electrical pleasure car, and still more so the growth of the electric vehicle industry. The number of plants efficiently equipped to manufacture electric motor-driven trucks and wagons is very small compared with the number of immense pleasure car plants, also making trucks, which dot the continent. It is not surprising, therefore that many should think of the electric in the future tense, when, as a matter of fact, it is very much in the present. It is not waiting to arrive; it is decidedly "here" and has been "here" for some time.

It is natural that when the owner of a fine touring car begins to take interest in the motor truck proposition he should think in terms of the car which has given him so much enjoyment. At first he will make little distinction between the pleasure car and the business car,—between luxury and utility. To spin over the boulevard at a high rate of speed cushioned on pneumatic tires is one thing; to haul freight at a profit by means of a 5-ton truck is another. This is a point many shrewd business men at first overlook.

It was not to be expected that the electric vehicle would jump into instant popularity, in view of the wider knowledge respecting the gasolene car, and in view too of the disadvantages under which the battery-driven vehicle has labored in the past; but I shall endeavor to show in this article that the electric is at the present time a recognized success both as regards sales and efficiency—the word "efficiency" comprehending such items as economy of delivery, low cost of maintenance and long life.

Magnitude of the Industry

About 7,500,000 people receive their support from the automobile industry of the United States, the pleasure car industry, of course, consuming the bulk of this employment. The total value of electric pleasure vehicles in this country is generally conceded to be $42,000,000, and of electrical commercial vehicles $11,000,000. Figures for 1910 and 1911 are not at this time available in complete and accurate form; but from the U. S. Government Census we know that in 1909 there were manufactured in this country, inclusive of electric pleasure cars, 3,639 electric vehicles, having a value of $6,561,500. This was an increase of 163 per cent. over 1904, and

Fig. 1. Interior of General Vehicle Company's Plant

judging from present indications the current year will lead 1910 by over 50 per cent. increase; from which it can be seen that this industry, while still in its infancy, from the standpoint of the wonderful possibilities before it, is growing rapidly and has already reached large proportions. The General Vehicle Co. did 425 per cent. more business in 1910 than in 1908, 15 per cent. more in 1910 than in 1909, and to date (August 1, 1911) our increase over last year has been 51 per cent., or a 160 per cent. increase over 1909, and 900 per cent. over 1908.

One of the interesting and convincing phases of the electric vehicle industry, as I see it, is the large percentage of re-orders received from those customers who have proved the value of this modern method of trucking and delivery. This condition is brought out emphatically by the large fleets operated by those who have been convinced of the electric's superiority. For example, nine New York mercantile houses own and operate between them no fewer than 252 electric vehicles, or an average of 28 each. Eight prominent brewers operate 195, or an average of 24.3, and these are practically all heavy trucks, distributed in Pennsylvania and Missouri as well as in Greater New York. Two Express Companies divide nearly 250

*In this article the term "Electric Vehicle" is applied to commercial vehicles only.

electrics between them, while nine electric light companies operate 221 of these vehicles.

The General Vehicle Company is the largest manufacturer of electric commercial vehicles in the world, having more such vehicles in actual service than all other makes of electries combined. "Mary Ann," the pioneer of the G. V. fleet, built by our predecessor company in 1901, is still doing good work for the Central Brewing Co. of New York, and provides a good example of the durability and long life of the electric vehicle. This was the first motor brewery truck in America. "Mary Ann's" capacity is three tons, her average daily mileage is still 22 miles, and the expense of mechanical repairs and renewals has been, in a nine years' average, less than $100.00 per annum. These figures are important in view of the very exaggerated annual depreciation allowances which one constantly sees applied to the electric vehicle.

Fig. 2. Brewery Truck Built in 1901, Still in Regular Service

It may be interesting to mention that this company has in the service of the brewing industry alone over $1,000,000 worth of electric trucks. In addition the electric vehicle is represented in over 100 different lines of trade, the breweries, department stores, express companies and electric light companies leading in the number of cars in service at the present time. The vehicle has entered the textile field, the coal and coke business, the dressed meat trade, hay and grain, and wholesale grocery deliveries, etc.; while Gutterson and Gould of Lawrence, Mass., have a $3\frac{1}{2}$-ton truck which does nothing but haul junk. Electrics are well represented in the Government service. The War Department (Bureau of Insular Affairs), for example, uses 19 of our vehicles in transporting stores, distilled water, ice, etc. in the Philippines. Only recently we received an order for twelve trucks for the Bureau of Yards and Docks, and these will be distributed to the various naval stations throughout the country, one truck going to the Island of Guam. This makes about forty electric vehicles in the service of the various U. S. Departments. We have trucks also in Rio De Janeiro, in the service of the Rio De Janeiro Tramway, Light and Power Co. The list of electric ambulances, mail wagons, bank wagons and furniture vans is steadily growing; and I should not neglect to mention the electric winch trucks, pumping wagons, railway emergency and tower wagons, in the service of the different manufacturers and electric lighting and railway companies, many of which are doubtless familiar to the reader.

Supreme in its Field

Within the sphere of its proper application the electric vehicle is the cheapest known means for merchandise transportation.

One condition which has assisted in defining the respective territories of the electric and the gasolene motor truck has been a careful analysis of the strong points of these two types of vehicles. I do not use the word "competitors," because in the broadest sense there is little or no competition between them. Dividing the work into three classes, viz., delivery, transfers and long hauls, it has been demonstrated to the absolute satisfaction of large users of motor trucks, that in delivery and in much of the transfer work, the electric is most efficient, while in the longer hauls the gasolene has found its best field. The economic field of the electric is largely in the city proper, and here it can handle practically 85 per cent. of deliveries. Hauls exceeding 50 miles per day are usually in the economic field of the gasolene; but in order to make the gasolene-driven car pay dividends over horses and electrics even in this field, the first stop should be beyond the 15 mile limit.

Under certain conditions the bulk of transfer work can be done economically with electrics exclusively. The Greenhut-Siegel-Cooper Company, of New York, make deliveries to Long Island towns and to Harlem and New Jersey points with three $3\frac{1}{2}$-ton trucks, getting from 75 to 80 miles a day out of each car by using the underslung battery. A truck will go from their 18th Street store to, for instance, Jamaica, Long Island and return, a distance of 24 miles; then perhaps to Harlem, six miles farther, and return to the garage where another battery may be installed. This fresh battery can be substituted in five to ten minutes, after which the truck is put on the route again, and the former battery placed on charge. The trip to Cranford, New Jersey, and return, a total distance of 39 miles, is made regularly every afternoon by one of these trucks; and the same truck has in many instances made a good long trip before noon with its first battery for the day.

The mutual division of territory between the two types of motive power to which I have referred, when accepted, as it is beginning to be, by all motor truck manufacturers,

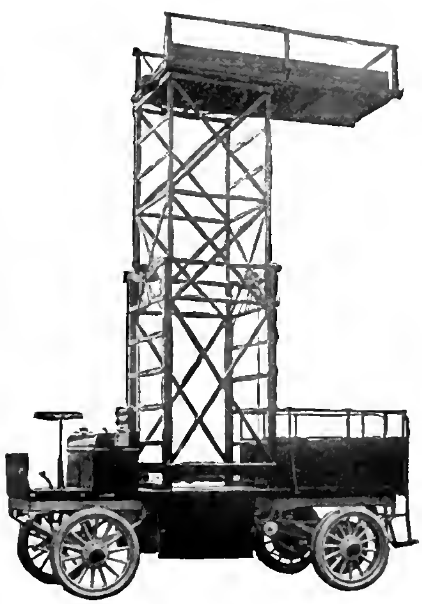


Fig. 3. Tower Wagon

will eventually be very helpful in increasing the sales of both types of vehicles, as firms having both long and short hauls can use both types to advantage and get the most out of each class. Several department stores in New York are already doing this, using the electric for short-haul and frequent-stop deliveries, and the gasolene for long hauls with few stops. Other lines of trade having the same problem to solve are rapidly falling in line.

Development and Standardization

Without going deeply into the history of the electric, it may be worth while to point

Fig. 4. Delivery Truck

out that most of the electric vehicles built prior to 1908 were equipped with two motors and storage batteries having an average capacity of 7 watthours per pound as the power plant, and with plain bearings in motors and road wheels. A great increase in the radius of action of the electric has since been obtained by the use of anti-friction bearings throughout, and a more efficient power plant consisting of a single motor and batteries of higher capacity, averaging 11 watthours per pound. 25 to 35 miles was considered a good day's work for the former wagons, while 45 to 60 is now obtainable.

Further than this, the electric vehicle has profited by the same improvements in material and design which have aided the automobile industry at large, and these, with a more efficient power plant, have contributed toward a substantial reduction in the cost of operation. Better spring suspension, for example, has proved beneficial to the tires and all other points of wear and tear.

The electric vehicle of today is lighter, faster, under better control, and more economical than that of several years ago, and is capable of doing a full day's work on one charge of the storage battery. It can be substituted for horses with every assurance of saving money for the purchaser, and is more dependable than vehicles propelled by any other power. It has been standardized consistently with a view to uniformity of design in all sizes. While efforts are constantly made to improve the product, changes of detail are usually made in such a way as not to affect the interchangeability of repair parts. One of the characteristic features of the design is the accessibility of all parts and the absence of complication. The various parts are not intermixed in such a way that injury to one could disarrange another; the controller is not built up with the steering gear, nor is the motor built into the axle or wheels. All parts are separated for convenience in care or replacement, and there is scarcely a part on the vehicle which may not be replaced by ordinary labor in a few hours at the most.

Fig. 5. Winch Equipped Truck

Some Interesting Data

The following tabulation presents important data, showing the improvement which has been made in the 1911 one-thousand-pound vehicle over previous designs. Approximately the same relative improvement has been made on the other standard sizes.

It will be seen from the above that the battery in the 1906 wagon was required to discharge at a three-hour rate, whereas in the 1911 wagon it is discharged at a six-hour rate; and that the 1906 wagon could barely run 30 miles on one charge, whereas the 1911 wagon can run 45, which is the guarantee, and under ideal conditions 72 miles. The saving in weight has been accomplished chiefly by the adoption of a single motor, simplified transmission, lighter battery and high-class steel, and not by sacrificing strength in the running gear or body.

The refinement of motor and control construction; the reduction of friction to a minimum; the improved mechanical design minimizing maintenance expense; the improved storage battery resulting in greatly increased capacity, longer life and reduced renewal expense; combined with intelligent selling and intelligent operation, have made the electric commercial vehicle an economic success.

COMPARATIVE DATA ON 1000 LB. WAGONS

	Vehicle and Battery 1906	Vehicle and Battery 1911	Per Cent. Change
Weight of wagon complete (approx.)	4500	3500	−22
Weight of battery	1400	1255	−10
Capacity of battery, ampere-hours	112	138	+23
Capacity of battery, kilowatt-hours	9.2	12.1	+32
Ampere-hours per pound	.08	.11	+38
Kilowatt-hours per pound	.00656	.00965	+47
Current required to run loaded wagon on level, amperes	35	23	−34
Speed of wagon on level, miles per hour	10	12	+20
Battery discharged in hours	3	6	+100
Mileage possible on one charge	30	72	+140
Life of battery in miles (approx.)	7000	11000	+57
Maximum renewals required, guaranteed in New York for 33,000 miles or 3 years		3	..
Cost of each battery renewal	$287.	$187.	−35
Flushing with water, times per annum	100	25	−75

THE BATTERY TRUCK CRANE AND ITS APPLICATIONS

By R. H. Rogers

There seems to be no limit to the variety and extent of the useful applications of electricity. A careful study of freight handling with particular reference to packages and material not of a free flowing nature, reveals a fertile and practically uncultivated field for the useful extension of electric power. Marvelous reductions have been made during the past few years in the cost of handling free flowing bulk freight by means of electrically operated machinery. On the other hand, the method of handling package freight, as such, and of the infinite variety of materials in our factories that are being changed from one kind of freight to another, is still in most cases a prolific source of high labor cost.

This line of work presents almost as many phases as it does kinds of material to be handled, its problems are intricate and its needs are varied and urgent; but the returns are sure and liberal.

To meet as many of the demands of this traffic as possible and to accomplish the desired ends with economy and rapidity the General Electric Company has devised a battery truck crane. This machine is designed to lift, carry and pull, and in one, two or all of these functions is found the most practical solution of almost every problem in the handling of package material.

The battery truck crane, as may be noted from the illustrations accompanying this article, is a neat and efficient looking combination of hoist, crane and vehicle, all of stable design and conveniently arranged. The vehicle is a one ton storage battery truck made very short and having the battery mounted on the top of the frame at the rear end. This places the greatest weight over the traction wheels and makes a satisfactory counterweight for the crane. The wheels are made smaller than normal, and a greater speed reduction to the dri.e wheels is employed to insure a high drawbar pull when used as a "tractor." The springs under the front end are of double strength to bear the overhung weights handled by the crane. The battery, motor and controller are of the standard type, and as a vehicle the handling presents no new features except the small radius in which the machine can be turned.

Battery Truck Crane Loading Freight Car

A crane arranged to swing 180 deg. is mounted on the extreme front of the vehicle and is supported near the upper end by a pivoted "A" frame and guy rods and at the bottom by a large ball and socket joint which allows some desirable flexibility without binding.

The crane is equipped with special attachments to suit the character of the work contemplated. These consist of rope and chain slings, barrel tongs, bale grapples, box hooks, snatch blocks and small tools. For very special work other equipments are designed and built to meet the requirements. The height of the crane can be made to suit local conditions, or several booms of different lengths can be used.

The electric hoist consists of a compact weatherproof motor, a controller, gears and a drum combined in one unit, capable of lifting one ton twenty feet per minute.

It handles thirty feet of hoisting cable and takes its current from the vehicle battery. The hoist is securely bolted to the vehicle frame at the foot of the crane, the cable passing up through the hollow top pivot, over the sheaves, and ending in a swiveled hook.

Touring Trailers Loaded with Raw Cotton

When loads of a half ton or less are handled the pulley is removed and the swiveled hook used direct. With loads of over one-half ton the pulley is put on and the cable end hooked to a shackle, leaving the pulley hook to carry the heavy loads. The hoist controller handle is connected to a lever convenient for the operator, who pulls to raise, pushes to lower, and lets go to stop at any point, for the lever goes to the central (off) position if released. The hoist contains, besides the automatic holding brake, a load brake which prevents excessive speeds when lowering. Lubrication is obtained from compression grease cups wherever needed.

All of these practically standard and well known components are welded into a well balanced and convenient machine, easy to operate and maintain. So much for the bare details of the machine itself: its applications are more interesting.

The time, money and space saving applications of the battery truck crane may be divided into three classes, viz: hoisting, hoisting and carrying on the hook, and towing trailers. The manner of using the machine is detailed in the following paragraphs:

Hoisting

Where material which may be subdivided into parcels of one ton or under has to be moved through a vertical distance of ten feet or less and deposited within a six or eight foot radius, the machine is brought to an advantageous position, the brakes set, and the hoist put into operation. The boom swings back and forth between the picking up and depositing points with each load. In this way box cars, gondola cars, wagons, power trucks, trailers and lighters are loaded with material or unloaded.

By its use 360 castings aggregating 65,000 lb. have been removed from a gondola car in five hours. This gave an average of 1.2 lifts per minute, the limit being the speed with which slings could be attached to the castings by two men. A box car was loaded with sixty-four 800 lb. barrels of plumbago in twenty-five minutes and four cars were loaded in two and one-half hours, including the time required to spot the cars. This work averaged two barrels per minute, hoisted nearly five feet and swung well inside the cars.

In each of the above cases, not only was the usual time greatly reduced, but fewer men were required, thereby making a double gain.

Hoisting and Carrying on Hook

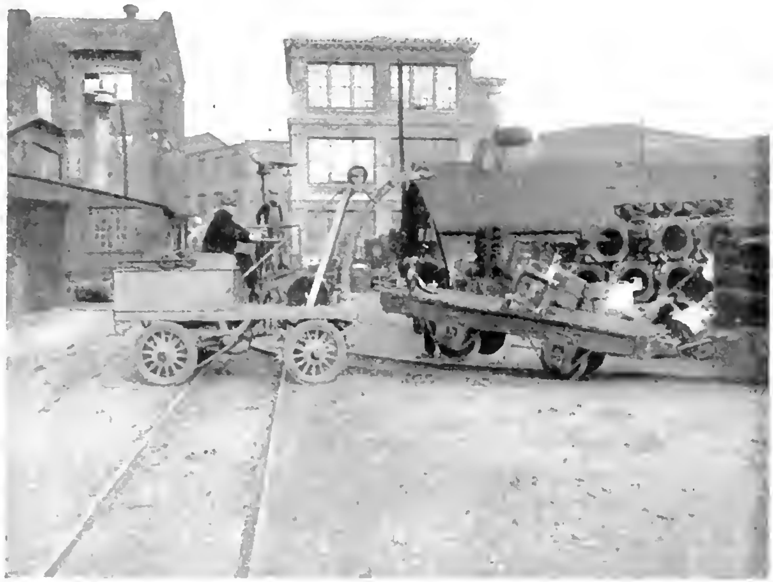
In this class of work the vehicle plays a prominent part by extending the radius of action to sixty miles if necessary. When material in large or small quantities has to be moved less than four hundred feet or in small quantities to any distance, the article is lifted by the hook, the vehicle started and in an incredibly short time the article is placed exactly where wanted—on the floor, in a high pile, or on a rack as may be required. The short wheel base allows short turns and the machine can be readily navigated about shop aisles, congested piers and warehouses, or among obstructions in a storage yard. For short hauls the whole operation is over in less time than would usually be taken to get the same load onto a wagon.

This class of service is more often used than either of the others, and ranges from the transfer of a thousand packages between a lighter and a nearby warehouse to the hasty trip to the stock-room for a barrel of oil. Its flexibility, simplicity and speed make it well adapted for heavy errand work about factory buildings, even when they are fully equipped with cranes and industrial railway. Derailed cars and spilled loads on the narrow gauge railway are quickly replaced, and the line cleared by the battery truck crane.

By this pick-up-and-run method sixty 800 lb. barrels of plumbago were moved 300 feet in one hour, one helper only being required. One hundred and fifty 300 lb. boxes of rubber were loaded into a box car from a distance of seventy-five feet in fifty minutes. Three boxes were slung together and a round trip was made every minute. In a store room, boxes of angle and flat iron weighing about 1000 lb. each were carried thirty feet and stacked in sorted and orderly piles at the rate of forty boxes an hour. One ton rocks were loaded onto trailers from a scattering pile at the rate of twenty-four an hour and were hoisted two feet and carried about twenty. Two 1200 lb. water meters were lifted from a hole in the ground six feet deep and carried to the shop bench a thousand feet away in thirty minutes. This shows remarkable economy when the usual aggregation of gin-poles, tackle, planks, rollers and levers is considered; for this whole job was completed before the ordinary tools could have been gotten together.

Towing Trailers

For the miscellaneous transfer of large quantities of package freight or other material through distances over about four hundred feet the best procedure is to use the battery truck crane to tow trailers in trains of about four each. To secure the maximum results there should be a train loading and another unloading while the machine with the third train is on the road between points, thereby eliminating any waiting; for as soon as the load is delivered the vehicle immediately starts out with the empties from the previous trip. The number of trailers per train and the number of trains will depend on the distance, character of load and time taken to load and unload the trailers. Twelve is the usual number, divided into three trains. It will thus be readily seen that one battery truck crane and operator keeps about 600 square feet of loading space working to its full capacity, a performance that can be seen any day at the Bush terminal, New York City.



Placing Derailed Flat Car on Track

From the logs of a number of these machines for a long period of service in the Bush terminal, the following average week's work at towing trailers has been deduced.

Number of packages handled	7,570
Average weight per package	230 lb.
Total weight handled (900 tons)	1,720,000 lb.
Average distance packages were moved	900 ft.
Of total time machine was working	80 %
Packages delivered per working minute	3
Number of different jobs worked on	30
Heaviest single load drawn	$12\frac{1}{2}$ tons
Cost of operator, interest, depreciation and power	$24.00
Cost of moving one package 900 ft.	$\frac{1}{3}$ cent
Cost of moving one ton (9 packages) 900 ft.	3 cents

Carrying Railway Motor Castings into Machine Shop

Thirty-tons of freight per hour can be moved one-half mile by this method under ordinary circumstances. For instance, 600,000 lb. of cotton have been moved one-half mile in a day, taking twenty-four bales per load and making a round trip every twelve minutes. This shows an average of two bales (500 lb. each) per minute through a distance of one-half mile. On a hurry order for cotton, 48 bales were alongside the lighter within twenty-five minutes after the order was given, thus demonstrating the flexibility and promptness of this system, by means of which one man can handle more ton-miles than by any other method. On small package freight (canned salmon) using two trailers per train, one battery truck crane has moved 1,000,000 pounds 600 ft. in nineteen hours.

A special line of trailers has been built for this work. The three wheels are 24 in. by 5 in., fitted with roller bearings, and the deck is twelve by four feet. The capacity is three tons if well distributed. The heavy towing tongue readily couples to the vehicle or to another trailer, and no trouble is experienced in towing a long string around obstructions, as they follow perfectly in the course of the battery truck crane. In serving warehouses or shops with low doors the trailers are pushed, the front wheel of the string being steered by hand. This procedure expedites the interchange of empties for loads, and vice versa at the loading and unloading points.

The practical freight handling men are keenly interested in this machine and its accessories and are quick

TIME		Work
Hours	Minutes	
6½		Piling stock in receiving department.
	55	Moving armatures in building 40.
1	10	Piling stock in receiving department.
	5	Taking armature building 40 to building 50.
3	10	Carrying armatures building 40 to building 18.
	15	Carrying solder building 46 to building 40.
	50	Carrying armatures building 40 to building 18.
1	15	Carrying armatures building 40 to building 18.
	15	Carrying barrels japan building 67 to building 40.
2	15	Carrying armatures building 40 to building 18.
	15	Carrying truck building 40 to building 106.
	25	Carrying truck building 106 to building 40.
	15	Carrying wedges building 72 to building 40.
2		Carrying armatures building 40 to building 18.
	15	Carrying wedges building 72 to building 40.
	15	Carrying base building 106 to building 40.
	15	Carrying base building 106 to building 40.
	40	Carrying barrels oil building 67 to building 40.
	20	Carrying barrels oil building 14 to building 40.
	20	Carrying wedges building 72 to building 40.
	10	Carrying armature building 40 to building 9.
	25	Carrying chains building 66 to building 18.
	20	Carrying barrels oil building 67 to building 30.
2	30	Carrying armatures building 40 to building 18.
	55	Carrying barrels oil building 67 to building 18.
	20	Carrying wedges building 72 to building 18.
	50	Carrying wire from building 69 to building 40.
	10	Carrying armature building 40 to building 18.
	45	Carrying coils and bars building 14 to building 40.
1	20	Carrying barrels oil building 67 to building 40.
	15	Carrying base building 40 to building 50.
	15	Carrying base building 40 to building 50.
	20	Carrying three shafts building 18 to building 9.

to devise and execute novel applications too numerous and special to be described here. Mill and factory engineers, managers and superintendents instantly see specific applications in their own line of work and it has developed that each proposed application expands into many actual uses not previously contemplated. This point is well illustrated by the log covering nearly fifty hours of actual work out of a possible fifty-six, just taking things as they came.

With ingenious operators and liberal equipments battery truck cranes properly administered eliminate lost motion and save money directly and indirectly where for years methods were thought to be practically perfect.

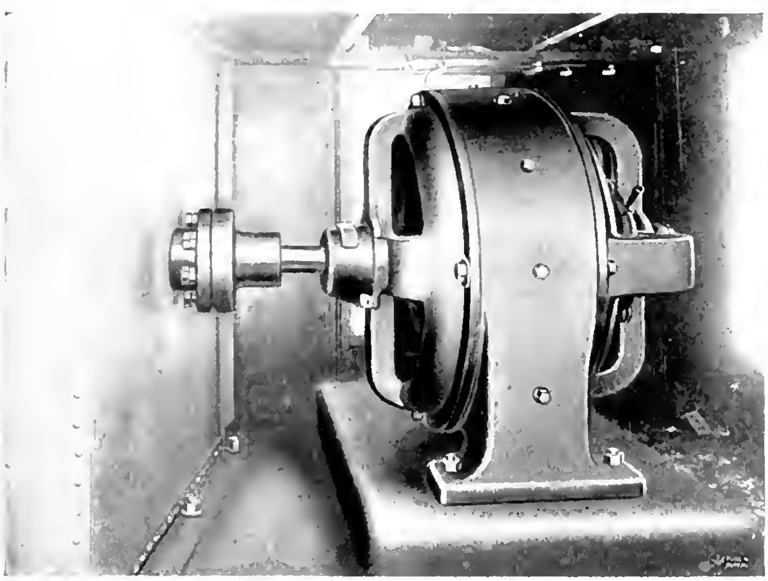
ELECTRICITY IN COAL MINES

Part III

By John Liston

Ventilating Fans and Air Compressors

Uninterrupted service is the primary requisite of a coal mine ventilation system. The imminence of the hazard to the workers underground involved in a failure of the supply of fresh air being, of course, dependent on the character and formation of the mine.



50 H.P. 230 Volt 200-400 R.P.M. Shunt Wound Motor Direct Coupled to 15 Foot Up-Cast Fan. Turkey Run Colliery, Shenandoah, Pa. Philadelphia & Reading Coal & Iron Co.

Mechanical ventilation by means of rotary blower or exhaust fans which give a positive and fully controllable supply of air is almost universal in coal mines, the furnace system being used only in small isolated mines, or as a temporary arrangement in some of the larger ones, while the water fall or trompe ventilator or the steam jet or water jet methods are rarely resorted to. In driving ventilating fans with electric motors it is customary to couple the motor and fan shafts together and avoid the use of belting as the nature of the load is such that with high speed fans direct drive minimizes the power requirements and economizes space.

Where large slow speed fans are changed over from steam to electric drive the retention of belting is often necessary, due to the difference between the speeds of the fan and the motor, but with both forms of electric drive the reliability of the service is increased, attendance cost reduced, and better speed control assured, while the installation of the fan itself is not influenced by the location of the power house. Where remote control is desirable, as in the case of fans situated at a considerable distance from the central or substations, it can be accomplished with remote control switches and any interruption of the service indicated promptly by connection alarm lights or bells in the motor circuit.

For mines using induction motors for other work, the question of adopting synchronous motors for driving the fans should be carefully considered, especially if the induction motor load is such as to seriously affect the power-factor of the generating and distribution systems as by utilizing synchronous motors of higher rating than is actually required for driving the fans, their excess capacity may be devoted to correcting lagging power-factor by supplying leading current to the distribution system. This will frequently obviate the necessity for providing unloaded synchronous condensers to counteract the influence which unloaded induction motors and transformers have on the power-factor, and consequently the effective capacity of both generators and conductors.

The theoretical and practical conditions governing the correction of lagging power-factors are now generally understood by the engineers of the coal mining companies, and as the various calculation and methods of utilizing both synchronous condensers and partially loaded synchronous motors have been comprehensibly covered by articles in the GENERAL ELECTRIC REVIEW—issues of March, 1909, February, 1910, and May, 1911, they will not be further referred to at this time.

When compressed air machinery is required in coal mines electric drive renders it possible to locate the compressors with a view solely to securing the best air service irrespective of the location of the prime movers, in contra-distinction to the necessary limitations of steam-driven air compressors. The motor-operated units may be installed in distant substations or in the mines, and as a result short pipe lines with a correspondingly reduced pressure drop may be used, while individual compressors can be provided for isolated working sections.

Sullivan Coal Cutting Machine on Power Truck

If automatic unloaders are used with the compressors to regulate the pressure, and by-passes provided so that the motor is enabled to start at very light loads, the conditions are most favorable to the use of synchronous motors on slow speed reciprocating compressors, as very little overload capacity is then required in the motor, and it may be designed as in the case of those driving ventilating fans to compensate for conditions of low power-factor.

It is not usually advisable to drive high speed centrifugal air compressors with synchronous motors, as the best operation of this type can be secured by the use of high speed induction motors. Both types of motors can ordinarily be direct connected to the compressor shaft, but belting is of necessity sometimes retained in changing over from steam to electric drive.

Rock and Coal Crushers

When motors were first applied to the centrifugal type of rock and coal crushers it was considered advisable to retain belt drive, due to the onerous starting conditions, excessive vibration and the possibility of the severe operating requirements resulting in stalling or injuring the motor. Familiarity with the use of electric motors, however, induced many of the engineers of the mining companies to attempt direct drive and both alternating and direct current motors are now successfully applied in this manner; being connected to the crusher shaft through flexible couplings.

When driving these crushers with engines it was necessary to utilize belting in order to obtain the required speed, and space economy was attained by installing the engine close to the crusher and reducing the belt-slip caused by short arc of contact by interposing idlers. This was accomplished at a sacrifice in the power applied in useful work and the cost of belting renewals was excessive, amounting in some cases to approximately $100 per month for a single crusher. It is manifest that direct motor drive not only eliminates this expense, but reduces the amount of space necessary, while at the same time applying a greater percentage of the power in useful work.

The efficiency of motor drive for coal crushers as measured by the output in crushed coal for a given motor capacity was recently demonstrated by an exhaustive test conducted for the United States Coal and Coke Company at Gary, W. Va.

A 200 h.p. General Electric induction motor was direct connected to a crusher having a normal output of 200 tons per hour, which, during the test, delivered 262 tons of crushed coal per hour without exceeding the guaranteed temperature rise in the motor. Owing to the heavy starting torque and severe intermittent overloads to which a motor must necessarily be subjected in this service, the polyphase induction type should be used when alternating current is available. If direct current motors are used with either rock or coal crushers, they should be enclosed to avoid commutator trouble from abrasive or conductive dust: reference to the accompanying illustrations of coal crushers driven by induction motors will show that this type need not ordinarily be enclosed.

75 H.P. Induction Motor Driving Bucket Conveyor at No. 2 Tipple, United States Coal & Coke Co., Gary, W. Va.

While the above references have only considered the centrifugal type of crusher, the electric motor can be adapted to any form of coal breaker, disintegrator, roll crusher or pulverizer, and where their operation calls for relatively slow speeds standard back geared motors can generally be applied.

Breakers and Tipples

The power losses involved in the operation of an engine-driven breaker are unavoidably great, due to the complex mechanical transmission of the energy through numerous shafts, pulleys, sprockets, sheaves, belts, ropes and chains interposed between the prime mover and the machinery actually performing useful work, which, in addition to consuming a large proportion of the available energy, occupy a very considerable amount of space and serve to complicate the internal arrangement of the breaker. Owing to the severe service conditions the belt renewals and general repair work constitute a continuous and heavy expense and very little saving in the primary power required is possible when the breaker is operating on partial loads.

A realization of the inefficiency of engine drive has led some of the coal operators to equip breakers of modern construction with individual motor drive, which, by eliminating a large percentage of the shafting, belting, etc., effects a great reduction in the power losses and maintenance charges, and by rendering it possible to run the various portions of the machinery independently, makes the power cost, when only part of the equipment is used, directly proportional to the amount of productive work.

The earliest attempt at individual motor drive was made with direct current enclosed motors, and was only partially successful, as the intense vibration inseparable from breaker operation tended to cause commutator troubles.

In those breakers where induction motors were used, the simplicity of the rotor and the absence of moving electrical contacts resulted in a practically complete immunity from motor troubles, and the breakers were supplied with current from a central generating station; no local reserve power plant being required.

For driving tipples individual motors have heretofore been more generally used than in breakers, and the typical modern steel tipple is usually equipped with separate motors for the conveyors, picking tables, screens, crushers, etc., although in some cases they are driven in groups by one or more large motors.

Where long conveyor or scraper lines are used the power waste inherent in rope transmission may be reduced by using a centrally located motor or individual motors for separate sections. If extensions to the system are made, as in the case of conveyor lines to culm or refuse piles, the additions may be made without interfering with the operation of the original equipment, by providing a separate motor for each new section.

All the surface auxiliaries of mines and collieries will as a rule benefit from the adoption of electric drive, which abolishes the necessity for separate power plants for distantly located washeries, slush dredgers, storage cranes, etc.

Breaker at Burnside Colliery, Near Shamokin, Pa., Showing Motor-Driven Car Haul
Philadelphia & Reading Coal & Iron Co.

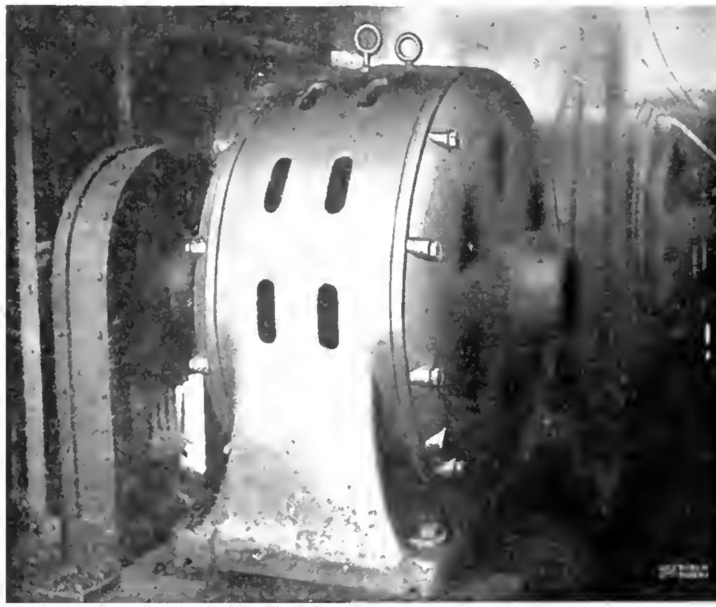
Coal Cutters

During the year 1909 the amount of coal mined by machinery in the United States was in excess of 142,500,000 tons or more than 38 per cent. of the total production for that year, about 13,000 machines of various types being used. Since their introduction the use of the motor-driven type has increased steadily and more rapidly than other forms, owing to the superior flexibility and economy of the electrical distribution and application of power: in the State of Pennsylvania alone, the tonnage produced by electric mining machines in 1903 was about 18,000,000, while in 1909 it had risen to more than 31,000,000 tons.

The typical modern coal cutter shown herewith is mounted on a self-propelling truck and all its movements in loading upon or unloading from the truck, and during the process of mining, are made under its own power without hand labor. The motive power is supplied by a specially designed, enclosed, direct current shunt wound vertical shaft motor provided with a simple rheostatic controller and wound for operating at the voltages commonly used for mine locomotives, so that current can ordinarily be supplied by the generator equipment provided for haulage, and as the mining machines are usually in service at night their use does not as a rule call for any increase in the generator capacity.

The extreme diversity of the conditions encountered in coal mining render it practically impossible to cover all the various forms of motor application within the limits of this article, and the foregoing examples are only intended to indicate the wide adaptability of electric drive. For similar reasons it is difficult to outline a generating and distribution system which will be of general utility, as any given standards must inevitably be greatly modified by local conditions and the capacity of the power plant required.

In general, it may be said that the first generators in the older developments were direct current units provided for lighting and locomotive haulage and were usually belt connected to existing engines, direct connected sets being adopted for additions to the original outfit. Engine-driven alternators were eventually added at the transmission distances increased beyond the economical range of direct current, but many isolated mines are still equipped for direct current service only. The increasing use of alternating current motors and the high combined efficiencies of high speed turbine-driven alternators led to the choice of high pressure turbines as prime movers for most of the new power plants, or else mixed pressure or low pressure turbines were adopted to supplement the engine equipment as they could ordinarily be operated with the exhaust steam of the engines already installed and in this way add greatly to the generator capacity of the power station without requiring extra boiler capacity.



Type I Form K 200 H.P. Induction Motor Driving 200 Ton Coal Crusher and in Background 300 H.P. Form K Motor Driving a Second Crusher of the Same Capacity. United States Coal & Coke Co., Gary, W. Va.

Comparatively high transmission voltages are now commonly used in this industry and most of the recent substations are constructed and equipped in accordance with the most advanced engineering practice, while on the other hand many mining plants illustrate in their miscellaneous electrical equipment the successive stages in the advance of electric manufacture during the past twenty years.

(To be Concluded)

ELECTRICITY IN MINING

By D. B. Rushmore

Engineer, Power and Mining Department, General Electric Company

General

In order to fully emphasize the increasing importance of the mining industry in this country and its influence on the prosperity of the nation at large, nothing can be more truly illustrative than a reference to the statistics of its enormous volume and growth.

In 1907, the value of the total mineral production of the United States in a crude form at the mines or metallurgical works was $2,069,000,000 and the total number of men employed in this business was approximately 2,500,000. Of this total output the combined production of anthracite and bituminous coal amounted to more than 480,000,000 short tons valued at approximately $615,000,000. The production of pig iron was approximately 29,000,000 short tons valued at nearly $530,000,000, and the production of copper 869,000,000 pounds valued at $173,800,000.

Comparing the above figures with the statistics for 1898 shows that the total value of the productions has increased nearly three times, and while in the year 1908 the output decreased very considerably, due to the general business depression, there is, however, not the slightest indication that the increase in the mineral production has anywhere reached its limits.

A further reference to the statistics will show that the value of the production in the last decade has increased considerably more than the quantity of production. For example, while the value of the coal output has increased nearly three times, the quantity produced has only grown somewhat more than twice. The reason for this difference is most naturally to be found in the added cost of operating the mines, due to the higher cost of both machinery and operating expenses.

This advanced cost of mining and the competition between different enterprises must evidently affect the earnings, and to increase these, mining methods have been resorted to that in many cases have not been well for coming generations. Undue waste in the exploitations of the properties has taken place. Low grade ores have been caved in and left behind during the extraction of richer portions. Thin coal seams are in many cases utterly destroyed by the working out of thicker seams not far below them. It is to prevent this waste of natural resources and to save the lives of the men employed in carrying out these industrial enterprises that the most energetic efforts should be resorted to, and when this is done the success of the mining industry at large can be considered satisfactorily solved.

The method that naturally first presents itself to accomplish this is one that would considerably reduce the cost of production and at the same time increase the safety of the operatives. That the electric operation of the mines will fulfill these requirements to a considerably greater extent than any other system is now generally recognized. Without exception, almost all new mines are being equipped for electric drive and a very large number of old mines have been changed, or are changing over to electricity. The great advantages of this system, resulting in increased efficiency, reliability and safety, have made it possible for existing mining companies to augment their output and earnings considerably. As the mines get deeper, it is obvious that the operating expenses increase correspondingly, and in some cases it would have been impossible to continue on a paying basis had it not been for the substitution of electric power in their operation. In other instances it has been found more economical to utilize the coal right at the mine instead of shipping it. Power can be efficiently generated at the colliery and transmitted at a high pressure over long transmission lines to industrial localities where a profitable market can be secured for it.

While the characteristics of the electric system are such that it is particularly well adapted for mining work, it is, however, as a result of a very thorough study of the requirements of this class of work and much experience in this line that the electric system has proved to be so successful. It is not only for the operation of the mines that electricity can be utilized: for electro-thermic smelting and for electro-chemical reduction of certain ores the use of electric power is constantly increasing and a near future will see an enormous growth in this field.

Advantages

One of the greatest advantages of the electric system is the economy with which the power can be generated and transmitted. The power house can be centrally located and large generating units provided, resulting in the most efficient system. The size and number of the units can be selected so that even if one unit has to be shut down for repairs a continuous service can be maintained by partly overloading the others. Power may also be purchased from existing transmission systems, or some available water power may be developed for the purpose. With one source of power and a large number of individual loads, an improved load factor results, with a consequent reduction in the size, first cost and operating expenses of the generating station.

For transmitting the power to the various shafts, buildings, etc., the electric system offers the greatest possibilities. It eliminates the long and expensive lines of steam and air piping and substitutes a system which is most simple and flexible. With the use of alternating current the power can be efficiently distributed over very large areas, extensions and alterations can be made without difficulty and with the least expense, while in many instances it can safely be used in places where steam lines would introduce the greatest discomfort, as in deep mines where the already high temperature would be further increased.

A perfect control is at all times possible with the electric system. Meters of either the recording or indicating type can be installed where desired and the performance of every individual machine ascertained. This is a very important point in all industrial undertakings, as it is possible to maintain the machinery in the best operating condition. Any excess power taken is at once readily detected and the defect can be promptly corrected. An accurate record can also be kept of the cost of the different operations.

The benefits of electric lighting have long been recognized and employed even in mines where the electric system has not been adopted for power service, and with the introduction of the improved types of portable electric miners lamps, the system should be still further appreciated.

The question of safety in using electricity for mining operations can pr perly be divided in two groups; i.e., safety as regards life and safety as regards apparatus. The dangers to which lives are exposed are explosions and shocks, of which the former only occur below ground. To prevent the ignition of "fire damp" gases by an arc from a motor, circuit breaker, etc., the most rigid precautions are now being taken. Motors of the enclosed construction without moving contacts are installed where there is danger of "fire damp" being formed. Circuit breakers of the oil-immersed type and enclosed fuses are used for the protection of the apparatus, and all high tension cables are thoroughly insulated and adequately protected where there is danger of men coming into contact with them.

The Bureau of Standards has recently issued a circular dealing with the standardization of electrical practice in mines. This circular covers in an admirable form proposed rules for the installation and operation of electrical apparatus in mines. If these rules are strictly followed it may be said that as regards safety the adoption of the electrical system can be considered as an undisputed improvement.

Power Generation

As stated before, the electric power required for operating the mines can generally be obtained in three different ways. It can be generated directly at the mine, an available water power site can be developed and the energy transmitted to the mine, or finally the power can be purchased from an existing public power supply company. The question which one of the above systems is preferable, is one which only can be answered in each individual case when all the conditions of price and other circumstances are known. That there is a large number of cases where power is being purchased, however, is evidenced by the steady increase of the power supply companies.

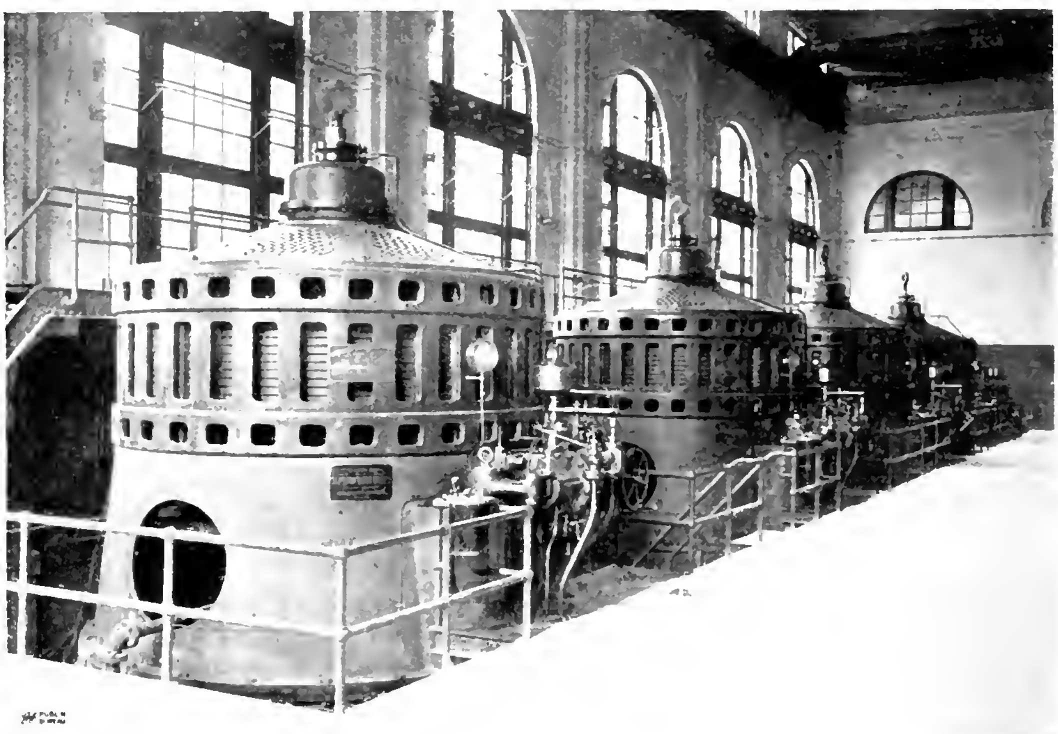
In coal fields the power is, as a rule, generated right at the mine, and this proves in most cases to be the most economical method, except where the value of the coal is exceptionally high. Steam turbines, having an exceedingly high efficiency, are then generally used for prime movers in modern installations. Where the water is scarce, or mixed with acid or other impurities, the use of gas engines would be more advantageous from an operating standpoint; but on account of the greater cost of gas producers and gas engines, a careful investigation should be made to ascertain if any available water power site could not be obtained and developed, or whether power could not be more economically purchased from any existing power company. That both these methods, in certain cases, are advisable is illustrated by the fact that one large coal mining company has recently entered into contract with a hydro-electric power company for furnishing power for operating its mines, and another company is just completing an extensive hydro-electric development of its own for the same purpose.

If it has been decided that the installation of a private generating plant at the mine would be preferable, the next point to settle is whether a steam or gas plant shall be adopted. With a reasonable amount of pure water available this question is generally easily settled in favor of a steam plant, and under such conditions condensing steam turbines are mostly selected for the prime movers, on account of their low first cost.

The steam consumption of the modern condensing steam turbine is very low, being sometimes more than 50 per cent. better than for the single slide valve engines generally used in mining districts, and from 10 to 15 per cent. better than for modern compound condensing engines. Another special feature is the small space it occupies, which in turn reduces the cost of the engine room. The simplicity and reliability of the steam turbine, when operating either singly, or in multiple, tend also to reduce the amount of attention necessary and so keep down the operating cost.

The principal claim that could be waged in favor of a gas engine installation would be a slightly less fuel and water consumption. As, however, the cost of the fuel at most coal mines is comparatively cheap, the actual saving in the fuel charges is more than counterbalanced by the increased interest and depreciation charges (owing to the greater first cost of the equipment) and the additional operating and maintenance expenses.

The cost of the generating plant depends largely on the character and conditions under which the development is carried out. As an approximation, however, it can be said that the cost of a complete steam



3000 Kw., 40 Cycle, 3-Phase, 4400 Volt, 300 R.P.M. Waterwheel-Driven Alternators turbine station, including buildings, boilers, turbo-generators, condensers and auxiliary apparatus, etc., will range from about $50.00 per kw. for a large plant, to about $100.00 per kw. for a small plant; and for corresponding gas engine plants, including buildings, producers, engines, generators, etc., from $100.00 to $175.00.

The development of a large number of available water powers by mining companies should not only be found profitable, in many instances, but also advisable in view of the present movement for the intelligent conservation of our mineral resources. In certain cases, the natural conditions of the development may be such as to permit cheap water storage facilities to be utilized in case of low water, or the installation of steam auxiliaries at the most convenient point. Several water power stations can also be tied together on the same system and the conditions may be such that one of them could advantageously be employed to take care of the peak loads. The cost of water power developments, including dam, building, hydraulic equipment and generators will range from about $35.00 to about $200.00.

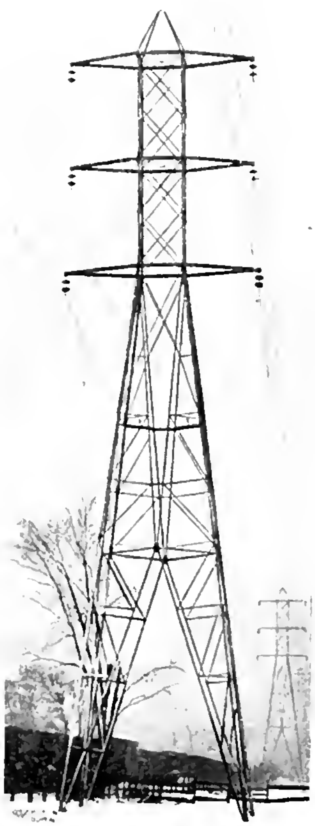
The question whether a direct or alternating current equipment is to be installed depends upon the conditions to be met. For large mining installations, the three-phase alternating current system possesses many advantages with regard to generation, distribution and operation, as well as safety. If the mines are scattered over a large territory, the power may be generated and transmitted at a higher voltage than is possible with the direct current, and in this way the efficiency of transmission is increased and the first cost of the transmission lines reduced. The simplicity of the squirrel-cage induction motor makes it especially suitable for severe service such as is met with in mines. There are no sliding contacts and no electrical connections to the rotating part—hence sparking is entirely eliminated. In cases where direct current would be preferable, as for mining locomotives, rotary converters or motor-generator sets can be provided for converting the alternating to direct current. For smaller mines where the power need not be transmitted for a great distance the direct current system may be adopted, the direct current motor being well adapted for the operation of hoists, mining locomotives, etc.

The voltage at which the power should be generated depends to a great extent on local conditions. Most of the electrical apparatus used in mining work are operated at from 220 to 550 volts, and in some cases even 2300 volts is used for pump motors, etc. For direct current systems, however, it is not desirable to generate at a higher voltage than 550, principally on account of the less satisfactory operation of the motors above this voltage, and the pressure that should be used is generally dependent on the local conditions in each individual case. With the alternating current system, however, the voltage of the generating units is not dependent on the voltage of the motors, but can be selected for the most economical results. If a large number of machines are located near the generating station, the voltage should preferably be the same as for these motors, so as to allow of direct distribution, while transformers could be used for stepping up the voltage to a value that would be most economical for transmission to more distant locations, where substation could be erected and the voltage again reduced to a value corresponding to these motors. The frequency of systems where purely alternating current is used should preferably be 60, so as to permit its use for lighting; while, if the secondary distribution is done wholly or partly with direct current, 25 cycles may prove the best, the current for lighting in such a case being obtained from the direct current circuits.

Transmission and Distribution

Where power has to be transmitted for any considerable length, the alternating current system should be adopted, as before stated. Allowing the same percentage loss in the line, the weight or cross-section of the conductors varies inversely as the square of the operating voltage, and as the conductors in the transmission circuits constitute one of the largest items of investment, it is desirable in certain instances to employ very high voltages. Raising the voltage, however, increases the investment for transformers, switching apparatus, lightning arresters and insulators, and the most economical voltage must therefore be determined for each individual case. As a very approximate rule, however, it may be said that a pressure of 1000 volts should be allowed for each mile of transmission. The value thus obtained would, however, be limited to about 100,000 volts, above which the condition becomes more complicated.

The line conductors are always bare, and may be either of copper or aluminum, the choice generally being governed by economic conditions. The conductivity of aluminum is about 63 per cent. that of copper of the same cross section and the weight only



Steel Transmission Tower

about 30 per cent. An aluminum conductor of the same length and conductivity as a given copper conductor, therefore, weighs only about 48 per cent. as much, and the cost of aluminum can be about twice that of copper to give a conductor of the same size and conductivity without increasing the cost. Copper conductors larger than No. 0000 are commonly stranded, while, owing to the mechanical unreliability of solid aluminum conductors, these are used stranded in all sizes, even the smallest.

In general, steel towers should be used for all transmissions of a permanent character, except where the first cost, maintenance and life of wood structures give the latter a commercial advantage. In some sections of the country, choice pole timber may be had very cheap, climate conditions may be conducive to prolonging the life of wood, and all conditions thus combine in favor of wood pole construction. However, as weather resisting poles are becoming scarce in most parts, and as the demands for reliable and continuous service are becoming more exacting, steel towers would be preferable. The more important reasons for the greater reliability of a steel tower line over one of wood poles are its substantial construction and ability to withstand sweeping storms, etc., the minimized troubles from lightning and its increased life. Double-circuit towers are preferably recommended as it is never wise to depend entirely on one circuit for transmitting the power in an important installation. The same weight of copper divided into two circuits and supported by slightly modified towers would considerably reduce the chance of a shut down and entail only a small additional cost for towers, a second set of insulators and the labor of stringing the second circuit. In many cases the smaller cables could also be more easily handled with two circuits. Independent lines passing through entirely different routes minimize the possibility of shut downs occasioned by snow, landslides, etc., and may be advantageous in mountainous regions, although the cost is considerably increased.

Two types of insulators are at present used for transmission work—the pin type and the suspension type. The former is not generally employed above 60,000 volts on account of its excessive dimensions, weight and cost for higher pressures. The excessive pin length also gives a weakening leverage, and the necessarily small separation of pin and conductor solicits puncture. For higher voltages the suspension scheme seems to be preferable. These insulators consist of a number of porcelain disks supported below each other and held together by means of clamps, one disk being required for each 25,000 volts approximately. The main advantages of this type of insulators are their adaptability, portability, simplicity of construction, strength and less cost. The stresses due to wire breakage will also be very much less, due to the sufficient lengthening of successive spans to take up the new strain.

The cost of transmission lines varies considerably due to the fluctuations in the market prices of the line conductors. It also depends to a great extent on the labor, the location and condition of the soil, and whether the line is built in summer or winter. Based on average conditions, it can be said that the cost per mile of a double-circuit wooden pole line will range anywhere from $650 for 2300 volts, to about $1050 for 40,000 volts. These costs do not, however, include the conductors, ground wire, right of way, clearing or freight charges. For steel tower construction the corresponding cost would range from about $1900 for 60,000 volts to about $2700 for 110,000 volts.

One or more substations, depending on the number and location of the different mines, will be required for housing the step-down transformers, the converting apparatus, and the control equipment. The design of the substation building and the equipment should be made with a view to economy and simplicity of operation, so as to minimize the necessary attendants. Due regard, however, must be given to possible future extensions. The design is fixed by the kind of service to be given, whether the distribution is purely alternating current or direct current, or a combination of both. The first system naturally permits the simplest design, as it only involves the installation of step down transformers, while if a conversion to direct current is to be made rotary converters with transformers, or motor-generator sets, with or without transformers, must be provided.

The transformers may be of the oil-cooled or water-cooled type, and up to medium voltages, of the air blast type. Oil-cooled units, however, are preferable for substations where water is scarce and the absence of auxiliary apparatus for their cooling considerably reduces the necessary attention. Direct current converting equipments are of two general classes, motor-generators and rotary converters. In systems generating energy at 25 cycles the rotary converter is employed very generally, because of its greater efficiency and lower cost as compared with motor-generator sets. Where the generating system produces 60 cycle energy the rotary converter has not been so much used, because of its somewhat less stability, and the direct current has been obtained from motor-generator sets. Both synchronous and induction motor-driven sets are employed, the synchronous motor being very desirable because of its ability to operate over-excited as a synchronous condenser for power-factor control. It is, however, subject to the dis-

Substation Containing 1500 Kw. Synchronous Motor-Generator Sets advantage that it is thrown out of step and shut down rather easily by disturbances and short circuits in the transmission system. The induction motor having no power-factor control is at a disadvantage in that respect, but is not as easily thrown out of phase sufficiently to be shut down. On account of its characteristics the rotary converters will almost always require step-down transformers, while motor-generators can be wound for pressures up to 13,000 volts—thus in many cases eliminating the necessity for transformers.

The switchboard should be located in an accessible position. It carries only the instruments, the low tension hand-operated oil switches, and the control handles for the high tension switches, which should be remote controlled and, together with the high tension connections, installed in perfectly protected places so as to avoid any danger of coming in contact with them. Suitable lightning arresters for protecting both the high and low tension systems must also be provided.

The secondary distributions should be laid out in the best possible manner, both from an economical and operating standpoint, and the construction should be most substantial so as to prevent any possible shut downs due to poor workmanship. For the overhead distributing circuits the conductors are either bare or insulated with weatherproof braid and are supported on insulators mounted on regular wooden poles with cross-arms.

For the underground construction in the mines, it is very essential that the wires be erected out of easy reach, but frequently the head room in the mines is such that this cannot be done. Owing to the excessive damp and acid atmosphere in many mines it is quite difficult to maintain a high degree of insulation on the wires, and hence, in many cases the low pressure wiring is run with bare wire, supported on glass or porcelain insulators. Where the danger of coming into contact with the wires is great, especially for high voltage wires, they should be thoroughly insulated and metal covered, the armoring not only protecting the insulation from deterioration but also from mechanical injury. It seems also advisable that, even with lead-covered cables, the insulation should be non-hygroscopic and as nearly as possible proof against the action of mine acids, because there is always the possibility of a defect appearing in the lead sheath, either through a defective joint, or through electrolytic action, or otherwise. If paper insulation is used, even a small opening of this sort may admit enough moisture to destroy the insulation at that point and cause a break-down. The use of non-hygroscopic insulation protected by a lead sheath seems, therefore, to offer the most reliable protection. The first cost is naturally higher, but the greatly increased life of the cable, together with greater freedom from trouble, will make it more economical in the end, and if the lead sheath be grounded, it eliminates entirely the danger of electric shock.

Hoisting

The hoist is one of the most important pieces of apparatus, and has a very direct bearing on the successful operation of a mine. Conditions vary greatly with different mines, and especially in different localities. Such factors as depth, incline, the number of levels, permissible or desirable speeds, conditions of ore, etc., are always more or less special in each case. As mining laws are made by the different states they necessarily vary somewhat, and, even when not fully observed, they introduce factors which qualify the conditions of hoisting men and ore. The amount of timbering required is often of importance as relating to hoisting conditions. Methods of loading ore affect the time required, as also does the question of the use of cars or skips.

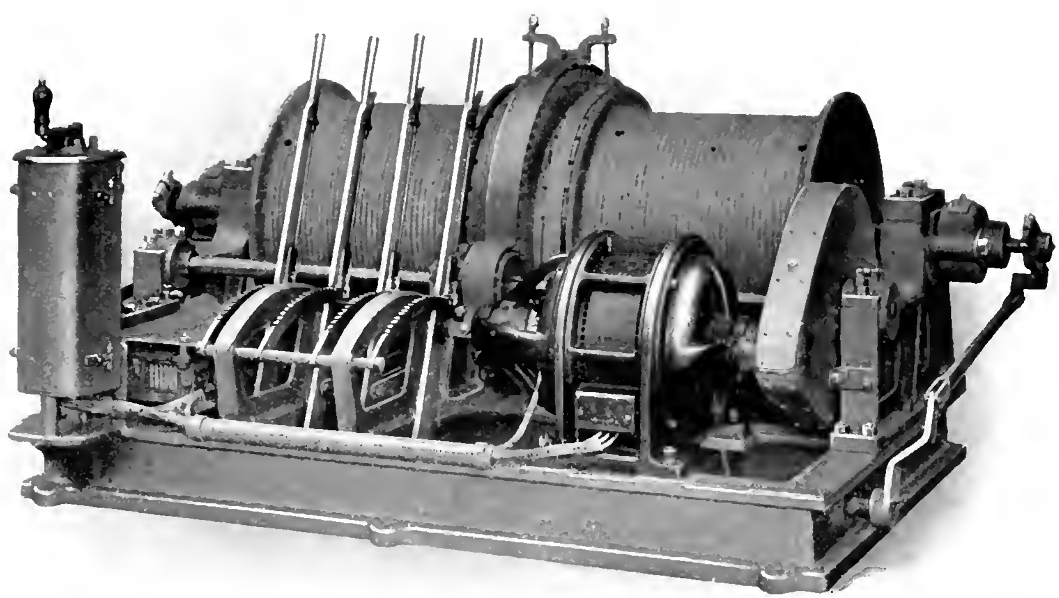
While a general discussion of the subject of hoisting is possible, most cases are entirely special and can be considered only in connection with the peculiar conditions pertaining to the particular installation.

The cost of installation of the hoisting plant may be an appreciable amount, while the cost of raising the ore may be but a small part of the total operating charge. In many cases, however, the output of the mine is limited by the capacity of the hoist, and the latter thus becomes of the first importance. Where shafts have not been sunk to their final depths the conditions of operation are of necessity constantly changing, and it is impossible to predetermine with exactness the precise conditions of operation which will be followed in practice.

Three forms of power, steam, compressed air and electricity, are to be considered for the operation of mine hoists, and the choice of the best system in any particular case is the result of a careful study of many different factors. Most important of these is the cost of operation and installation. Steam hoisting plants are, however, known to be very inefficient, but the exact figures are usually difficult to obtain. With non-condensing engines and an extremely intermittent load on both engines and boilers, the economy necessarily is very poor. Steam engines must be designed for starting conditions, where they take steam under full stroke, and this necessitates their running with an early cut-off when hoisting. With a number of plants close together, there is no way of returning power to the line or of smoothing the peaks of the load. It is impossible, when a steam engine is used, to store power in retardation. There is also a limit in the depth at which steam engines can be satisfactorily placed, and their installation in mines is thus very undesirable.

The use of hoists operated by compressed air has long been considered and at present some installations are being made. Some kind of power, generally steam or electric, must, however, be provided for driving the air compressors, which are necessary for obtaining the compressed air. With the usual features of such equipment it is further necessary to provide means for cooling the air during compression and re-heating it again before use, and in general, serious questions would arise concerning the efficiency of any system using compressed air for hoisting.

The electric system, however, has every advantage, which gives it a decided preference for hoist operations. The cost of installation and operation is much reduced, power can be returned to the system in braking and in lowering unbalanced loads, and a much improved load factor results. Safety devices preventing overwinding and limiting the acceleration are easily provided, and for underground installations the electric hoist is especially well adapted.



Double Friction Drum Electric Mining Hoist, with 3-Phase Induction Motor

Large electric mining hoists are almost universally driven either by shunt wound direct current motors, or polyphase induction motors, the characteristics of which especially adapt them to meet the peculiar conditions imposed. While in many of their characteristics, these two types of motors are similar, they differ widely in others, which are of more or less importance—depending upon special conditions of individual cases. The free running speed of either motor is limited, and the speed variations with load changes are small. When driven above their normal speeds both act as generators and may, therefore, be used as a brake when lowering unbalanced loads, returning power to the supply system. The speed of the shunt motor for a given load may be varied between standstill and full speed, either by changing the potential of the supply system or by inserting resistance in series with its armature. However, because of the inefficiency of the latter method, it is seldom, if ever, used in connection with large hoist motors. The only practical method of obtaining a similar variation in the speed of an induction motor is by changing the amount of resistance connected in its armature circuit. Where the conditions, however, are such that it is desirable to run the hoist at a reduced speed for any length of time, the efficiency of the induction motor drive may be improved by using a motor designed for two speeds, but the advantages gained thereby are seldom sufficient to offset the increased first cost and the necessary complication of the control.

As pointed out, the efficient speed control of the shunt motor may be obtained by varying the voltage of the supply system, the usual method being to provide a generator for each motor and vary the generated potential. As mine shafts are usually scattered over a considerable area, and the conditions in close proximity to the shafts are not such as to permit of the economical generation of electric power, the central electric station is usually placed at a considerable distance from the hoists; the power is generated and transmitted to the mines as alternating current and is then transformed at each shaft into direct current by motor-generator sets. The losses caused therein must be charged against the shunt motor when comparing its efficiency with that of the induction motor, which may be connected either directly or through highly efficient static transformers with the alternating current distributing system. The torque and current for the two types of motor are approximately proportional within their operating limits.

Many systems of electric hoisting have been prepared, each with the view of meeting some particular condition, or eliminating some real or apparent objection in the others, but virtually all the installations are confined to four systems:

Double Flywheel Motor-Generator Set Consisting of Two 170 Kw. Shunt Wound Generators Driven by a 450 H.P. 2080 Volt Induction Motor—Speed of Set 600 R.P.M.

First. The first and simplest system consists of a polyphase induction motor, direct connected or geared to the hoist drum. The speed of the motor is controlled by a variable resistance in its rotor circuit. Because of the magnitude of the currents involved, this resistance is usually some form of water rheostat. A common type of water rheostat consists of a tank, usually of boiler plate riveted together, and divided into two compartments; one the rheostat proper, and the other a cooling tank. The electrolyte is pumped from the cooling tank into the rheostat proper, entering at the bottom of the rheostat and flowing out over the top of an adjustable weir, back into the cooling tank. The resistance in the rotor circuit is varied by changing the height of the electrolyte in the rheostat proper by means of the adjustable weir. The electrodes are usually thin iron plates hung on insulators, all phases being in the same compartment. At least one electrode per phase is of extra length, extending below the lowest level of the liquid, in order to prevent the rotor circuit from being opened. The most common form of electrolyte is a simple salt solution. The control of the rheostat is by means of a lever located on the operating stand.

The power taken by the motor in this system is constant during the period of acceleration, but the efficiency for this period is very low, approximately 45 per cent. No power is returned to the supply system during the period of retardations, and the power consumption for small movements of the cage or skip is very large. On the other hand, the efficiency during the period when the hoist is running at full speed is high, approximately 90 per cent., and no power is consumed while the hoist is at rest. The efficiency over the complete cycle of operation obviously decreases rapidly with a decrease in the time during which the hoist is driven at full speed; and it follows from this that when hoisting is to be done from several levels, the efficiency at the maximum depth alone cannot be used as a basis for comparing the hoist driven by the induction motors with other systems. The efficiency of the cycle increases with an increased rate of acceleration, from which it follows that an induction motor for hoisting should be designed for a high maximum output to permit of a rapid acceleration. The power returned to the system in lowering the empty skip is approximately 20 per cent. of that taken by the motor in hoisting the loaded one.

Second. In the second system, the hoist is driven by a direct current shunt motor, receiving power from the alternating current supply system through a synchronous or induction motor-generator set. The hoist motor is controlled by varying the voltage of the generator, which is separately excited, one generator being used for each motor. The power consumed during acceleration is much less than for the induction hoist motor, the efficiency being approximately 80 per cent.; and a considerable part of the energy stored in the revolving parts of the hoist is returned to the supply system as the hoist is brought to rest. On the other hand, the efficiency when the hoist motor is running at full speed, is lower than that for the induction hoist motor, being approximately 82 per cent., and the losses of the motor-generator set when running light, must be supplied during the time when the hoist is at rest. In view of the fact that a mine hoist is idle 50 per cent. or more of the time under ordinary conditions, this is an item in the total power consumption which cannot be neglected. It follows from what has been stated that the advantage of the direct current hoist motor over the induction hoist motor in the efficiency through the complete cycle is greatest for short lifts, in which case the period of acceleration is a large percentage of the total cycle and the time during which the hoist is idle is a minimum. When the empty skip is lowered with this system, about 30 per cent. of the power consumed in hoisting the ore unbalanced is returned to the system.

No definite rule can be laid down by which a choice can be made between the two systems, each having advantages and disadvantages, peculiar to itself, which have a more or less important bearing on the choice, depending upon the special conditions of the individual problem. The first system has the advantages of low first cost and simplicity, but is often at a disadvantage in respect to efficiency. On the other hand, the higher efficiency of the second system is frequently more than offset by its increased first cost and its greater cost of maintenance.

Both systems are open to the objection that the power drawn from the supply system fluctuates between very wide limits during each cycle, generally reaching a maximum during acceleration, becoming negative during retardation for the second system, zero, or practically so, at the end of the cycle, and negative for both systems when lowering unbalanced loads. The effect of this wide fluctuation in the load during each cycle is to seriously impair the voltage regulation of the supply system unless its capacity is large as compared with the fluctuations, or unless the number of hoists driven from the same system is sufficient to produce a fairly uniform load. This is seldom the case for a mine power system. Also, if power is purchased, the price is usually made up of two components; one based on the total kilowatt-hours consumed, and the other on the maximum demand.

It therefore becomes necessary in most cases to provide some means whereby power may be taken from the supply system and stored during the portion of the cycle when the demand for power is less than the average, and returned when the demand exceeds the average.

Third. Such a system is the third, in which advantage is taken of the low first cost and efficiency of the flywheel as a means for storing and returning large quantities of power for short intervals. This system is similar to the second, except for the addition of a flywheel to the induction motor-generator set, and an automatic regulator for varying its speed. In its most common form, this regulator consists of a water rheostat connected in series with the induction motor armature. The resistance is varied by means of movable electrodes suspended from an arm mounted on the shaft of an induction motor, which is connected in series, either directly or through series transformers, with the induction motor of the flywheel set. The regulator motor is so connected that its torque opposes the weight of the electrodes, which are partially counterbalanced to reduce the size of the regulator motor to a minimum, and to permit of an adjustment of the regulator for different values of line current. When the line current exceeds the value for which the regulator is adjusted, the torque of the motor overbalances the weight of the electrodes, lifting them and inserting resistance in the armature circuit of the induction motor. This causes it to slow down, and allows the flywheel to assist in driving the generator during the peak loads.

Fourth. The fourth system is used when, for the purpose of meeting some peculiar condition, it is advisable to drive the hoist by an induction motor and at the same time eliminate the peaks from the station load. The adoption of this system is warranted when the hoist is located underground at such a distance from the surface that it becomes necessary to transmit power to it by alternating current, and when the shaft is not large enough to allow the flywheel of the motor-generator set to be taken underground.

This system, which it will be noted is the first system, to which has been added a converter equalizer, includes a rotary converter connected on the alternating current side to the supply system, and on the direct current side to a motor driving a large flywheel. The field of the direct current motor is controlled by a regulator actuated by the line current. When the power taken by the hoist drops below the average, the field of the flywheel motor is automatically reduced, and the flywheel is speeded up, the power being taken from the supply system. When the hoist motor load exceeds the average, the operation is reversed, the flywheel slowing down and returning power to the system.

The efficiency of this system is generally slightly lower, and the weight of the flywheel is slightly greater, than for the direct current motor and the flywheel motor-generator set. It has the advantage, however, over the third system, in that the operation of the hoist motor is not dependent on the operation of a converter equalizer. Consequently, in the event of the failure of the latter, hoisting may be continued, provided, of course, that the capacity of the power system is sufficient to take the load, which would be the case if the equalizer were used simply to reduce the power bill.

Either the third or the fourth system may be used where the supply system is direct current; in the third system, by substituting a direct current motor for the induction motor of the flywheel motor-generator set, and in the fourth system by omitting the synchronous converter of the flywheel converter system.

A comparison between the steam system and these four electrical systems is given in the following table, in which the fuel and ore ratio for each are given for a small system hoisting from a 2000 ft. level, and a large system hoisting from a 6000 ft. level:

	Coal Burned Tons Per Day	Ore Hoisted Tons Per Day	Tons Ore / Tons Coal
Hoisting from 2000 ft. level small hoist:			
Steam hoist	47	1780	40
Electric hoist First system	13	1780	137
Second system	15	1780	119
Third system	16	1780	110
Fourth system	15	1780	119
Hoisting from 6000 ft. level large hoist:			
Steam hoist	65.5	1580	24
Electric hoist—First system	23	1580	69
Second system	24	1580	66
Third system	25	1580	63
Fourth system	27	1580	59

In determining these values, it is assumed that the steam hoisting engines are non-condensing, that the steam consumptions are 65 lb. and 55 lb. per indicated horse power hour respectively for the large and small hoists, and that power for the electric hoists is supplied from a moderate steam turbine station using units of 1000 kw. each or larger for the smaller hoist, and 2500 kw. or larger for the larger hoist. In determining these ratios the power consumption has been increased 10 per cent. to cover the transmission losses.

In addition to the saving in fuel which may be realized by the use of electric hoists, there is a very material reduction in the labor, the cost of which is chargeable against the hoist. This may amount to the wages of one or two men in the boiler house if power is developed by the mining company, or of the whole boiler house force if power is purchased, and frequently the wages of one man in the hoist house.

So many factors enter into the cost of electric hoisting that each individual case must be analyzed separately. An approximate estimate of the power consumption would be from $1\frac{1}{4}$ to $2\frac{1}{4}$ kilowatt-hours per 1000 ton feet, the tonnage, in the case of unbalanced hoisting, including the weight of the ore and skip, while for balanced hoisting only the ore.

Pumping

A large number of mines, especially coal mines, are, due to the absence of natural drainage facilities, absolutely dependent on a pumping equipment for their continuous operation; and the importance of installing the most efficient system is at once appreciated when the enormous quantities of water, that in certain instances must be removed, is considered.

The most important advantage of the electrically driven pump is its higher efficiency, this in certain cases being as high as 70 to 75 per cent. or from 25 to 40 per cent. greater than for steam or air pumps. In the matter of flexibility the merits of the electric mine pumps are the ease with which they can be moved from point to point in the mine, and the economy of space, which should receive careful consideration in cases where the mine conditions demand that pumps be placed in the smallest possible room.

The pumps that are generally used for mining operations can be divided into three classes, i.e., the sinking pumps, used for development work or for emptying flooded mines, the main pumps which are permanently installed in the mine, and finally the auxiliary pumps used for pumping water into a central pump from various depressions in the mine which cannot be naturally drained.

The sinking or dip pump is generally designed for being lowered in a vertical shaft, and is either mounted on a float or suspended from the hoisting cables so as to always operate at the surface of the water. The motors for operating these pumps can be either of the direct or alternating current type, but as they are often liable to be entirely submerged the enclosed induction motor is preferable on account of its simple construction and the absence of moving contacts. In the operation of these pumps the load increases inversely as the head, and the motors should be so designed that their efficiency increases with the increasing head.

The main pumps, which are mostly of large capacity, are used for emptying the sumps where the water from various parts of the mine is collected. If these sumps are of a sufficient size for storing the water collected during the day, the pumps can be operated at night and the load factor considerably improved. The pumps used for this service are either of the reciprocating or centrifugal type, of which the latter in most cases seems to be the most desirable. Although the centrifugal pumps in the past have been adapted for conditions where the height of lift has been moderate, and where larger volumes of water have had to be removed the recent installations have indicated that remarkable improvements in the multi-stage centrifugal pumps now make them especially efficient and satisfactory for delivering water against heads of 1000 to 1500 ft. or more. This type of pump is particularly well suited for direct connection to high speed motors, preferably of the polyphase induction type, thus eliminating the friction losses of a gear device. The space occupied by the centrifugal equipment is considerably less than for the reciprocating set, and the ability with which it can handle sandy and muddy water is well appreciated.

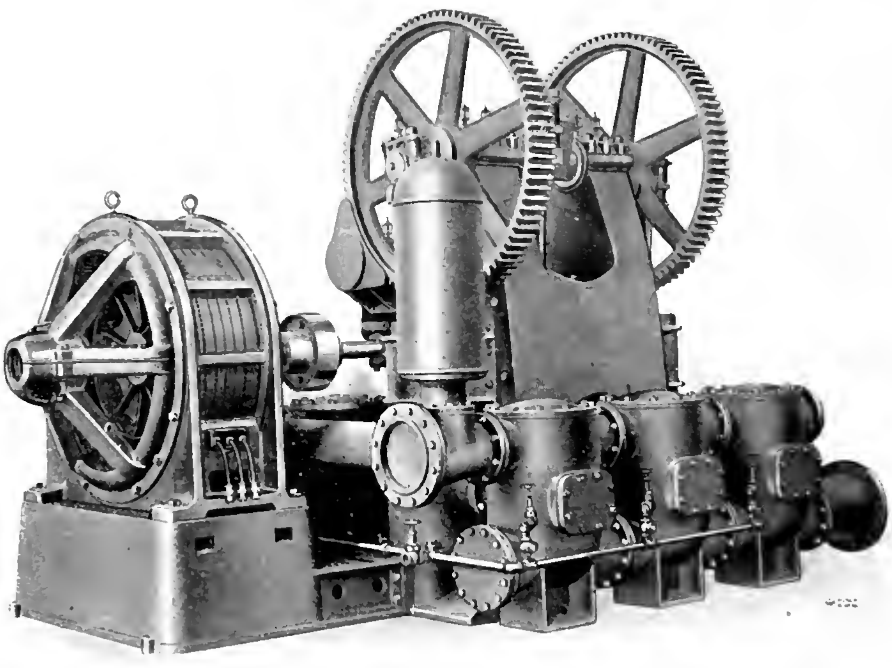
The auxiliary pumps for pumping water from places located below the main pumps are either of the stationary or portable type. Owing to their large number and scattered location they are mostly driven by direct current motors receiving the current from existing trolley circuits. Of special interest among these pumps is the portable pumping set, which is mounted on a truck and can easily be hauled to any portion of the mine by a locomotive and immediately put into service.

Air Compressors

Although the direct application of electric motors is preferable for the majority of mining machinery, there however remains one particular case where compressed air is still much used, viz., for the operation of rock drills. This air is obtained from air compressors, which can either be of the large stationary or of the small portable type. The large compressors are generally located at some centrally located place and piping run to the various drills, while the small compressors are mounted on a truck together with the driving motor and located in proximity to the drill. As the pressure required for the drills must be comparatively high, about 80 lb. per sq. in., the reciprocating type of converter is generally used. On account of their characteristics they must necessarily be driven at a low speed and occupy consequently a very large space, especially if the old method of steam engine drive is used. The substitution of an electric driving motor, however, not only increases the efficiency and reduces the space, but almost entirely eliminates the maintenance charge, as no special attendant is required. For their operation the synchronous type of motor is especially well adapted on account of the steady load and the low torque required in starting. The improving effect that these motors have on the power-factor of the system is also of importance in their selection.

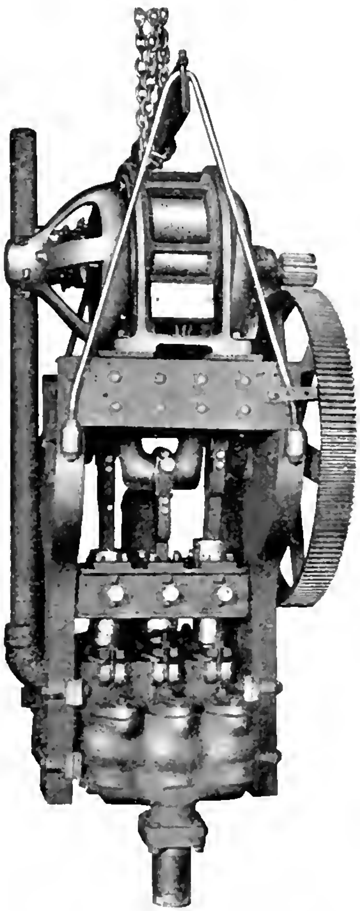
Haulage

Possibly no other branch, where electricity has been applied for mining operations, has met with more thorough appreciation than the introduction of the electric locomotive for mine haulage. Its high efficiency, due to the low first cost, maintenance and attendance charges, its simple control and its rugged and durable construction make it exceedingly well adapted for mining work. The use of steam locomotives, especially, for underground work is obviously highly impracticable on account of the fire risk, the smoke and the necessarily higher headroom required. Compressed-air locomotives are also poor substitutes on account of their high first cost, lower efficiency and limited radius of action due to their small storage capacities.



125 H.P. Induction Motor Driving 10 by 12 in. Triplex Pump

The mule, which has been one of the competitors of the electric locomotive is now also being universally discarded; as actual experience has shown that the cost per ton of hauling is from 50 to 75 per cent. cheaper



$4\frac{1}{2}$ by 6 In. Vertical Triplex Sinking Pump Driven by $7\frac{1}{2}$ H.P. Induction Motor

by electric than by mule haulage. This is, of course, evident, when the number of mules that are necessary for performing the same work as a locomotive is considered. The increased cost of feeding, the large percentage killed or injured, and the additional amount of air necessary in underground work are all factors in favor of the electric drive.

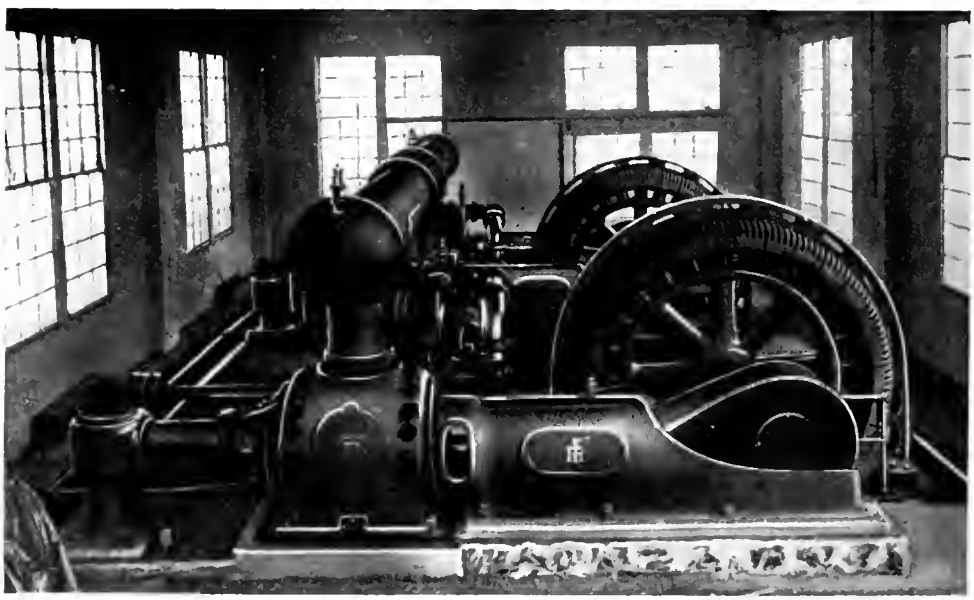
The direct current two-motor locomotive has come to be generally recognized as the standard type for mine work. There are two general forms of this type, one in which the side frames are placed outside of the wheels and the other in which the side frames are placed inside of the wheels. For a given track gauge the outside frame type allows the maximum space between the wheels for the motors and other parts of the equipment, renders the journal boxes more accessible, and gives somewhat more space at the operating end for the motorman. The inside frame type restricts to a certain extent the space between the wheels available for motors and other equipment, but allows for the minimum overall width a construction that is necessary in those mines where the props are set close to the track or the space outside the rails is otherwise limited. The wheels being outside the frame, this type in case of derailment is somewhat more readily replaced.

There are two standard methods of mounting the motors: in "tandem," i.e., one motor placed between the axles and the other between the forward axle and the front end frame; and "central," i.e., both motors placed between the axles. The "tandem" arrangement permits of a short wheel base and is adopted for the light and medium weight locomotives, as these are usually required to operate over sections of the track having short radius curves. On the heavier locomotives the motors are mounted "central." The longer wheel base is permissible in this case for the reason that the heavy locomotives operate on the main haulage roads which, as a rule, are comparatively straight and have easier curves. With either arrangement the locomotive frame is proportioned to give an equal distribution of the weight between both pairs of driving wheels.

Motors may also be "end" mounted by placing each motor in the space between the axle and the forward and rear end frames respectively. This permits the minimum wheel base, but is very seldom used and is adopted to meet exceptional conditions only.

For hauling cars between the working face of the rooms and the main or cross entries the gathering type of locomotive is now recognized as the most efficient. The general construction of this type is similar to the locomotives for main haulage, with the exception that they usually are of a less tonnage and provided with cable reels. The reel proper is supported by the motor frame and rotates on a ball bearing between the main gear and the top of the motor. The armature shaft is also provided with ball bearings. The motor is connected directly across the line in series with a permanent resistance which protects it from a heavy rush of current when the locomotive is standing still. A combined switch and fuse is also inserted in this circuit—the fuse for protection against short-circuits, and the switch for convenience in case it is desired for any reason to open the circuit; but the latter is not involved in any way with the ordinary operation of the reel. The motor has sufficient capacity to permit its being stalled for any length of time without overheating. The reel is equipped with about 500 ft. of flexible heavily insulated cable. The inner end of this cable is connected to a collector ring on the under side of the reel, and the outer end is fitted with a copper hook for attachment to the trolley wire. A carbon brush mounted on an insulated stud attached to the motor frame collects currents from the ring, from which it is conducted to the controller circuit.

On leaving the entry the cable is hooked over the trolley wire, and as the locomotive moves forward the reel motor is overhauled and acts as a series generator, its counter-torque being sufficient to produce a tension on the cable that causes it to pay out evenly and drop along the roadbed without producing any kinks. Owing to the braking effect of this counter-torque, the reel ceases rotating the instant the locomotive comes to a standstill. As soon as the locomotive starts back and slackens up on the cable, the motor action comes into play and the reel winds up the cable. The action is analogous to that of a spring having infinite length. The tendency of the motor is to produce a peripheral speed at the rim of the reel that is higher than the linear speed of the locomotive so that there is a constant tension on the cable, which insures its being wound compactly. The operation of the reel is entirely automatic; there are no switches or shifting levers for the motorman to handle, and he is therefore free to devote his entire attention to running the locomotive.



Air Compressors Capacity 2650 cu. ft. at 100 lb., each Direct Driven by a 450 Kv-a. 6000 Volt 125 R.P.M. Synchronous Motor

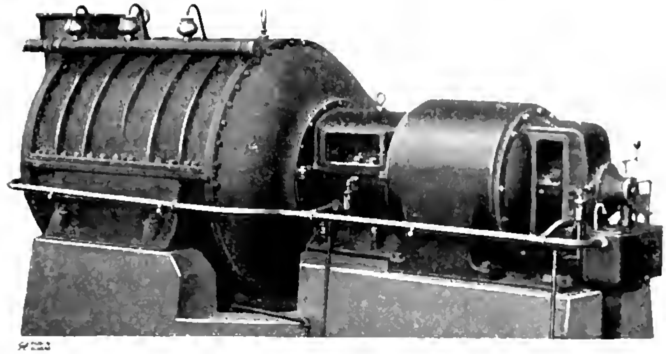
As will be seen, the complete mechanism is self-contained and is very simple and compact. It is mounted on two straight supporting bars bolted to the locomotive side frames. These bars, with the cable guides and protective resistance of the motor, are the only extra parts used, so that the reel mounts on any standard locomotive without complicating the latter in any way. As the reel proper covers the motor and gearing, the latter is protected from falling coal or rocks. The large diameter of the reel is also a valuable feature, as it minimizes greatly the wear on the cable. With cable reels of small diameter the cable is forced to bend sharply on a short radius which reduces considerably the life of the insulation.

The mechanism requires no oiling whatever. Beyond applying a little graphite or vaseline to the ball-bearings occasionally, no other lubrication is necessary, the vertical countershaft being carried in a sleeve of anti-friction material that needs no oiling. Bearings are hardened steel balls, so that practically the only parts subject to wear and renewal are the cable, the wood rollers of the cable guides and the carbon brushes. The maintenance is consequently reduced to a minimum.

For passages and gangways where the grading is such as to prohibit the use of the cable reel locomotive, the combination or crab type is preferably used. This locomotive is mostly of the same construction as the reel type with the addition of a hoisting drum and steel cable, by means of which the loaded cars are pulled up the slopes and then delivered to the main tracks in the regular way. As this type of locomotive in addition can perform the duties of the straight haulage and cable reel type it is often considered indispensable in mines where a limited number of locomotives are to handle the entire output.

In some of the first combination locomotives manufactured, the hoisting drums were arranged to be operated by means of one of the locomotive motors through gearing and clutches, but in the later types the hoisting drum is driven by an independent motor, giving an improved efficiency, at the same time insuring a more positive and simple contact.

In mines where the headings have attained considerable length the output can frequently



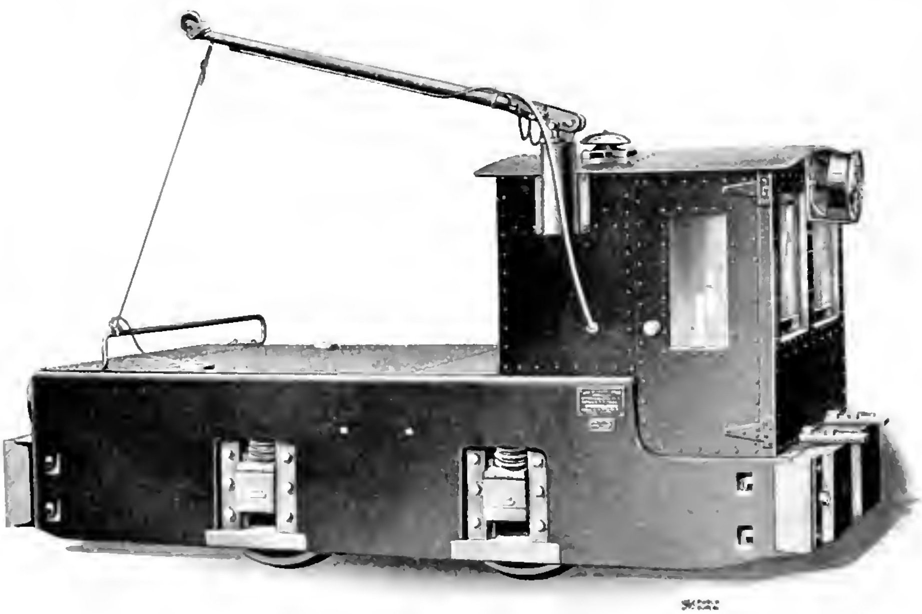
Motor Driven Multi-Stage Centrifugal Air Compressor

Thirteen Ton Mining Locomotive

be handled most economically by instituting what might be termed "express haulage;" i.e., the trips over the main haulage road are concentrated into trains of a capacity sufficient for a 20- or 25-ton locomotive. On well laid tracks, having 50- or 60-pound rails, four-wheel two-motor locomotives of this weight operate successfully. Where, however, light rails exist it is inadvisable to concentrate this weight on four drivers, so instead of a single 20-ton locomotive, two 10-ton locomotives are coupled together and operated as a single unit, which, while developing the same tractive effort, has its weight distributed on eight drivers.

The tandem locomotive is also adapted for those cases where conditions of operation require trains of a certain tonnage, and the gauge is so narrow that two motors of sufficient capacity cannot be used.

The method of coupling locomotives in tandem is extremely simple and permits the complete control of motors, brakes and sand valves of both locomotives from the operating end of one. The first or "primary" locomotive is equipped with a four-motor controller and the other, the "secondary" locomotive, with a two-motor controller; flexible cables terminating in two multi-conductor plugs and their corresponding sockets carrying the control circuits of the four-motor controller over to the secondary locomotive. The vertical screw type brake stand is used on both locomotives, but on the "primary" the foot plate to which the stand is bolted, is provided with two sets of bolt holes, one set for holding the stand parallel to the end frame and the other parallel to the side frames. In the latter position, by means of a chain connection through the end frames, it operates the brake lever systems of both locomotives. By pulling out the cable plugs, disconnecting the brake chain and turning the "primary" brake stand parallel to the end frame—an operation requiring but a few minutes—the locomotives are separated and may be operated singly as independent units.



Mine Locomotive Equipped with Cab

Mining locomotives can also, if desired, be equipped with alternating current motors. These are of the same general construction as the direct current locomotives and are equipped with two three-phase induction motors. Their operation requires two overhead trolley wires, with the track rails comprising the third leg of the three-phase circuit. To collect current two separate trolleys of the standard mine type are used, these being mounted on either side; but for certain conditions a double trolley, i.e., two poles on a common base, can be furnished.

The motors have a special high torque winding, the same as those used for crane and hoist service. The rotors, or secondaries, have polar windings which terminate in three collector rings mounted at the end of the rotor shaft. By means of these rings starting resistance is connected into the rotor circuits, the controller being arranged to vary the resistance by suitably graduated steps. Aside from a slight variation in speed due to changes of load, the induction motor is a constant speed machine, but with the variable external resistance in the rotor circuit a speed and torque characteristic somewhat similar to that of the direct current series motor is obtained. The locomotives are geared for a maximum speed of about 6.5 to 8 miles per hour. With the controller on the last notch (and neglecting a slight change due to drop in voltage along the road) they tend to maintain approximately this speed irrespective of the load or grades. The rotor resistance, however, is proportioned to permit running with this resistance in circuit for short periods at full tractive effort, so that fractional speeds for accelerating, switching, etc., are readily obtained.

As the induction motor is inherently high speed a double gear reduction is used. This necessitates a method of mounting the motors different from that used on direct current locomotives.

The motor frame is bolted to a sub-base or suspension bracket. One end of this bracket is mounted on the axle and the other end is spring suspended from the locomotive frame. A pinion on the end of the rotor shaft engages with a gear that is keyed to a countershaft, which is carried in bearings attached to the under side of the suspension bracket. The other end of this shaft carries a pinion that engages with a gear keyed to the locomotive axle. This arrangement maintains all gear centers constant and also embodies the flexible spring suspension feature of the direct current locomotives. With the exception of the method of mounting the motors and the arrangement of the control circuits, direct current standard construction is followed throughout.

Alternating current locomotives can be furnished for any standard frequency and voltage, and for any weight up to and including ten tons. Ordinarily, in the field for which they are adapted the service can be handled by comparatively light locomotives.

Mine locomotives are occasionally employed for outside surface haulage and where limitations of height do not prevent, it is sometimes desirable to provide a cab for the protection of the motorman. The standard cab is mounted over the operating end and is built up of sheet steel and angles well braced and securely riveted throughout to insure a strong, rigid structure. The cab is provided with a door and suitable windows which permit a clear view on all sides.

Ventilation

The proper ventilation of underground mines is of the greatest importance, and on the continuous and successful operation of the ventilating machinery depends the lives and efficiency of the operators inside the mine.

The ventilating machinery for mines, in general, does not differ greatly from other cases of ventilation. Either low speed fan blowers or high speed low pressure compressors are employed, both of the centrifugal type. For driving fan blowers either direct current or alternating current motors can successfully be used. Where the distribution is by direct current the motors can be either of the shunt or compound wound type, the latter being preferred for very large fans where the starting torque is great. With an alternating current system of distribution induction motors are often used, their advantage being the high starting torque and a possibility of speed variations for changing the air supply. This latter point, however, is not of such great importance, as actual practice has shown that the losses in the rheostatic motor control are about the same as the losses due to a mechanical shuttering of the fan. Where fans can be entirely shuttered, the starting torque is not very large; and considering the rather bad effect that an induction motor has on the power-factor of the system, the use of synchronous motors is greatly preferred. Where the fans are installed in remote places induction motors would possibly be more advantageous on account of the little attention they require. If possible the motors should be direct connected so as to avoid the use of belting—thus insuring a more reliable operation and an economy in the required space.

For centrifugal compressors synchronous motors are not so well adapted on account of their high speed, and induction motors would be preferable. Where the compressor, is of large capacity and can be installed in the generating station, it may be driven by an efficient steam turbine and the generator and motor losses eliminated.

Coal Cutting

Three types of electrical coal cutters are in general use, i.e., the disk type, the bar type and the chain type. Of these, however, the chain breast type machine is the most extensively employed in this country.

The motors are usually of the direct current compound wound type, insuring a large starting torque and an improved operation where a widely varying load and large momentary overloads are of frequent occurrence.

For operation in mines where the formation of "fire-damp" is apt to take place the motors should be of the enclosed type to insure safe operation. In this respect, the polyphase induction motor has a decided advantage, due to the absence of movable contacts, and investigations are now being carried on with a view to its development to suit the conditions imposed by coal cutting machinery.

Drillings

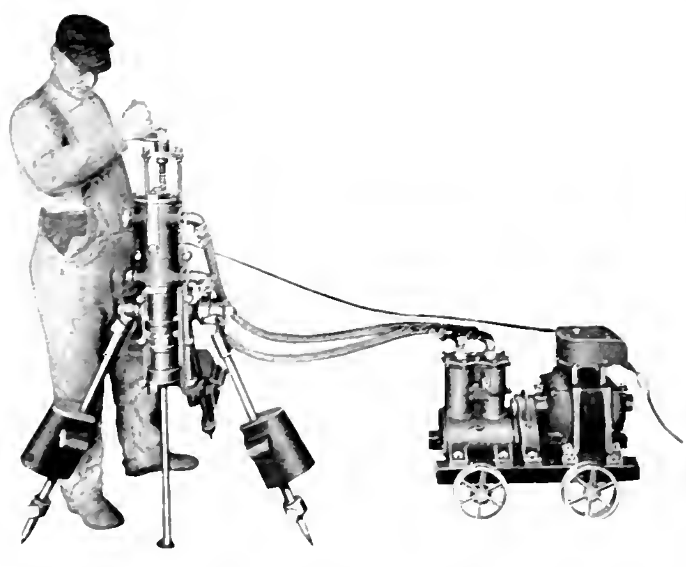
For the last five years the "electric-air" drill has been in successful operation in all classes of mining work, both in this country and abroad. It is really an air drill driven by pulsations of compressed air created by a duplex air pulsator actuated by a standard electric motor. The drill is of the simplest type possible, a cylinder containing a moving piston and rotation device, with no valves, chest, buffers, springs, side rods or pawls. The cylinder is larger but the piston is shorter, making the weight of the drill unit about the same as, or even less than, that of the corresponding air drill.

The pulsator is a vertical duplex single acting air compressor. It is geared to a motor, either direct or alternating current, and mounted on a wheel truck for easy handling.

The size of the motor ranges from 3 to 5 h.p., dependent on the size of the drill, and it is claimed by the manufacturers that the "electric-air" drill, for the same work as the ordinary air drill, will only consume from one-third to one-fourth as much power.

While purely electric drills have not proven satisfactory in the past, it has mostly been due to the failure of some of their vital and delicate parts to withstand the terrific strains imposed in rock drilling. An electric rock drill, however, is now in the market and it is claimed by actual experience that all previous difficulties have been overcome and that a very successful operation is obtained. It is of the rotary hammer type design operated by an electric motor which is mounted on the frame of the drill proper. The mechanism of the drill consists of two parts, a revolving helve containing the hammers, and the chuck mechanism for holding and rotating the drill steel. A flexible belt connection between the motor and drill permits a variation of speed to any degree desired, with the result that all the advantages of hand drilling are obtained without the disadvantages usually incident to machine drilling. The drill and motor are of simple and rugged design, free from springs, solenoids, or other devices that tend towards complication and to make the cost of maintenance excessive.

The drill requires about $1\frac{1}{2}$ to 2 h.p. for its operation including loss in transmission from the source of power to the drill, and tests have shown that an ordinary air drill of the same capacity would require from 12 to 18 horse power per drill. Either direct current or alternating current motors can be used for its operation.



Electric Air Drill

Rock Crushers, Breakers and Tipples

For operating the various auxiliary machinery used in mining work, such as crushers, stamp mills, picking tables, screens, conveyors, etc., electric motor drive is being universally used. Induction motors of the squirrel cage and slip ring type are in use, either direct connected to driving shafts or to individual machines. The absence of commutator trouble, due to the severe vibrations of this kind of machinery, makes it preferable to the direct current motor.

The reduction or entire omission of the numerous belts formerly used in this class of work naturally results in a considerably increased efficiency and consequent decrease in the operating expenses, while at the same time it greatly improves the safety and reliability of the installation.

Electro-Magnetic Ore Separators

There occur in Nature many combinations of minerals whose specific gravities are too nearly alike to permit of their separation by any of the usual concentrating devices. In such combinations where one of the minerals is magnetic, or may be rendered magnetic by the application of heat, magnetism offers an efficient, and often the only method of separation. For reasons connected with the subsequent reduction of zinc ores the presence of iron is highly objectionable, and this, together with the similarity of the specific gravities of the iron and zinc materials, gives rise to one of the most important applications of the electro-magnetic separation.

There are, in addition, a number of other instances where magnetic separation would prove entirely practical. The present methods of mining in this country, with its numerous deposits of high grade iron ore, have resulted in a neglect of the less rich fields. For the concentration of this ore, the magnetic separation would be most suitable, and as the richer ores are exhausted, there must necessarily be a steady increase of its application to this class of work.

The electro-magnetic separator has been developed into an efficient machine with economical power consumption both for operation and excitation of the magnets. It is of a most rugged construction and not liable to break down or get out of adjustment. It is easy to operate and the cost of maintenance is very low.

Dredging

Dredging is now considered to be the most improved method for recovering valuable ore deposits, especially gold, below the water level in streams. It can also be employed on the land, in which case the dredge is built in a dry pit dug for the purpose, and when the hull is completed, water is let in by a ditch or flume.

The successful operation of dredging machinery is now an established fact, and that it is far superior to the steam operated dredge in cost of operation, space economy and reliability has, by actual experience, been proven beyond a doubt. This fact, however, is mainly due to the proper design and application of the electric motor and the present efficient methods of transmitting the electric power.

The digger consists of a steel ladder of massive construction, built to support the bucket line and resist the heavy strains while in operation, especially near bed rock. The bucket lips, bushings and rollers are made of manganese steel, which possesses the best wearing qualities and reduces the cost of maintenance to a minimum.

The speed of the bucket line varies from fifty feet (with 18 to 25 buckets) to seventy-five feet (with 35 to 50 buckets) per minute, depending upon the condition of the ground.

For operation and control of the digger, a variable speed induction motor is used. This is located on the lower deck and belted to the driving pulley, which is generally situated in the rear of the pilot house on the upper deck. The duty imposed upon this motor is severe, as it must operate under conditions calling for power varying from 75 per cent. overload down to 25 per cent. of its rated capacity. A drum type controller for forward and reverse operation is provided, including the necessary resistance for continuous operation on any notch of the controller from one-half to full speed.

The maximum starting torque is required and obtained at about the fourth point of the controller, thus leaving three points on which to bring the motor up to half speed, at which time nearly full rated torque is required. As a result of these conditions, the ordinary motor designed for intermittent service cannot be successfully applied.

To keep the dredge in place and to move it about or hold it against the bank when digging, head lines are used, which are controlled from the forward end and operated by a six-drum winch driven by a variable speed motor. The winch motor, while of smaller capacity, is of the same staunch construction as the digger motor, and is equipped with a suitable controller and resistance to permit its continuous operation from one-half to full speed. It has been found advisable to equip the motors for this service with solenoid brakes, by means of which the motor can be brought to a standstill almost instantly. It is then ready for the reverse operation without the usual reversing of the motor through the controller, which is not only bad practice but may result in a burnout due to the heavy strain on the windings.

The high and low pressure pumps for supplying water to the screens and sluices are generally connected to the same motor. A constant speed squirrel-cage motor of compact construction and large overload capacity, with a speed of about 900 r.p.m. is usually installed for this work and is supplied with extended shaft at both ends, these extensions being provided with flange couplings for direct connection to the pumps.

To prevent the filling up of the basin, in which the dredge floats, when digging in shallow water, it is sometimes found necessary to install a sand pump, which carries the fine tailings from the sluice boxes to the top of the rock pile by way of the stacker. This pump requires considerable power and is never used unless absolutely necessary.

One pump is used for priming the large pumps or for supplying water to the tables during the "clean up," and generally consists of a small, high speed motor direct connected to a centrifugal pump.

Either the shaking or revolving screen may be used to separate the gravel from the clay and permit the fine particles containing the gold to pass through on to the gold tables and sluices below. For this service, a constant speed motor is recommended, which can be placed on the upper deck and belted down to the driving pulley of the screen.

After screening, the large rocks are carried on a belt conveyor to the end of the stacker and deposited on the spoil in the rear of the dredge. For operating this conveyor, a constant speed motor is installed at the extreme end of the stacker, where it can be readily housed.

With the exception of the digger and the winch, squirrel-cage constant speed induction motors are recommended for use throughout the dredge.

Gold Dredge—Capacity 7½ cu. ft.—Electrical Equipment: Three 125 Kw. 60 Cycle 4000/460 Volt Three-Phase Transformers, One 7½ Kw. 4000/115/230 Volt Transformers, Switchboard and the Following 440 Volt Induction Motors: Bucket 200 H.P., Winch 25 H.P., Screen 35 H.P., Stacker 25 H.P., 10 In. High Pressure Pump 75 H.P. 10 In. Low Pressure Pump 35 H.P. and 4 In. Priming Pump 10 H.P.

Lighting

The superiority of electric lighting is well recognized in mining work. For overhead illumination it does not differ at all from the ordinary arc lighting systems, but for underground work incandescent lamps are almost exclusively used, especially in coal mines. These should be adequately protected from breaking by being provided with substantial lamp guards, and the sockets should be of an acid-proof and moisture-proof design.

The problem of producing a satisfactory hat and hand lamp to supersede the present oil lamp, which will always remain a constant source of danger and discomfort, has for many years been the aim of a number of inventors, and numerous designs of more or less value have been put on the market. There is, however, one type which has just been developed and which promises to be a great improvement in this line.

This lamp consists of a miniature Tungsten unit operated from a light portable storage battery. It is rated at one mean horizontal candle-power, but due to an effective reflector, as high as 5 candle-power is obtained in the beam of light at a four or five foot distance. The lamp socket consists of a hard moulded compound unaffected by moisture, acid or gases and completely encloses and protects all metal parts. The steel reflector, which is enameled both inside and outside to prevent the action of gases and moisture from destroying it, is also supported from the lamp socket. The complete lamp is especially compact, light in weight and mechanically strong. It is designed so as to replace the old type of oil lamp, now in general use, without any modification to the cap.

The storage battery is of the portable type, designed to be either carried on a belt or from shoulder straps, or by a handle as a lantern. The cell is protected by a japanned steel case with an acid proof moulded cover. The terminals are brought out through an acid- and moisture-proof compound receptacle, from which an armor braided rubber insulated cable connects to the hat lamp. The battery has a capacity of 10 ampere-hours and is of sufficient size for operating a lamp for twelve to fourteen hours.

When used as a hand lantern the lamp socket and reflector are removed from the cap receptacle and inserted into the receptacle on the side of the battery, simply taking the place of the cable attaching plug.

Telephone and Signal Systems

No other means gives a more complete control over all parts of a mine than does a telephone system, and it will eventually supplement all other methods of signalling. The saving of time and the facility with which orders and messages may be verbally despatched to the various departments in the mine is readily appreciated when the variety of characteristic accidents is considered, such as fire, explosions, water freshets, etc. The fact that the superintendent of a mine may remain in his office nd be in direct talking communication with every part of the entire mine system is of such a great importance that it more than outweighs the initial cost of the installation.

The underground wiring for a mine telephone system costs usually less than for overhead systems, as poles are not required and there are no holes to dig. The wires are

Miniature Tungsten Headlight Deriving Current from Portable Storage Battery

simply run through the rifts and down the shafts on standard wood brackets equipped with common glass insulators. Although in some mines ordinary iron wire has been used with entire success, it is, however, recommended that rubber covered wire be used in all underground circuits which are, in any way, subject to moisture or dampness. In certain instances, it would be considered good practice to use lead-covered cable, providing the installation would warrant the expense.

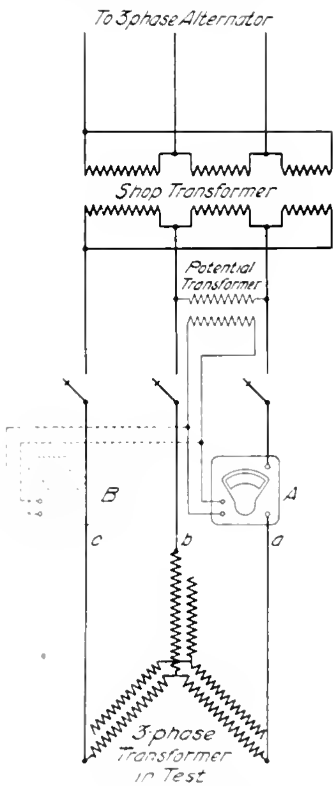
The principal mine telephones are of the magneto type with especially constructed talking and signalling apparatus, accessibly arranged in moisture-proof cases. The bells are of the most improved construction, usually iron-clad, water-proof and rust-proof. Where the number and importance of the stations to be served by a telephone system justify it, a central office with a switchboard should preferably be provided.

DIARY OF A TEST MAN

[CONTRIBUTED]

XII. INCORRECT METER CONNECTION

I wish to call attention to a mistake in connecting meters that came to my notice while on transformer test that resulted disastrously to two wattmeters, and but for great good fortune would have cost the man in charge of the test his eyesight.



The core loss of a three-phase 11,000 volt transformer was required to be checked, and after balancing up the currents on the three phases, the tester connected in a wattmeter (A), as shown in the sketch, to read the input on one phase; presumably intending to multiply the reading of this meter by $\sqrt{3}$ to obtain the total core loss of the transformer. This, of course, is not the correct method of taking wattmeter readings on three phase work, and as soon as the foreman in charge became aware of what was going on, he gave instructions to the man conducting the test to connect in a second wattmeter. This the tester did, opening up the outside lead for the current coil of the wattmeter (B) and connecting the potential coil to the potential transformer employed for the first wattmeter. In doing this a second mistake was made, more serious in its consequences than the first; for not only would the connections as made not give the proper readings on the wattmeter because of the incorrect phase relations between voltage and current, but as soon as the tester attempted to bring up the voltage of the transformer, there occurred a volcanic eruption through the cases of the wattmeters, directly in the face of the tester, that completely destroyed the instruments and so unnerved the tester that he was unable to continue with the test.

An inspection of the diagram will show that the insulation between the two coils of the wattmeter was all that separated the two phases in which the wattmeters were connected. On low voltage instruments this resistance, of course, is not intended to withstand high pressure and consequently broke down, short circuiting the phases and doing the damage already mentioned.

FACTORY

XIII. GROUNDED WINDINGS THROUGH CONDENSED STEAM

The short-circuit on an overhead transmission line, an account of which you published in the October number of the REVIEW, is interesting but certainly unusual. A case recently came to my notice of a short-circuit due to a defect in a motor, the points of similarity between this case and the other being that this was also brought about indirectly by the atmospheric conditions under which the motor was operating; and secondly, that it was equally effective in shutting down the whole system to which the motor was connected.

The machine in question was a 300 h.p. slip ring induction motor, and was operating in a factory where the use of steam was required in several of the manufacturing processes, and where the atmosphere in which the motor had to work was consequently pretty well charged with moisture, owing to the condensation of considerable quantities of escaping steam. At various intervals inspection of the core and winding of the motor would reveal the fact that they were covered with an appreciable coating of damp, owing to the condensation of steam on them. In conditions such as these, a coil winding in the stator will probably not be found to suffer from the presence of this dampness; but in the case of bar wound machines with unprotected bondings at the ends of the bars, the damp will collect and cause a path for leakage. If there is any weak spot in the winding, this may then cause a short-circuit of so many turns by grounding the winding at two points.

In the particular case under notice, there was considerable leakage from the bondings on the stator conductors along the damp to the core, and this caused the windings to become grounded at some other point by partially grounding another part of the circuit through the damp. The result was that a short-circuit occurred due to these two points becoming grounded. It was perhaps additionally unfortunate that the actual grounds should occur in the slots carrying the beginning coils of two different phases; so that in effect this amounted to a dead short-circuit across two of the incoming lines, and the system (which was comparatively a small one) was in consequence shut down.* The teeth of the stator core where these two grounds occurred were badly burned.

XIV. "FAULTY METHOD OF SOLDERING CABLES"

To the Editor of the GENERAL ELECTRIC REVIEW,

Dear Sir:

I am aware that the REVIEW is not a comic paper; indeed no one realizes more fully than I the necessity for the sustained effort which you are, I know, making to maintain the dignity and the high tone of the paper, the qualities in which it is, to my mind, pre-eminent. You will probably therefore feel a reluctance to lapse into levity even for a few moments; and yet I am asking you to publish this letter. For some months I have been in possession of the facts relating to a genuine electricity-in-mines comedy, facts which would bring a smile to the face of many an over-worked mine engineer; but I have been denied the means of giving these facts to the world. Your "Diary of a Test Man" has given me hope. More than once I have seemed to perceive, between the lines of the contributions there, a slight relaxation of the cast-iron law of deadly seriousness, and I am hoping there may be room for my simple narrative.

Down in the darkness of our mines there are men, trained in the rudiments of electrical knowledge, performing their share in the great scheme of electrical engineering. Engaged for the greater part of their time in tending electrical apparatus in one form or another, they are known by the name of electrician, wireman, and other terms. Lacking many of the essentials of greatness, they receive, as guerdon for their labors, little of fame, and not much of anything else except their weekly pay, which is commonly less than that of a vice-president, or even of a department head. And spending nearly all of their waking hours 1000 feet beneath the sod, their life is not one continual garden of roses. Such an one was the Spider, night wireman to the XYZ Iron & Coal Company.

I do not know why he was called the Spider. During the course of an acquaintance extending over several months, no clue was vouchsafed to me as to his real name, and hence I can only allude to him now as the Spider. He drank. I think there can be but little doubt that during the week-end he drank heavily. His reasons were plain and logical. What was there in his weekly round to afford him any joy, even any relief from the drab monotony? Nothing; and that would to many appear sufficient reason for his seeking a little bibulous exhilaration in the off-time. But I think this was only, after all, a secondary consideration with the Spider. Did he not owe it to himself, to his employers, to those in the mine depending on the electrical service, to fortify himself, during his leisure time, against the rigors and the hardships of his six nights' toil? Scoffers will object that, if he really wanted to carry out the fortifying idea, he was going about it in quite the wrong way. Water, they will say, would be quite strong enough; or at all events, warm milk, with possibly a slice of lemon. . . . . But who are we to judge him? Every man according to his lights.

On this particular Sunday night there was a cable-running job in an underground transformer house. I am not certain of the details, but I think there were two 300 kw. transformers to be connected to the switchboard 10 feet away, the high-tensions to the oil switches in the incoming feeder circuit, and the low tensions to the oil-switches on the distribution panels. The Spider arrived, descended into the darkness, and made a safe, but stormy passage to the transformer house. He had probably had an extra festive time during the previous thirty-six hours. His eye,

*In a well built machine, trouble of this kind would not occur. The remedy is to see that the ends of the conductors in bar-wound machines, operating in damp atmospheres, are covered in by being well taped-up and insulated with a moisture-proof varnish, to render them impervious to the moisture which will inevitably collect on the outside of the coils.

it is true, had not the glint of steel, nor his step the elasticity of a Greek athlete's; but his nose was a poem, and appeared as a Vision of Dawn.

The Spider had been baring cable-ends for some two hours before he discovered that he had left the pit-bottom office without possessing himself of either solder, soldering flux or insulating tape. Commonly he carried these accessories around with him in an evil-looking bag. This night he had none. To his great disgust it was borne in upon him that he would have to make the extra trip to the office to get them; which was annoying, as the way was dark and bestrewn with boulders, and the Spider's step was—well, too nautical, too all-embracing.

He got there somehow, not in good condition, muttering quite audibly. He found his solder, but for the life of him could discover no flux and no tape. In a short time he became convinced that there was neither flux nor tape in the place; and was preparing to navigate back to his job and sink his worries in sleep, when, right on top of the ambulance-chest, he espied the objects of his search. Sure enough there was the little tin of paste, about 3 inches in diameter, and a nice comfortable-looking reel of tape. Oh Spider, if you would but pause and think! At least pause, since thought in your present condition. . . . .

He was hasty; he could not stop to consider. With a husky cry of joy that at last his quest was successful, he plunged again into darkness. He soldered his leads. He finished his job. Day broke overhead.

That is the tale. The sequel, which is all explanation, is soon told. With the new day arrived a new set of men, refreshed with sleep, clear of eye and quick of discernment. The ambulance man was perhaps unusually quick of discernment. One glance at the top of the ambulance chest told him that some petty, thieving night-bird, with criminal intent, had wantonly stolen a new tin of priceless ointment, invaluable for burns, bruises, bumps, barber's rash, housemaid's knee and other ailments, and beautifully scented with fragrant lily of the valley; while the same thief had also purloined a brand new reel of antiseptic adhesive tape (the warmth of the hand is sufficient to make it adhere), the finest surgical application for lacerations, abrasions, contusions, hallucinations (. . . . . to the n+1). Having something of the sleuth in him (his father was a policeman) he put it up to the Spider. Our hero, brokenly, and with tears in his eyes, confessed that in a moment of temporary mental aberration . . . .

F. A., Detroit, Mich.

NOTE

The following men have recently entered the Testing Department of the General Electric Company:

Aspinwall, J., University of California
Baker, Guy State University, of Oklahoma
Bishop, R., University of Michigan
Blythe, W. E., Stevens Institute of Technology
Cayot, C. E., University of Kansas
Champlin, F. J., Yale University
Coulter, R. S., University of Missouri
Furtick, G. H., Clemson College
Glover, C. V. C., Georgia School of Technology
Hardin, L. H., Clemson College
Harris, W. C., Virginia Polytechnic Institute
Hoffman, H. A., University of Kansas
Humphrey, H. K., University of Illinois
Hyde, R. B., University of Nebraska
Ilgner, H. I., University of Wisconsin
Jeffrey, A. J., Virginia Polytechnic Institute
Keller, A. D., University of Wisconsin
Kline, C. H., Pennsylvania State College
Lawrence, B. F., Clemson College
Loubet, L. M., University of California
Lovell, C. G., Syracuse University
Milling, J. C., Clemson College
Montgomery, O. C., University of Nebraska
Morse, H. G., Worcester Polytechnic Institute
Murrish, W. U., University of Wisconsin
Olmsted, C. S., Syracuse University
Persons, J. T., Jr., University of Texas
Regan, H., Clarkson School of Technology
Shanklin, G. D., University of Kentucky
Smith, J. E., Cornell University
Smith, M. C., Virginia Polytechnic Institute
Spratt, W. C., Clemson College
Summer, H. N. Pennsylvania State College
Walton, Georgia School of Technology
Weil, L. S., Tulane University

The following instructors spent all or a large part of the summer in the Testing Department of the Schenectady Works:

Belsky, C. J., University of Wisconsin
Cady, H. R., University of Pennsylvania
Dickerson, H. S., Purdue University
Hehre, F. W., Columbia University
Magnusson, Prof. C. E., University of Washington
Miller, B. E., University of Wisconsin
Peach, P. L., Cornell University
Robbins, Iowa State College

CARYL D. HASKINS

As we go to press we learn with the deepest regret of the sudden death of Mr. Caryl D. Haskins, Manager of the Lighting Department of the General Electric Company. On November 6th Mr. Haskins left Schenectady on a three months' business tour in the west. While in Salt Lake City he was seized with an attack of pneumonia, from which he died on the morning of Saturday, November 18th. Mrs. Haskins and their young son were with Mr. Haskins at the time of his death.

Of great personal charm, Mr. Haskins was one of the most popular men in the General Electric Company; but, while his loss will be felt most keenly by the men with whom he came into daily contact, at the same time the whole of the electrical profession by his death suffers a great bereavement. He was widely known as the author of a number of standard books on electrical subjects, and as a lecturer on current electrical matters. Although only 44 years of age at the time of his death, there were probably few men better known throughout the industry in this country.

Mr. Haskins' connection with the General Electric Company dated from the time of its consolidation with the Thomson-Houston Electric Company, with which organization he had been connected since the latter part of 1889. He came to live in Schenectady in 1900, and it was in 1906 that he was appointed Manager of the Lighting Department, a position which he continued to occupy until the time of his death.

Both in his professional and private capacity, Mr. Haskins enjoyed a wide circle of acquaintances, by whom he was universally respected and admired; and the news of his sudden death will be received with the profoundest grief by all of his many friends.

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First Floor of Bonwit, Teller & Company, New York City. Illumination by Intensified Arc Lamps
(See Page 613)

GENERAL ELECTRIC REVIEW

ARC LIGHTING

The various departures of electrical activity have by now become so specialized that only with difficulty can engineers engaged in any one of these fields keep apace with what is going on in other lines of work with which they never come into active touch; and in their efforts to keep themselves posted, at least on the essentials, they must of necessity waste considerable time in sorting their available information, and in recognizing what are the essentials and what are merely details of passing interest. Arc lighting is but one of these many specialized fields. The present issue of the REVIEW should be of considerable service to those desirous of ascertaining what are the position and prospects of arc lighting at the end of 1911. The number has been prepared chiefly with a view to providing such a record; and in order to indicate in as brief space as possible the lines on which the survey has been laid out, these few editorial notes must serve an introduction.

The articles by Dr. Steinmetz and Professor Elihu Thomson really cover all the essential points with regard to the development of the last few years, and the prospects for the immediate future. Of recent years an idea that the arc lamp for exterior, as well as interior, illumination had not the possibilities of the metal filament incandescent lamp has met with a good deal of credence, and it is upon this point that many engineers are looking for authoritative information. The two articles we have referred to, coming from engineers of great reputation and indisputable authority, should carry considerable weight in showing that there is an almost limitless future before the arc lamp. More specifically, and in addition to such general considerations, Dr. Steinmetz's article indicates the essential difference between the modern high efficiency arcs and the earlier carbon lamp, differentiates between the luminous lamp and the flame arc, and indicates the proper field of application of these two lamps as determined by their operating characteristics.

These lamps are later dealt with in greater detail, as to their design, construction and characteristics. Special attention is directed to the luminous arc lamp as designed for decorative street lighting. This lamp is illustrated on the cover of this publication, as well as by a number of cuts with accompanying text in the body of the paper. The luminous lamp, as applied to headlight use on interurban and suburban cars, is also the subject of an article. The paper on flame lamps is followed by a description of the flame lamp installation on the Ambrose Channel Lightship, New York harbor, which is of unique interest as showing the weather-resisting properties of the lamp. The most noteworthy example of interior arc lighting to date, viz., the Bonwit, Teller & Company intensified arc lamp installation, New York City, is described in detail.

Considerable space is given in this issue to station apparatus used in arc lighting installations. Contributing industries have been created, such as the manufacture of constant current transformers for series arc lighting systems, and mercury arc rectifier outfits for converting alternating current to direct current supply for the direct current luminous lamp. These are part and parcel of the whole installation, and a practical review of arc lamp work would be incomplete without detailed reference to these devices. The theory of operation of the constant current transformer and the series rectifier are therefore discussed in some detail, while other articles deal with more practical points, such as design, installation and operation. An idea of the magnitude of the arc lamp business, as cared for by a single factory, may be obtained from the published description of the new arc lamp factory at the Lynn works.

ARC LIGHTING*

By Charles P. Steinmetz

As introduction the author touches upon various wave motions with which we are familiar; the field wave of the alternating current, the wireless telegraph wave, Hertzian waves, radiant heat, light and X-rays. Light, and the methods of producing light, are then considered. Luminescence, of which the flame arc and the luminous arc are the two exponents, is discussed. The differences of principle in these lamps are defined (page 570) as well as structural differences; and detailed attention is then paid to the essential characteristics of the two lamps and their bearing upon their proper field of application—Editor.

The first question, when discussing methods of illumination, is: "What is light?" Light is a vibration, or wave motion, which passes through space at the enormous speed of nearly 200,000 miles per second (3×10^{10} cm. per sec.).

There are many different kinds of wave motion. Sound is one, for instance. If we set a string in vibration, we can see these vibrations, if they are slow enough, i.e., a few per second. If now we increase the frequency of vibration, as by tightening and shortening the string, the eye ceases to distinguish them; but when we reach 30 beats per second, we begin to hear them, as a deep bass sound. Further increasing the frequency causes the tone to become more penetrating and higher and higher in pitch, until finally, at 4000 to 6000 vibrations per second, it again ceases, and the frequency is too high to be perceived by the ear as sound. Other vibrations are the water waves in the oceans and rivers, and the alternating currents in our transmission circuits, etc.

The alternating current, which runs motors or lights lamps, is a vibration or wave: during every cycle, the current first flows in one direction, then stops, reverses and flows in the opposite direction, then stops again and reverses back to the original direction. The current in the conductor, however, is not the only phenomenon; but with every half-wave of current and of voltage an electric field rushes out from the conductor into space, with the velocity of light, nearly 200,000 miles per second: a magnetic field, starting and reversing with the current, and an electrostatic field, starting and reversing with the voltage. In alternating current transmission, it is the current and the voltage in the conductor which are industrially used in supplying power; the electric field outside of the conductor is not used, and is usually observed only when it causes trouble, as for instance by disturbing adjacent telephone circuits, or when the electrostatic component of the field becomes strong enough to disrupt the insulation.

Inversely, in wireless telegraphy, the electric field of the current is used in transmitting the message. A high frequency alternating current, of some hundred thousand cycles per second, is sent into the antenna. From it there issues, with the velocity of light, an electric field, the wireless wave, and where this strikes another conductor, such as the receiving antenna, it induces a current in it: with sufficiently delicate measuring apparatus, this induced current can be perceived at a distance of hundreds of miles. In wireless telegraphy it is thus the electric field of the current in the conductor (the sending antenna), which is used, and not the current, as in alternating power transmission. As this electric field moves at the speed of light, about 200,000 miles per second, if the frequency of the current in the wireless sending antenna is 100,000 cycles, the field travels 2 miles during each cycle, that is, the wave length of the wireless wave is 2 miles. If the frequency is one million cycles, the wave length is $\frac{200,000}{1,000,000}$, or two-tenths miles, or about 1000 feet.

The frequencies used in our alternating current transmission and distribution circuits are low, 25 and 60 cycles per second; but higher frequencies often occur in such circuits, of thousands, hundreds of thousands, and even many millions of cycles per second. They are the result of disturbances, due to external causes, such as lightning, or due to internal causes, such as switching, arcing grounds, etc. High frequency currents are observed by bringing a conductor near them: the electric field of this high frequency current, that is, the high frequency electric wave, when impinging on the conductor (the "resonator" or "receiving antenna"), induces a current in it, which can be observed by a sufficiently sensitive apparatus. In this manner such electric waves, of hundreds of millions of cycles, have been observed and

* An address delivered before the Arc Lamp specialists of the General Electric Company at Lynn, September 7, 1911.

studied. They are frequently spoken of as "Hertzian waves."

When we come, however, to frequencies of hundred thousands, or millions of millions of cycles per second, this method of observing the electric wave fails, as can easily be seen; at a velocity of 200,000 miles per second, a wave of one million of millions of cycles (10^{12}) would during each cycle travel only a distance of $\frac{200,000}{10^{12}}$ miles, or 1/80 inch. That is, the wave length of an electric wave of one million of millions of cycles is 1/80 of an inch.† In the receiving conductor, a complete cycle (or two half-waves) would cover a space of 1/80 inch only, and the current would reverse in direction every 1/160 inch. That is, the receiving antenna is limited in length to 1/160 inch. Obviously, in such a short conductor, no matter how intense the wave, the induced voltage would be altogether too small for observation. However, even at frequencies of many millions of millions of cycles per second, we can still observe the electric wave, by interposing a conductor into the path of the wave. While the individual induced currents are too short to be perceived, their heating effect can be observed by a temperature rise of the conductor. Thus, if we hold our hand in the path of such a wave, we feel it as heat, and we therefore call such very high frequency waves "radiant heat."

Coming to still higher frequencies, finally, at several hundred millions of millions of cycles, the eye perceives these waves as light; and there is a fairly narrow range of frequencies, from about 400 to 700 millions of millions of cycles, in which the waves are visible to the eye, and therefore are called light. Still higher, at the extreme range of frequencies, of 10,000 millions of millions of cycles probably, are the X-rays, etc.

Thus, the electric field of the alternating current transmission line, the wireless telegraph wave, the Hertzian waves, the radiant heat, light and X-rays, are the same kind of wave or vibration, traveling through space at the same speed of nearly 200,000 miles per second, and differing from each other merely by their frequency and therefore their wave length, i.e., the distance traveled per cycle. The great range of frequencies, from 25 cycles to 10,000,000,000,000,000 cycles per second, requires different methods of observation: the alternating current instruments at low frequency, the wireless antenna or resonator, the heating effect, the eye within the visible range, and finally, at X-ray frequencies, the photographic plate. Equally different must also be the methods of production of the various frequencies. At low frequencies, alternating current generators are used. They become difficult of construction at a few hundred cycles, and impracticable beyond a few hundred thousands of cycles. Beyond this, up to hundreds of millions of cycles, the condenser discharge supplies the only means of producing the electric waves. Finally this becomes impracticable, as no condenser can be built small enough to give sufficiently high frequency in its discharge; and so in producing the extremely high frequencies of radiant heat and light, other methods become necessary.

Of foremost interest is that narrow range of electric wave frequencies, which is visible to the eye, and called light. Two methods exist of producing light: an indirect method, called "incandescence," and a more direct method, called "luminescence."

The Indirect Method of Producing Light—Incandescence

If we raise the temperature of a body by putting energy into it (chemical energy of combustion in the flame, electric energy in the incandescent lamp), finally a very small part of the energy is given out as radiation, of a frequency sufficiently high to be perceived by the eye; the body becomes visible, and we call it "incandescent." With increasing temperature, the percentage of the energy which is visible increases, that is, the efficiency of light production rises; but even at the highest temperature, where every existing material dissolves into vapor, and any further increase of temperature thus becomes impossible (the crater of the carbon arc), only a very small part of the energy (estimated as from 5 to 10 per cent.) appears as visible light, while most of it radiates at lower frequencies, as the so-called radiant heat. Thus the method of light production by incandescence is an indirect one: we produce heat, and indirectly, as a kind of by-product, a small amount of light. The cause of the very low efficiency is inherent in the nature of energy: heat energy is the lowest form of energy, and it is therefore easy to convert any form of energy practically completely into heat. But the conversion of heat energy into any other form of energy is always very inefficient; and wherever we pass through heat energy,

†For comparison: The wave length of 25 cycle alternating current would be $\frac{200,000}{25}$ or about 8000 miles.

as in the steam engine, the incandescent lamp, etc., we must be satisfied with low efficiencies.

Thus the efficiency of light production by heat is low, and is a function of the temperature; and the enormous development in this direction, which culminated in the modern tungsten lamp, has been essentially the development of the means of utilizing higher temperatures in the light-giving radiator. Thus from the candle flame or gas flame, with perhaps 0.1 to 0.2 per cent. efficiency, we have advanced to the gem lamp, which probably approached 1 per cent., and finally to the tungsten lamp, of about 2 per cent. efficiency. A gradual further advance in efficiency may undoubtedly be hoped for, and instead of 0.8 candles per watt, as in the present tungsten lamp, we may reach 1, $1\frac{1}{4}$ or even $1\frac{1}{2}$ candles per watt, by reaching to still higher temperatures and more selective radiation. However, the indirect character of the light production, with heat as an intermediary form of energy, precludes the possibility of ever reaching efficiencies comparable with those with which we are familiar in other energy transformations; that is, there is no hope of approaching the ideal 100 per cent. of efficiency—estimated at 50 to 100 candles per watt—in any future type of incandescent lamp.

The enclosed carbon arc lamp of old, which has for many years done the street lighting, and is only just beginning to give way to the luminous arc, is also an incandescent lamp. The light comes not from the arc flame, but from the incandescent crater of the positive carbon; and its relatively high efficiency is due to the high temperature of the crater (the highest existing temperature, the boiling point of carbon). Still its efficiency is limited in the same way, and not comparable with that of modern luminous arcs and flame arcs.

Direct Conversion of Electrical Energy into Light by Luminescence

In the flame arc and luminous arc lamp, electrical engineering has finally advanced beyond the crude method of producing light indirectly, as a by-product of heat. In neither of these lamps is the light a temperature effect; but we have a more direct conversion of electric energy into light, that is, "luminescence." The efficiency of light production thus is not limited by the temperature law of incandescence; theoretically there is no limit to the efficiency, and practically efficiencies have been reached far beyond those possible with temperature radiation. That the light of the flame arc and luminous arc is not a temperature effect, i.e., does not result from high temperature, is easily seen by comparing the luminous arc and the enclosed carbon arc: the efficiency of light production of the former is much higher, and nevertheless its temperature is only about half that of the latter.

In the flame arc and the luminous arc, the light is given by the arc flame, that is, by the vapor stream which conducts the current across the gap between the terminals, and not by the tips of the terminals, as in the carbon arc of old. Otherwise, however, there is an essential difference between the two classes of high efficiency arcs, the flame arc and the luminous arc, which is not always realized.

The Essential Difference Between the Flame Arc and the Luminous Arc

The flame arc is a *carbon arc*, that is, the current is conducted across the gap between the electrodes by a stream of carbon vapor, just as in the earlier carbon arc. This carbon vapor stream is made luminous and light-giving, by introducing into it mineral compounds, mostly calcium salts. These light-giving compounds are introduced by *heat evaporation* from the electrode, by using carbons impregnated or mixed with such compounds—"flame carbons." As the positive terminal is the hotter one, evaporation from it is more rapid, and it is more efficient in feeding the light-giving mineral matter to the arc flame. Therefore in the flame arc, the *positive electrode* must always be a flame carbon, while as negative electrode a plain carbon may be used, or a less heavily impregnated flame carbon. In alternating flame arcs, in which alternately each electrode becomes positive, usually both carbons are flame carbons. Thus in the flame arc, the light-giving material is not the conductor of the current; the conductor is carbon vapor.

In the luminous arc, the light-giving material is used as the vapor conductor. As carbon vapor does not give any light, carbon is not used, and is objectionable, and iron and titanium compounds are the materials most commonly used in the luminous arc. Since the vapor stream or arc conductor issues from the negative, when using the light-giving material as arc conductor, it is fed into the arc from the negative terminal.

That is, in the luminous arc the *negative electrode* material gives the light and the efficiency, and the positive electrode is immaterial, usually made non-consuming by giving it a size large enough to keep cool.

Thus, the flame arc owes its luminosity and efficiency to heat evaporation of the light-giving material from the positive, the luminous arc to electro-conduction of the light-giving material from the negative electrode; the former being a colored carbon arc, the latter a luminous metal arc.

The Bearing of the Lamp's Characteristics on Its Proper Field of Application

It is important to realize this difference in the nature of the two classes of high efficiency arcs, since on it depend the characteristics of the arc lamps, which determine their proper field of application; and in electric lighting more possibly than in most other applications of electric power, the success of an installation essentially depends on the use of the proper apparatus in the proper place. To realize what is the proper field of application of the flame lamp, and what of the luminous arc lamp, the tungsten lamp, etc., their nature and characteristics must be understood. No matter how valuable and useful an illuminant may be, it still may be a failure when installed at a place and under conditions to which it is not fitted. While often the users of illuminants have strong preferences for the one or the other type, and while this makes it necessary to supply a type of lamp for conditions to which it is not so well suited as some other type, all efforts should be made, in order to secure satisfaction of the user, to convert him to the use of that type of lamp which is best suited to his conditions.

In the flame arc, the light-giving material is fed into the arc flame by heat evaporation, and the amount of light-giving material, and thereby the efficiency, depends upon the temperature of the carbon tips. At lower currents, the lesser heating of the carbon terminals causes a rapid falling off of the efficiency; or the size of the carbons has to be greatly reduced and their life thereby sacrificed. The flame arc thus is best in large units of light: it enables us to get many times more light from the same power, but does not enable us to get the same light as the enclosed carbon arc with much less power.

Arc Lamps for Street Lighting

This materially limits its usefulness in street lighting. Probably in 80 to 90 per cent. of all street lighting, the enclosed carbon arc has been an entirely satisfactory unit of light. While a moderate increase of light, of 50 to 100 per cent., would be appreciated, no great benefit would result from a five-fold or ten-fold increase of light; and if the latter had to be paid for by an increased cost of operation, it would rarely be economical. However, replacing the enclosed carbon arc by the flame arc of equal power consumption necessarily increases the cost of operation, due to the higher cost of carbons. Thus, in most cases, the improvement desired in street lighting is a moderate increase of light, with a material reduction in power consumption and cost of trimming, that is, a material reduction in operating cost.

To this field the flame arc is less suited than the luminous arc. In the latter the light-giving material is fed into the flame by the electric current; the amount of light-giving material, and with it the efficiency, does not depend on the temperature of the terminals, and hence does not fall off as rapidly with decrease of current. This makes the luminous arc more suited than the flame arc for the development of low-power lighting units, as required by economical consideration in most cases of street lighting.

The flame arc is a carbon arc, and the life of the carbons is short, if air is admitted. Thus the flame arc lamp, which has been extensively used for decorative and display lighting in this country, is a short-burning arc lamp, requiring frequent trimming. This has excluded this type of lamp entirely from street lighting in this country. To get long life of the flame carbons, the arc has to be enclosed. In this manner, in the modern long-burning or enclosed flame lamp, a life of carbons of 70 to 100 hours is reached. However, unlike the ordinary enclosed carbon arc lamp, in the enclosed flame carbon lamp mere enclosure of the arc is not sufficient; since the light-giving materials are solids and are deposited as a smoke after passing through the arc. The lamp must therefore contain an effective air-circulating system, whereby the smoke is carried away from the lamp globe and deposited in some form of condensing chamber.

One of the difficulties with the long-burning flame arc lamp has been the development of suitable carbons. The short-burning flame carbon in an enclosed lamp loses in efficiency. With the decrease of the carbon consumption, the amount of mineral matter fed into the arc flame, and with it the efficiency, also decreases. Enclosed flame carbons therefore, to give as good efficiency as the short-burning flame carbons, must contain more mineral matter. Too large a percentage of mineral matter, however, tends to the formation of non-conducting slag and thereby causes sticking or failure to start; and the enclosed flame carbon thus required some development different from the open flame carbon.

On the other hand, in the luminous arc, the absence of carbon permits the use of electrode materials, such as metallic oxides, which are not combustible, and the luminous arc thus is a long-burning open arc; that is, with free access of the air, a life of 100 to 200 hours and more is feasible. The absence of any air-tight enclosure makes the trimming and tending of the luminous arc lamp simpler; and especially in street lighting, where the lamps usually are not given any special care, this is a material advantage.

The color of the flame arc is yellow, as the only materials which give high efficiency to the flame arc are calcium compounds (lime), and their color is yellow. White flame carbons are being manufactured, but are so inferior in efficiency that they are little used; and a white flame carbon, comparable in efficiency with the yellow flame carbon, has not yet been developed. As regards the luminous arc, in the titanium compounds materials have been found which give a highly efficient white light, and luminous arc electrodes thus always are made to give white light. The physiological inefficiency of the yellow color of the light under the usual street lighting conditions should exclude the flame lamp from this use, as long as white flame carbons are non-existing. Inversely, the yellow color of the flame arc gives it, when seen from a short distance, a glare, which a white light of the same intensity does not show. The yellow light of the flame arc is therefore superior to the white light of the luminous arc for decorative and display lighting, as in front of stores, etc., where only the short distance effect is considered. At high intensities, as for instance when seen from a short distance, a yellow light appears far brighter than a white light of the same intensity; while at low intensities, as from a long distance, the white light appears brighter than a yellow light of the same and even of higher intensity. This can nicely be observed on streets illuminated by the enclosed carbon arcs of old and a few decorative yellow flame arcs: from near-by, the white carbon arcs appear to give very little light compared with the much more powerful yellow flame arcs; yet when looking at the same street from a long distance, the white carbon arcs stand out as prominently as the yellow flame arcs, or even more so, though the latter may give from five to ten times as much light. Most American street lighting, from economic necessity, must be low intensity lighting. The relatively large areas covered by American cities, and the practice of using the same class of illuminant for the suburbs as for the centers of the cities, requires an arc illumination of a far greater mileage of streets per thousand population, than is the case, for instance, in European cities; and the use of high intensity lighting units, such as high power flame lamps, in this case would make the cost of street illumination prohibitive except under special conditions, as in large densely-populated cities. With the low intensity of street illumination, required by the large mileage of streets of American cities, white light is required to give a reasonable apparent brightness, while the yellow light would appear dull and inferior. This makes the yellow flame lamp inferior to the luminous arc for general street lighting, even if a sufficiently small power flame lamp unit existed.*

The luminous arc, as a metal arc, is inherently less steady than the flame arc, which is a carbon arc; that is, it exhibits greater and more sudden fluctuations of arc resistance. The reason of this is the lower temperature of the metal arc. The conductor which carries the current across the gap between the terminals, is a vapor stream of electrode material, of the temperature of the boiling point of that material. Naturally in such an extremely hot vapor stream surrounded by air, even when carefully enclosed and with well controlled air draft, minor variations of the mass of vapor, and therefore of its resistance, must continually occur, and show in the luminous arc as fluctuations of voltage at constant current, or as fluctuations of current at constant voltage. In the carbon arc, the temperature of the vapor stream—the boiling point of carbon, about 3700 deg. C.,—is so high that the air and everything becomes conducting, and as a result, variations of the amount of carbon vapor do not give proportionally large variations of arc resistance; while this is

* In European cities, the conditions are different, and arc lighting of streets is extensively used only in the interior of the cities, while the suburbs are left to gas lighting. In this case, a very high intensity of illumination is economically possible in the limited area in which arcs are installed, and the flame lamp is thus extensively used.

what occurs in the metal arc, which has a lower temperature—about 2000 deg. C.— at which the air is non-conducting. The result is that at steady operation—that is, when giving practically constant volume of light—the voltage fluctuations of the luminous arc are greater and more rapid than in the flame arc. In consequence thereof, the design of a satisfactory luminous arc for limited supply voltage, that is, for a 110 volt multiple circuit, is far more difficult than that of a flame arc, and the latter therefore has a decided advantage for multiple distribution. This advantage does not exist in series, or constant current circuits, as the voltage fluctuations of individual lamps overlap and equalize in the number of series connected lamps. Thus the luminous arc lamp is at its best as a series lamp, or in constant current circuits, and the flame arc lamp as a multiple lamp, or in constant potential circuits.

Closeness of Automatic *Voltage* Regulation *not* the Criterion of Steadiness of Light

This inherent fluctuation of the arc is the reason why the luminous arc requires a different regulating mechanism from that of the enclosed carbon arc of old. In the latter, by a floating system of control, the arc length is continuously varied with the variation of the arc resistance, and thereby approximately constant voltage at the lamp terminals maintained. As the light of the carbon arc comes from its incandescent terminals, and the arc stream gives no light, the variation of the arc length has no appreciable effect on the volume of light. In the luminous arc, however (and also in the flame arc), the light comes from the arc stream, and any variation of the length of the arc stream would correspondingly vary the amount of light. Thus the control in the luminous arc lamp required to give constant volume of light must be such as to maintain constant arc length, irrespective of the fluctuations of arc resistance. An attempt at regulating a luminous arc for constant lamp voltage, by varying the arc length with the variation of the arc resistance, would thus cause a variation of the light, that is, would impair the steadiness of the lamp. Thus the voltage regulation curve of an arc lamp is no indication of the steadiness of the light; but, on the contrary, with metal arcs a close voltage regulation at the lamp terminals would in general result in a poor regulation of the volume of the light. Where, therefore, in such lamps a floating system of control is used, as is necessitated by the limited supply voltage in the constant potential magnetite lamp, and as is employed in many flame lamps, the amount and the rapidity of the variation of arc length, brought about by the control mechanism, is reduced as much as possible, so as to cause the least impairment of the steadiness of the light. This difference in the light-giving radiator, and the resulting difference in the required control for steadiness of the light, is not always realized, but is rather important.

From the differences in the nature and character of the flame arc and the luminous arc, and other illuminants, such as the tungsten lamp, follow the differences in their proper field of application. These probably can be best realized by considering some of the main applications of arc lamps.

In this respect, however, we must be careful to see the real proportion of things, and this is not always easy. A special case, under special conditions of application, may lead to the use of a special type of lamp. Such a special installation naturally must be given much more attention by the engineers, than the standard type of installation, which does the work all over the country. The special installation is discussed and described in the engineering papers. Outsiders, and even the engineers themselves, are then very liable to consider such a lamp, which was adapted to an exceptional application, as important as, or even more important than, the standard type, which is devised for, and fits, the majority of conditions of illumination. To illustrate this: A large city desired, and could afford, a very high grade high power illumination, and for this, the 6.6 ampere luminous lamp was developed. It is used in this city and a few other places, where exceptionally high grade lighting is economically feasible. It has been described and discussed so much that to most engineers this 6.6-ampere luminous arc lamp appears perhaps more important in the lighting field than the standard 4-ampere lamp. We must realize, however, that for every 6.6-ampere magnetite lamp which is being used, probably half-a-dozen or more 4-ampere lamps are installed, as the smaller unit is far more suited to the average conditions of street lighting. We must therefore guard against over-estimating the importance of special, and therefore much-discussed, types in comparison with the standard types, which are little discussed since their use and usefulness is obvious.

Now as regards the tungsten incandescent lamp, it probably can be safely stated that it is so greatly inferior in efficiency to the luminous arc and the flame arc*, that where efficiency of light production is of any consideration, there is no excuse for using tungsten lamps, where luminous or flame arc lamps can be used.

The Application of Various Illuminants to the Seven Main Fields of Artificial Lighting

a. *General street lighting.*

This is by far the largest field of application of arc lamps. Probably 80 to 90 per cent. of all street lighting is in districts where the population density is not such as to economically permit a high intensity of illumination, and a relatively low intensity is economically necessary. This field has been fairly well satisfied by the series enclosed alternating arc lamp, and economical advance lies in the direction of a moderate increase of illumination—50 to 100 per cent.—with a material decrease of cost. The low intensity of illumination requires white light; and the only illuminant which can rationally be considered for this field, is the 300 watt luminous arc, that is, the 4-ampere magnetite lamp. The flame lamp, which gives a very great increase of light, with a moderate increase of cost, is usually unsuitable, as the great increase of light is not sufficient compensation for the increase of cost, and the yellow color of the light further handicaps the lamp in this application. The tungsten lamp is too inefficient for use: to give the same amount of light as the magnetite lamp, would require an excessive cost of power, and still would, due to the yellow color, not give the same appearance of brightness as the luminous arc.

b. *Special high intensity high grade street lighting* in those cases, such as the interior of large cities, where the population density warrants a higher cost of illumination.

This field is shared by the 6.6-ampere luminous arc and the series flame arc. The former has the advantage of greater steadiness and of white light; the latter is yellow, but has the advantage of greater efficiency and of operation on alternating current circuits, while the luminous arc is a direct current lamp, operating from mercury arc rectifier circuits. In this class of lighting, the tungsten lamp also finds an application, in lamp clusters on ornamental posts. Although giving only a small fraction of the light, with the same power, as the luminous arc or flame arc, yet through the ornamental character of tungsten post lighting, the perfect steadiness of the light, and the use of moderate sized units at short distances from each other, a good illumination is secured.

In this application the intensity of illumination is so high that the yellow color of the light is physiologically not the serious objection that it is with low intensity general street lighting.

c. *Very low intensity road lighting*, as in villages, country roads, etc. Here even the luminous arc is too large a unit of power to be considered, and the only illuminant which comes into consideration is the tungsten incandescent lamp, in 40 to 100 watt units.

d. *Multiple or constant potential street lighting* as it exists in a few large cities. Here the flame lamp as well as the constant potential magnetite lamp is available. The former has the disadvantage of yellow color, while the latter is difficult to design with sufficient steadiness and efficiency, and the development of really efficient white flame carbons would naturally turn this entire field over to the flame lamp.

e. *Decorative and display lighting.* This is usually on constant potential, and the flame lamp is thus at an advantage in steadiness. Furthermore, the yellow color of the flame lamp in this field has the advantage of being more conspicuous and attracting attention, especially if the general illumination is by white light. This field therefore has been, and justly is, exclusively covered by the high power yellow flame lamp.

f. *Indoor lighting.* For high class indoor lighting, as dry-goods stores, etc., neither the luminous arc nor the flame arc is suited, since neither is perfectly free from contaminating the atmosphere. The intensified arc and the tungsten lamp thus are the illuminants covering this field. In factories, machine shops, foundries, etc., the above objection does not apply; and the higher efficiency gives the advantage to the luminous arc and flame arc. Where the lighting is on a series circuit, the white light would give the advantage to the luminous arc lamp. When, as is usual, the indoor lighting is on multiple circuit, 110 or 220 volts, the flame arc has the advantage of greater steadiness, while the luminous arc lamp must be used where the color distortion caused by the yellow color of the flame arc is objectionable,

* 0.8 horizontal candle-power per watt in the tungsten incandescent lamp; 2 to 3 candle-power per watt in the luminous arc lamp; 3 to 5 candle-power per watt in the yellow flame arc lamp

as in distinguishing metals in a machine shop, etc. The development of an efficient white flame carbon thus would turn this field also over to the flame lamp.

In concluding by speculating on the future, the two developments which are most needed now in the further improvement of arc lighting are:

The development of a series alternating luminous arc, which, at a low power consumption, could replace, on existing alternating arc circuits, the series enclosed alternating carbon lamp, and would give a material increase of light at a material decrease of operating cost; and

The development of a white flame carbon, comparable in efficiency with the yellow flame carbon, as such a white flame carbon would probably turn all the multiple or constant potential arc lighting over to the flame lamp.

THE ELECTRIC ARC AND LIGHTING BY ARCS

By Professor Elihu Thomson

Describes the phenomena which accompany an electric discharge through various degrees of vacuum and shows that the true electric arc can form at pressures far below that of the atmosphere. Mentions the great increase in efficiency which has been obtainable from the latter-day arc lamps with luminous arc stream; and indicates the probable course of further improvement with regard to color values.—Editor.

When electricity passes through gases, the discharge or current takes on characteristics depending on the density of the gas or vapor, its nature, and the peculiarities of the current or discharge.

With the very highest vacua it appears to be impossible to cause a discharge to pass, and it is probably true that in a perfect vacuum, if such were possible, no potential however high would overcome the insulation given by the vacuum. Hence it follows that the only non-puncturable insulation layer is a layer of absolute vacuum. The vacuum is, of course, no bar to static or magnetic induction.

In the highest vacua available electric discharges only take place at great potential differences, and then have a character which indicates a resistance so high that only a small current can be passed. At a still lower condition of vacuum, say one one-millionth of an atmosphere, the phenomena of radiant matter of the Crookes' and Roentgen ray tube are manifested. There is under these conditions no possibility of the formation of an electric arc discharge between the electrodes. The chief phenomenon is the projection, at very high velocities, of electrons constituting the stream of cathode rays, which can be deflected by a magnetic field or an electrified body (electrostatic field).

In the Roentgen ray tube the condition of highest vacuum, which demands potentials of 100,000 volts or more to cause any current to pass, is that which gives X-rays of greatest penetrating power, and the tube is called hard; while at a lower vacuum and lower potential the rays which get outside the glass walls are not so penetrating, being absorbed almost totally by moderate thicknesses of skin or tissue, and becoming thereby exceedingly dangerous.

The cathode rays or showers of electrons moving at very high velocities in a Crookes tube are powerful excitants of fluorescence in many substances exposed to them, and readily effect chemical decompositions. In such a tube, when the cathode rays are focussed by a concave cathode upon the so-called target, the energy of the discharge may easily be so great as to heat to intense whiteness in a second or two considerable masses of platinum or iridium, melting them down like wax in a candle flame.

The phenomena just alluded to suggest nothing akin to the arc, so called. Even when the vacuum is further lowered there is still little resemblance to the ordinary arc flame, for the luminous glow now fills the interior of the vessel and its intrinsic brilliancy is low compared with that of the true arc stream. Still we have now reached a state in which it is rather dependent on circuit conditions, whether we may have an arc or not. If the conditions are such that the negative electrode can furnish an unlimited supply of ions, and the potential at the terminals of the tube is maintained during increase of current, then as in the mercury arc, a small preliminary or initial discharge is at once followed by the establishment of a characteristic arc which, as with mercury and all true arcs, has a falling resistance with increase of current, and is therefore unstable, needing on constant potential circuits a steadying resistance in series with it. On a constant current circuit the arc formed is limited by the value of the current supplied.

From what has been said it will be seen that true arcs can form at pressures far below the atmosphere. In such cases the arc stream between the electrodes either fills the enclosure very nearly or exists as a diffuse luminous stream, neither so hot nor so luminous as is the case when the pressure of the gas or vapor is greater.

At the ordinary atmospheric pressure, the energetic movements of the ions, the increased rate of collision, the concentration of the stream conveying the current, and the diminished length of arc stream for any given potential between the electrodes, gives us a focus of heat, so to speak; a gas stream at an exceedingly high temperature. At pressures higher than that of the atmosphere the arc in a gas becomes still more dense or contracted, more highly luminous, and demands increasing potentials to maintain arcs of any given length.

It is interesting to note here that the sudden discharge of a condenser, or spark discharge, attended by a very sharp crack or report, is a stream of a very high intrinsic brilliancy, much more brilliant in fact than the ordinary hot gas constituting the arc stream between two separated electrodes. Still, such sudden condenser discharge is in reality a momentary arc—a hot stream of gas of exceedingly short duration. Why then is it so very brilliant? The answer is probably that although it is formed in air at ordinary pressures the extreme suddenness and high temperature causes the discharge to take place under a pressure of many atmospheres, owing to the inertia of the air around. The sharp crack is an evidence of that fact, and as Prof. R. W. Wood has shown and even photographed, there is a very intense and short wave of compression sent out in all directions from the spark. This can only originate in a sudden and violent pressure at the spark, as if a fulminating cap had been exploded there.

Formerly when an electric arc was referred to, the carbon arc was meant unless there was some particular reference to other materials for the electrodes. Arc lighting began with the open carbon arc, and while metallic arcs were well known, their occurrence was generally something abnormal, such as arcing at switches, across insulation, or the like. In the past ten years not only has the carbon arc been greatly modified by the introduction of refractory materials into the carbon electrodes, but the electrodes themselves may be without carbon, as in the case of the magnetite arc. The result of these developments has been to make the chief source of light the arc stream itself, loaded with fine particles at an exceedingly high temperature—particles which from some property akin to luminescence enhance the the light giving power of the arc and greatly increase the efficiency obtainable. In the carbon arc, as is well known, the chief source of light was the highly heated carbon positive; the positive crater.

Looking back over the past developments in the art it at first seems somewhat singular that the carbon arc, open and enclosed, continuous current and alternating, held its place for so long a period. It is probably to be explained by the attention of engineers being diverted into such fields as electric railways, alternating current distribution, motor applications, and the many others which opened one after the other in a more or less unbroken series. And it is significant that only after this pioneer work had been accomplished, was much attention given to the improvement of efficiencies of the lights or lamps, both arc and incandescent. It is easily recalled that as far back as twenty-five years ago there were not wanting prophets who were willing to predict the gradual extinction of arc lighting by the spread of incandescent work. So long as the electric arc remains much more efficient in the utilization of energy for light than any other means of artificial illumination, it is likely to maintain its position as the ideal source for large spaces. In the forms of luminous flame arcs now in use, the color of the light varies considerably, depending on the materials which are used in the electrodes and which, when highly heated, emit the light of the arc. There can be no question, however, that the ultimate survival will be a white light like that of the sun, assuming approximately the same efficiencies to be attainable as in the case of the arcs more or less colored. A ruddy light of high intensity is particularly bad for the eyesight. The red rays represent far more energy for a given intensity than green or blue, and it seems to be a fact that injury and strain of eyes depends in some measure at least on the total energy absorbed at the retinal surface. It is nevertheless curious to notice at times the selection of orange colored glasses by persons with weak eyes, in preference to green or blue, which latter cut off the harmful red rays.

The improvement in incandescent lamps due to the introduction of tungsten filaments instead of carbon is not alone one of efficiency, or getting more light for the same energy. There is also the gain in beneficial effect, due to the lessened relative proportion of red rays present, and the close approximation to daylight. In the same way the forms of luminous arc which will eventually be available generally, will not only keep the extraordinary efficiencies which have been attained, but there will be no fault to find with the light on account of its color value.

Sometimes the efficiency of a scheme of illumination is neutralized by concealing the light sources, and reflecting the rays from ceilings that at best diffuse only a moderate percentage of the rays, and the surface of which soon deteriorates. Too much stress has often been laid on eye injury from bright light sources in the field of view. The fact is that our most enjoyable weather out of doors is when the sun shines and not when clouds or fogs deaden the aspect of things. What luminous source has a tithe of the intensity of the sun? Moreover, shadows add to the visibility of objects and should be tempered, not avoided. Spaces in which the light sources are seen, are alive and cheerful, akin to the open sky with the sun shining, or the moon and stars at night; while, where the sources of light are concealed, there is a cheerless or deadened appearance, as when the sky is overcast. The thing to avoid is the placing of strong lights too low down so as to be in the near range of vision of an observer. The brighter the light source the higher it should be hung so as to avoid inconvenience and to scatter the light.

Concerning arc lamp mechanism, the principles of operation separating the electrodes and feeding them as consumed — remain the same as in the early lamps. Such modifications in construction as are needed, owing to greater arc length, extra size and weight of electrodes, and the like, have changed the general structure and made it more unwieldy as compared with former structures, and the disposal of smoke or fumes from the luminous arcs has introduced new elements in the working out of a design. In the early days of arc lighting but little attention was given to neat design in methods of support or hanging of lamps, although many of us realized the desirability of better methods, which fortunately characterize much of the work of present day arc lighting.

Those whose memories take them back to city streets lighted only by occasional oil or flame gas lamps, of a few candle-power each, can realize what a revolution, or better, evolution, street lighting has undergone owing to the development of electric arc lamps. So much is this stimulus due to the electric arc, that improved forms of gas mantle lamps, even in these latter years, have been called by such names as gas *arcs*, and the appearance of the lamp itself has been made to approximate that of an electric arc lamp. Imitation of this kind is the best recognition of the preeminence of the arc for lighting large spaces; a position which it will doubtless hold for an indefinite future period.

THE DESIGN OF LUMINOUS ARC LAMPS

By C. A. B. Halvorson, Jr.
Designing Engineer, Arc Lamp Department, Lynn

This article points out some of the most important fundamental features embodied in the design of the luminous arc lamp, and discusses the advantages accruing from the adopted arrangement of the electrodes, their peculiar composition, and their specific polarities. The article includes a description of the latest types of luminous arc lamps, for both general and ornamental street illumination.—Editor.

Since the installation of the first circuit of series luminous arc lamps at Schenectady in the spring of 1903, no radical departure from the early principles of design has been found necessary. However, marked improvements in the electrodes have been made, resulting first in increased efficiency and greater steadiness of the arc, and second, in simplification and improvement in the lamp mechanism.

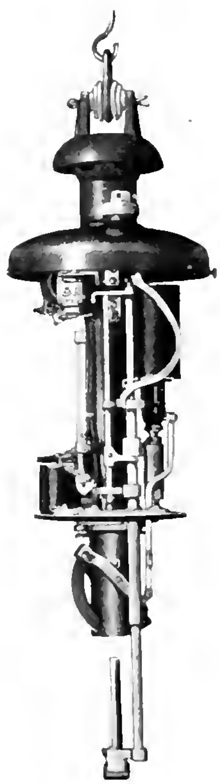

Fig. 1. Early Type of Luminous Arc Lamp

Before any principles of lamp design could be established, it was found necessary to do a vast amount of research and experimental work on the electrodes and arc, because practically nothing was known of the characteristics of the metallic arc up to that period immediately preceding the exploitation of the luminous arc lamp in 1903.

The early model of luminous arc lamp, shown in Fig. 1, embodied a number of fundamental features and principles of design, among which may be mentioned the following:

First: The magnetite electrode which determines the characteristics of the arc—the negative or lower of a vertical electrode combination.

The characteristics of any metallic arc are determined by the negative electrode material which is liberated by the current, and which in the case of a magnetite arc issues from a molten pool on the tip of the electrode in the form of a blast and forms the arc conductor *A*, (Fig. 2).* It is intensely brilliant and bluish white in color, and is surrounded by a concentric envelope *B* of solid particles which appear as a luminous flame, yellowish in color. This flame is surrounded in turn by a rapidly ascending

Fig. 2. Normal Arc of the Luminous Lamp

* These phenomena are dealt with more fully in "Radiation, Light and Illumination," by Dr. C. P. Steinmetz.

current of air *C*, indicated by the arrow, which is largely responsible for the characteristic shape of the arc structure as a whole, viz., that of an inverted cone.

In order to appreciate the part played by the heated current of air *C* in the formation of the magnetite arc, reference should be made to Fig. 3, in which the position of the electrodes has been reversed; the magnetite electrode, which is negative in polarity, being the upper, and the copper electrode, which is positive, being the lower. *A* is the vaporized negative material, which in Fig. 2 forms the arc conductor throughout the entire length of the space between the electrode tips, but here performs that function through only a part of the arc stream; the remainder *H* being formed from the positive copper electrode by heat evaporation and imparting a green copper color to the arc. In this case the negative electrode material is carried outwardly and up by means of the current of heated air *C*, the greater part of vaporized negative material joining the envelope *B* to form a wide sweeping luminous flame *D* of much lower brilliancy than *A*, the total output of light being very much less than that

Fig. 3. Luminous Arc with Electrodes Inverted

obtained with the electrodes arranged as shown in Fig. 2. Furthermore, the potential drop across the inverted arc is greater than that across the normal arc, assuming the same current consumption and an equal distance between electrodes in each combination.

Since the arc conductor issues from a pool of molten metal, it is obvious that,

Fig. 4. Luminous Arc with Reversed Polarity of Electrodes

when using the same electrode in both cases, the entire volume of heat generated by the arc in the inverted position passes over the tip of the negative electrode, making it hotter and more fluid than is the case when the negative electrode is arranged below the arc, as shown in Fig. 2, where the ascending currents of air *C* tend to cool it. Moreover, the negative spot travels around faster with an increase in the fluid surface, and therefore flickering is more apt to result from the inverted arc (Fig. 3.) In commercial magnetite electrodes, the fluidity of the negative electrode tip has been greatly reduced by the addition of certain refractory materials, but as these do not add to the brilliancy of the arc, the use of large amounts is detrimental. Consequently, in order to reduce the fluidity of the inverted electrode to that of an electrode in the normal position, the efficiency of the inverted arc must be lower.

The photographs, Figs. 4 and 5, are of interest as showing the characteristics of the arc formed between the same electrode combinations used for the arcs of Figs. 2

and 3, respectively, but with the current reversed, the copper in both cases being the negative electrode and the one determining the light-giving characteristics of the arc.

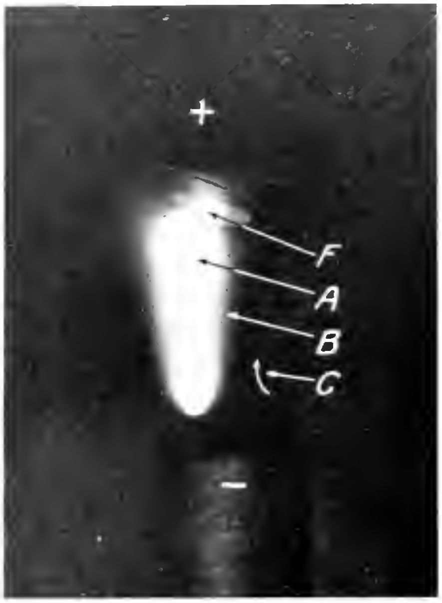

Fig. 5. Luminous Arc with Electrodes Inverted and Polarities Reversed

These arcs are lacking in brilliancy and show the well-known yellowish green copper light and some of the more volatile components of the magnetite electrode, which gain admittance to the arc by heat evaporation, but which do not, under this method of operation, increase the brilliancy of the arc. The amount of vapor in these arcs seems to depend largely upon the temperature of the electrode, that is, upon the size of the electrode for a given amount of energy consumed at the arc.

From the foregoing it is obvious that the logical arrangement of the electrodes for the production of the commercial magnetite arc is that shown in Fig. 2. As the arc is formed naturally, all forces external to the arc assisting, it follows that greater efficiency and less coloring of the spectrum from the positive electrode, and less flickering due to the fluidity of the negative electrode, accrue from this arrangement.

Second: For commercial reasons a positive electrode of copper sufficiently large to be practically non-consumable by oxidation or combustion.

In its present commercial form, the positive electrode of this arc consists of copper rod of such diameter that its surface acts as a baffle to the rapidly ascending vapor currents, deflecting them sharply and thereby exerting a steadying influence on the arc.

In addition to this steadying effect obtained by means of convection currents, there is some steadying accomplished by the formation of minute metallic drops on the surface of the positive electrode. These are condensed from the metallic vapor in the core of the arc and tend to anchor it (Fig. 6), in addition to supplying by heat evaporation some material to the arc stream, thus preventing oxidation or heat evaporation of the face of the copper.

Third: Electrodes apart on starting the lamp mechanism.

Since the vapor is liberated from a pool of molten metal, the electrodes must be kept apart when the current is cut off from the lamp, otherwise the electrodes might "freeze" together. Furthermore, as the surfaces of the electrodes are not first-class conductors when cold, it is desirable to bring them into forcible contact in order to insure satisfactory starting.

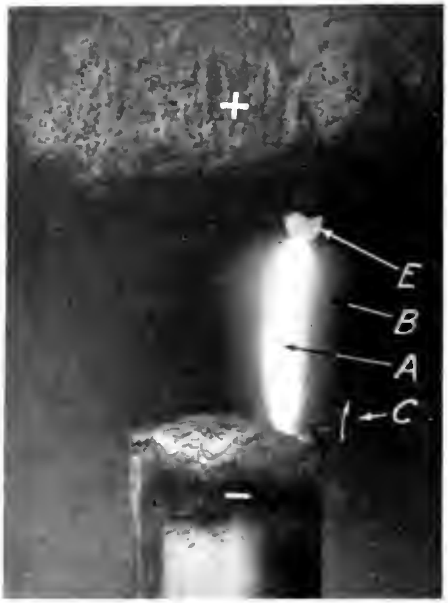

Fig. 6. Luminous Arc Showing Formation of Minute Metallic Drop on Surface of Positive Electrode

Fourth: The arc length mechanically fixed at every feeding operation of the lamp mechanism.

In the case of the magnetite arc, the light is given off by the arc stream. The electrodes are maintained at a low temperature and give off no visible radiations, differing in this respect from the carbon arc, in which the light is given off by the incandescent carbon tips, very little coming from the arc stream. It follows, therefore, that at a given current consumption the intensity of the luminous arc depends upon its length, and as an arc of this character is inclined to vary more or less in resistance, it is evident that to give constant light the electrodes must remain stationary after the arc is struck.

Fifth: A central chimney for disposing of the smoke from the arc and forming the backbone of the lamp structure.

The production of light by the magnetite arc is accompanied by some smoke, which, if permitted to condense on the globe, would soon give it a dirty appearance. It is therefore necessary to provide means for removing the products of combustion from the vicinity of the arc and electrodes. Since, as has been shown, these vapors are carried upward by the natural convection currents, a central chimney A, (Fig. 7), with its lower opening surrounding the positive electrode, supplies the simplest means of disposing of these fumes. As the arc is formed naturally, variations in velocity of external air currents do not greatly affect it.

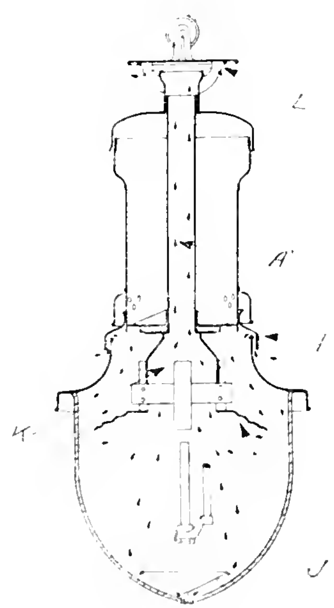

Fig. 7. Diagram Showing Circulation of Air

Referring to Fig. 7, the circulation of the air can be observed. The heat of the arc sets up a draft in the chimney A, which receives its supply of air through an annular opening I. The incoming air current is deflected around the reflector J, washing the face of the reflector and the inside of the electrode box K and passing out through the chimney top at L. In this lamp sufficient height of chimney is provided to always insure updraft, regardless of extreme and violent changes in external conditions. The chimney naturally forms the support for the lamp mechanism.

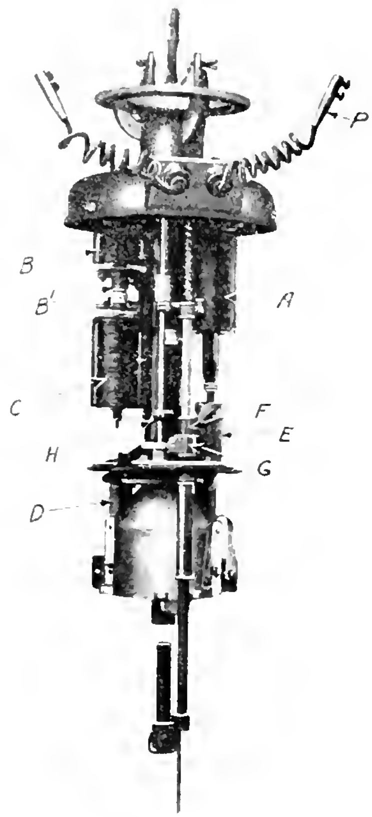

Fig. 8. Later Type of Luminous Arc Lamp

Sixth: A lamp mechanism including the following elements:

(*a*) *Starting coil to actuate lower electrode at each feeding operation.*

(*b*) *Protective cutout coil with contacts.*

(*c*) *Shunt coil to limit voltage at the lamp terminals; i.e., effect each feeding operation.*

(*d*) *Resistance to insure proper potential* *at the electrode tips when brought into contact to strike the arc.*

(*e*) *Air dashpot to retard too rapid separation of electrode tips.*

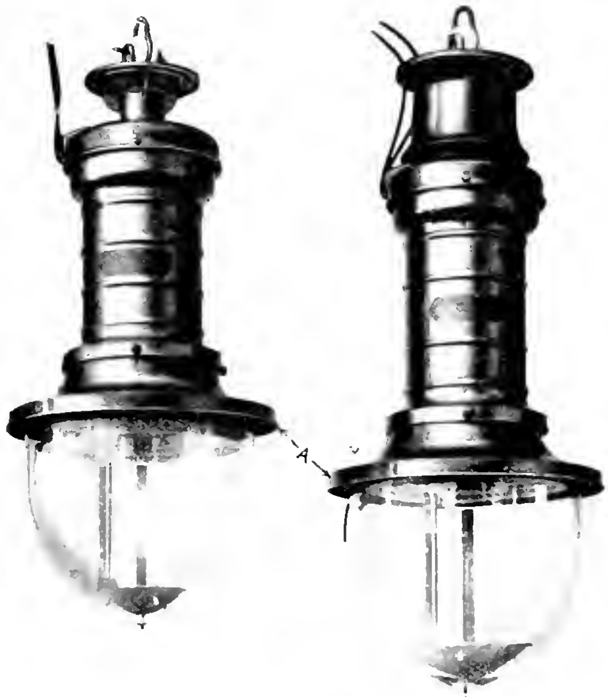

Fig. 9. On Left, 4 Ampere Luminous Arc Lamp; On Right, 6.6 Ampere Luminous Arc Lamp

The later type of luminous lamp is shown in Fig. 8, and in all essential details is similar to the 1903 model, so that only the later type need be described. The mechanism is extremely staunch, a maximum of strength being provided for a minimum weight of material. The magnetite electrode is fed upward toward the stationary positive copper electrode by means of a rod passing through a pair of shoe clutches, the upper one *F* lifting the mechanism and the lower one *G* adjusting the arc length, the amount of movement being limited by two stops, one of which *H* is adjustable. The advantages of the rod feed over other types has long been recognized, because when once made all adjustments remain unchanged, whereas those lamps that employ a clutch mechanism acting directly on the electrodes are subject to variations in arc length, due to irregularities in the electrodes. Another great advantage accruing from the construction of this lamp is that all the mechanism, including clutches, dashpot, contacts, etc., is housed in a chamber above the baseplate of the lamp, thus preventing stickiness or inaction which, in those lamps employing different construction, might be caused by heat and smoke from the arc.

The cycle of operation is as follows: The current enters by the positive terminal **P** (**Fig.** 8), passes through the starting resistance *D*, through the contacts B^1, and through the lifting coil *A* to the line. This coil, by means of its armature and the clutch *F*, brings the negative electrode into forcible contact with the positive, starting the arc, when the magnet *B* becomes energized and separates the contacts B^1, opening the circuit through the magnet *A*, de-energizing it and allowing the lower electrode, retarded by the dashpot *E*, to drop back by gravity. The electrodes remain in this position until the voltage at the arc momentarily increases to such a value that the shunt coil *C* closes the contacts B^1, when the cycle of operation is repeated. When the negative electrode is consumed, the contacts B^1 remain closed, maintaining the circuit through the starting resistances and lifting coil *A*.

Fig. 10. Globe Lowered for Trimming

The exterior views of the 4 and 6.6 ampere lamps are shown in Fig. 9, the 6.6 ampere lamp being a trifle longer on account of using a longer electrode to make up for the increased electrode consumption due to the higher current. One of the important features in the design of casing for this lamp is the extension of the canopy *A* beyond the globe, which prevents any accumulation of dirt and dust on the lamp from running down over the globe during a rain storm. In a steady downpour the water drips naturally from the entire circumference of the canopy, while in the case of rain accompanied by high winds all the water is driven off under the lee of the canopy.

Fig. 10 shows the globe lowered on its hinge *A* for trimming. This arrangement has been received with great favor by lamp trimmers, as it prevents the globe from swinging around in the wind, as would be the case if it were suspended by a chain. A smaller globe breakage also results from the use of this device. The accessibility of the tripping rod *F* greatly facilitates the trimming of the lamp.

Fig. 11 shows how the light is distributed from the arc, and the arrangement of the concentric rings in the reflector for eliminating the shadow projected by the ash pan. Since all magnetite lamps require an ash pan, it is obvious from the intersecting lines *E* and *D*,

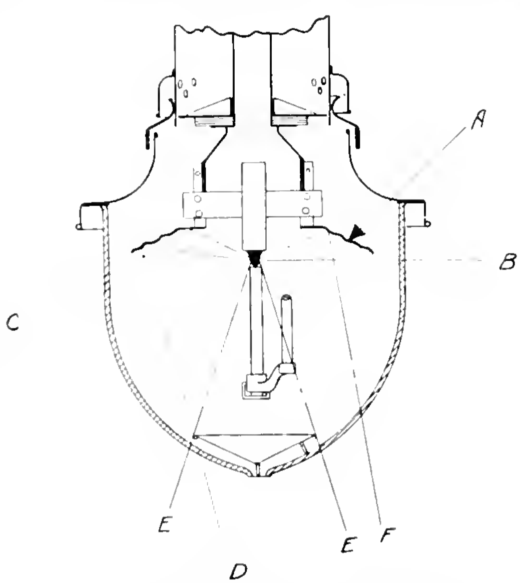

Fig. 11. Arrangement of Arc, Reflector, Globe and Ash Pan in Luminous Arc Lamp

that the further away this ash pan is placed from the arc, the less difficult it is to eliminate the shadow cast by it. The arrangement shown is ideal in all respects, for it accomplishes the placing of the reflector in the most efficient position within the globe, and permits the use of a globe of a size that is pleasing both by day and by night. Laying

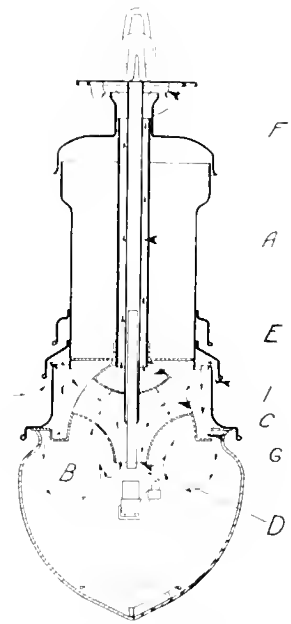

Fig. 12. Early Type of Luminous Arc Lamp with Negative Electrode Above and Positive Below

all other considerations aside, the layman usually judges the value of a lamp by the size and appearance of the globe, so that its design is of the utmost importance.

From time to time luminous arc lamps have been built according to other principles. Fig. 12 shows an early type that used a negative electrode above and positive below. Since an anode sufficiently large to be non-consuming would obstruct the light materially when placed below the arc, a much smaller electrode is used, which is consumed, and therefore enters the arc stream by heat evaporation.

The natural characteristics of such an arc are shown in Fig. 3, where the air currents sweep upward around the arc stream, to its detriment, as the negative material is prevented from filling the space between the electrodes, the greater part being driven out of the path of the current so that the lower half of the arc is formed by heat evaporation of the small positive electrode. In order to utilize to the best advantage an arc arranged in this manner, it is necessary to force the electro-conductor into its proper position by means of downwardly moving air currents, as indicated by the arrows *D*, Fig. 12.

This is accomplished by making use of the heated air currents *A* set in motion by the

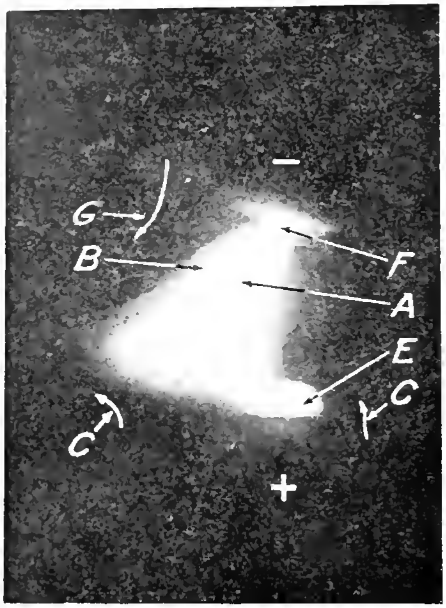

Fig. 13. Arc Formation Produced by Downward Currents of Air. Inverted Electrodes

formation of the arc, and by their passage through the chimney to draw in a fresh supply of cold air, as indicated by the arrows. It follows, therefore, that the brilliancy of the arc depends upon the velocity of the descending air currents *C* at *D*, which in turn depends upon the heat generated at the arc, the height of the chimney, the difference in pressure between the inleading ducts *C* and the outlet at the chimney *F* and on the arc length.

A photograph of a magnetite arc thus artificially produced is shown in Fig. 13, and is interesting when compared with the arc normally formed, Fig. 2, as it shows clearly the effect of the various forces employed in its production.

LUMINOUS ARC LAMPS FOR ORNAMENTAL STREET LIGHTING

The committee appointed by the National Electric Light Association to investigate ornamental street lighting quite recently made its report on what has actually been done in the way of artistically mounting modern lighting units and briefly commented on the decorative effects obtained. The report stated in part:

"As regards arc lighting, there is very little which should properly be classified as ornamental. The fixtures employed are rather better than has been common in this country, but neither the fixtures nor the illumination would strike a visiting foreigner familiar with street lighting in continental cities as implying anything more than a workmanlike attempt to furnish adequate illumination in streets deserving it. There are indeed very few arc installations in this country which should properly be classified as ornamental lighting save in isolated spots. We may, therefore, pass by the arc lighting matter as simply embodying vigorous efforts in the right direction without in any sense entering the field of decorative lighting."

It has nevertheless been possible to detect during the past few years a steadily increasing interest in improved street lighting. In

Fig. 14 Luminous Arc Lamp Designed for Ornamental Post

addition to a universal desire for more light, there has been an equally strong sentiment in favor of the adoption of illuminating units that are of noticeably artistic designs and therefore produce as pleasing effect by day as by night. Such civic activities have led to the use of incandescent units in connection with ornamental standards, as being the only combination available which would lend itself to artistic treatment. Although these combinations are now being quite generally used, the desired effects are obtained at a sacrifice of efficiency and economy of operation.

With a full realization of these facts much new work has been carried out during the past eighteen months, with the result that at about the time the above report was made public, a series luminous arc lamp combining characteristic high illuminating efficiency and adaptability to ornamental lighting was ready for commercial exploitation.

Fig. 15. Luminous Arc Lamp for Ornamental Post

Figs. 14 and 15 show an exterior view of the lamp complete, ready for installing on the ornamental post in the position shown in Fig. 17. Fig. 19 is an illustration of the lamp mounted on one of these ornamental poles such as may be obtained from the various manufacturers. The lamp casing C (Fig. 14) constitutes the capital of the supporting post

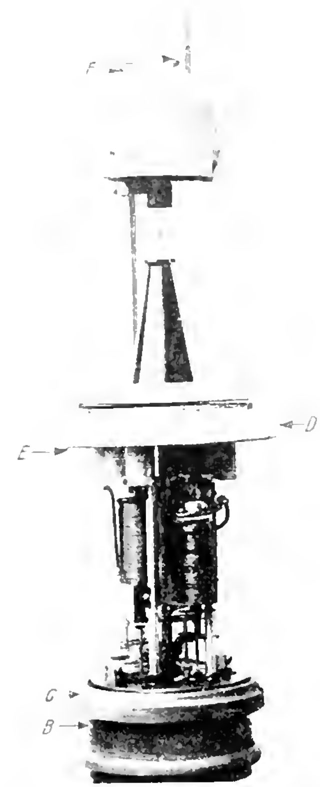

Fig. 16. Method of Insulating Lamp from Ornamental Post

or column, as shown in Fig. 17, and is so designed that by releasing the latch A (Fig. 14), it may be lowered to give free access to the lamp mechanism (Fig. 22), as readily as a similar operation is accomplished on an ordinary arc lamp. The casing is supported between the high voltage insulators D and B (Fig. 14); the latch engaging the flange C (Fig. 16), and the upper part of the casing being guided and held in position at E (Fig. 14). In this manner ample protection from the weather is afforded to the mechanism.

As the lamp is designed to be operated from a series rectifier outfit, it is necessary to provide proper insulation from lamp to ground, as well as adequate protection for the trimmer.

With this end in view the lamp is placed on a high voltage strain insulator B (Fig. 14),

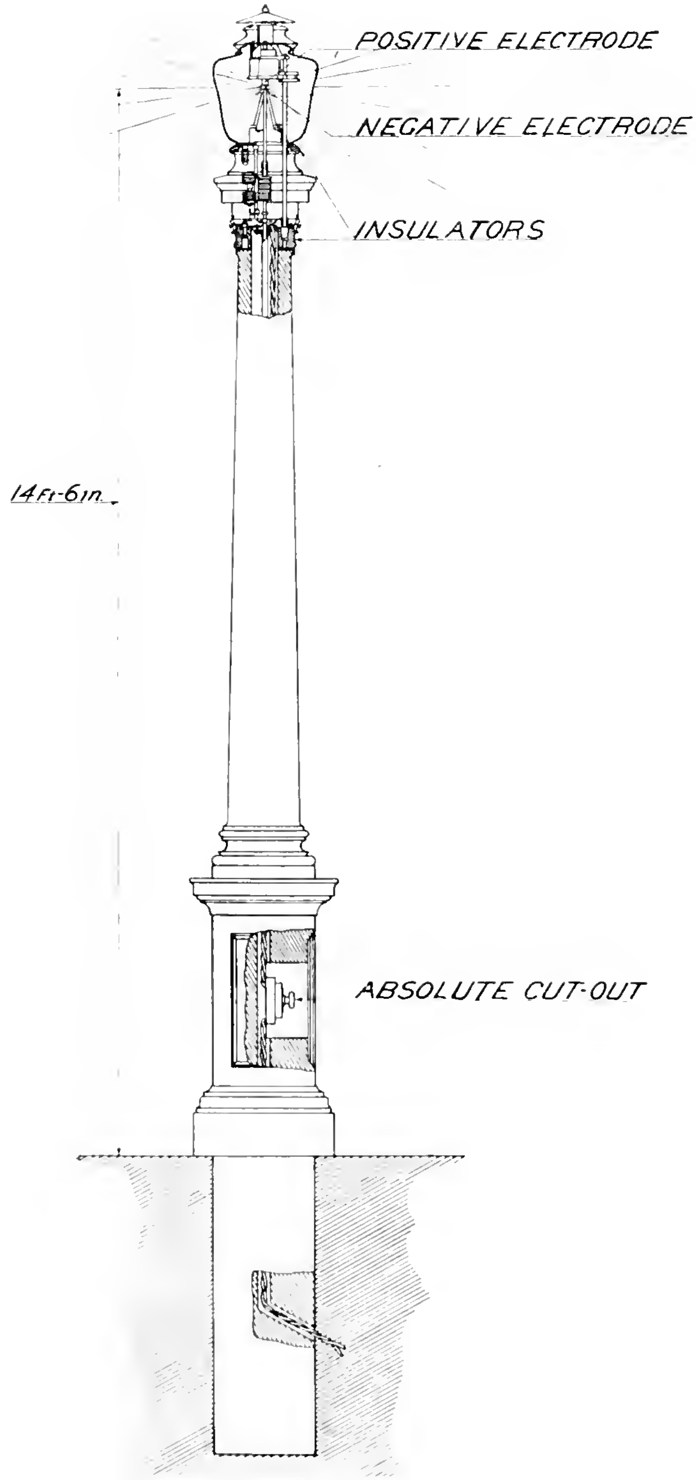

Fig. 17 6.6 Ampere Luminous Arc Lamp Mounted on Ornamental Pole

which is fastened to the pole by three deeply recessed screws placed 120 deg. apart; the lamp being held to the insulator by three other recessed screws permanently secured to the insulation. The changing of the lamps for any purpose is easily accomplished by removing three nuts, the studs projecting upward and being held in place ready for the installation of the new lamp. This detail is shown in Fig. 17.

Within the base of the pole an absolute cutout is placed (Fig. 17), so that the trimmer may disconnect the lamp from the line before starting to work on it.

The ornamental cover of the chimney *F* (Fig. 14) is also highly insulated from current carrying parts, and it is practically impossible for any ground to take place here. The insulator *D* acts also as the globe seat (Figs. 14 and 17).

In operation and design the mechanism is essentially the same as that of the standard mechanism of the direct current series luminous arc lamps already described. The arc is struck between a stationary non-consumable copper upper electrode and a movable magnetite lower electrode, $\frac{9}{16}$ in. in diameter and 18 in. long, burning under normal updraft conditions. The lower electrode is carried on a rod *A* (Fig. 21), actuated by the standard type of shoe clutch mechanism. The current is carried to the electrode by means of a flexible spiral connection contained in tube *A* (Fig. 18), which is telescoped by the electrode rod. A single side rod *A* (Fig. 20), telescoping the supporting tube *B* (Fig. 20), supports and carries the electrode, fume dome and chimney *C* (Fig. 18) so that no shadows on the globe are visible when the lamp is properly placed, with the side rod toward the side walk.

The lamp is equipped with a diffusing globe that is unique in design in that it is perfectly filled with light and no circular shadows are cast upon it by the electrodes.

It is equipped with an attaching ring fitted with bayonet slots *A* (Fig. 23), which are engaged by the bosses *F* (Fig. 16), so that by turning the globe on its axis it may be

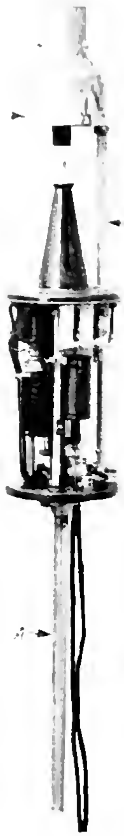

Fig. 18. Complete Mechanism of Luminous Arc Lamp

removed without disturbing the alignment of the electrodes. If, on the other hand, it is desired to raise the globe for cleaning, without removing it from the lamp, this may be accomplished as shown in Fig. 20, by raising the globe and turning it on the axis of the supporting rod *A*; the electrode box and globe being handled as a unit and supported in the position shown by a locking arrangement located within the tube *B*.

A large ash pan *A* (Fig. 22), is provided, which is easily removable.

Fig. 22 shows the method of trimming: the upper end of the electrode is inserted in the guiding bushing *B*, after which the opening in the lower end of the electrode is forced over the expanding thimble *B* (Fig. 21), on the end of electrode rod *A*.

The cycle of operation may be traced by referring to Fig. 24. The current enters terminal *P*, passing through the starting resistance, starting magnets, and the cutout

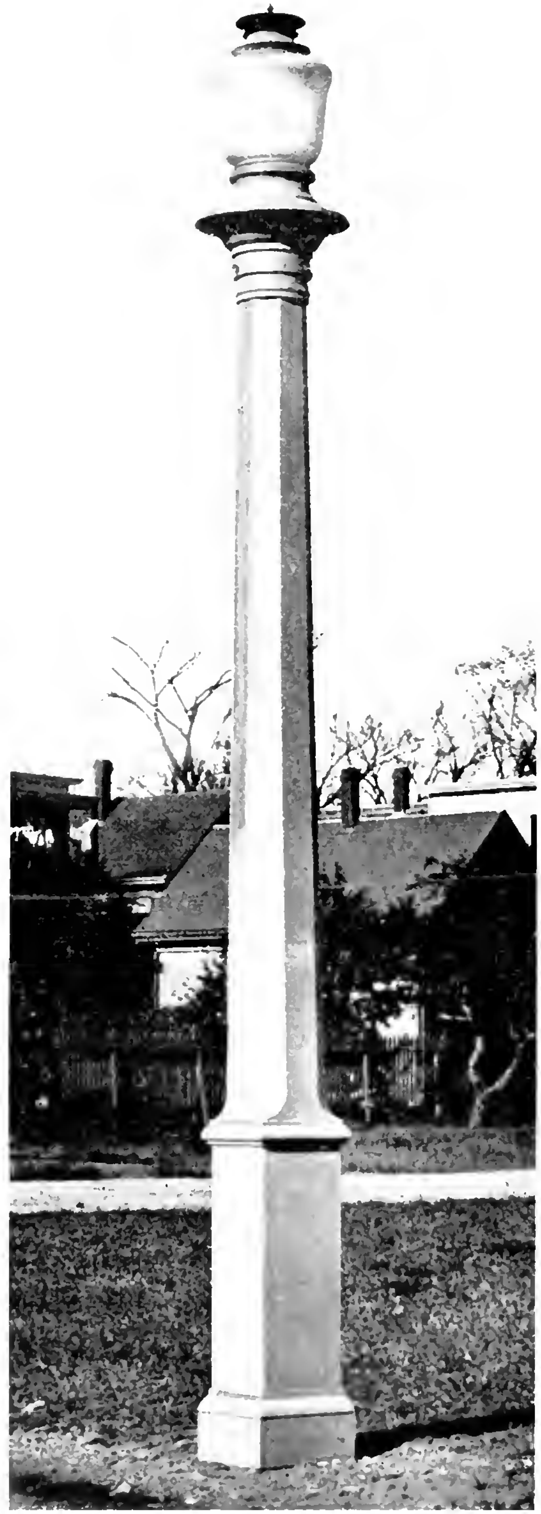

Fig. 19. Luminous Lamp on Ornamental Pole for Street Lighting

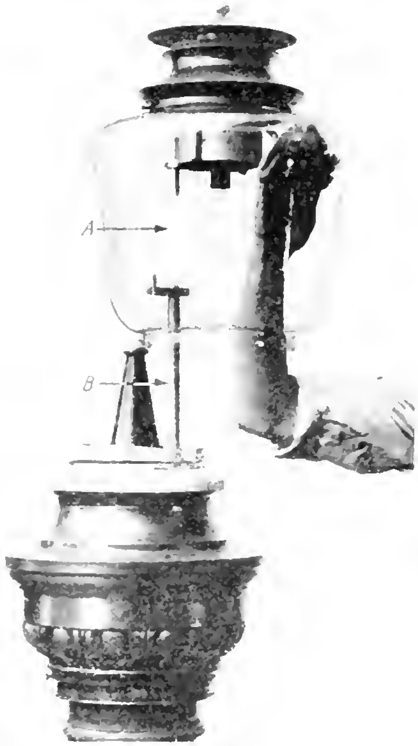

Fig. 20. Globe Raised for Cleaning. First Operation in Trimming Luminous Arc Lamp

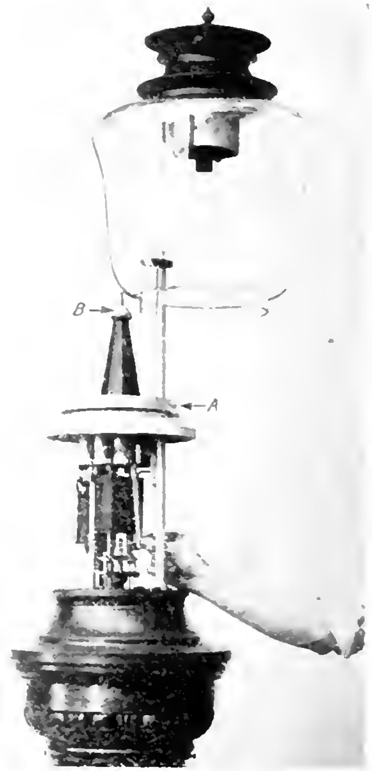

Fig. 22. Casing Lowered and Placing of Electrode. Second Operation in Trimming Luminous Arc Lamp

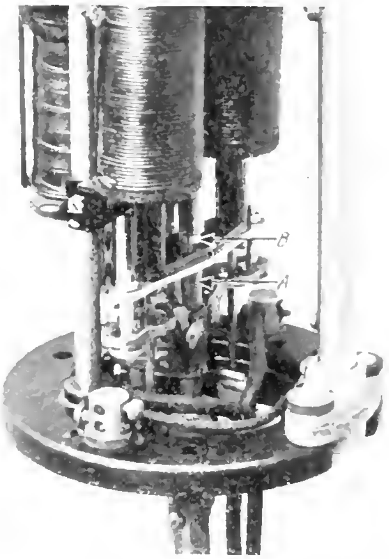

Fig. 21. Clutch Mechanism of Luminous Arc Lamp; also Method of Connecting Lamp to Circuit

Fig. 23. Luminous Arc Lamp Globe Fitted with Attaching Ring

contacts to the negative terminal. The starting coils are thus energized and the lower electrode is brought into contact with the positive, establishing the arc and the circuit through the series cutout coil; this coil, on becoming energized, separates the contacts and opens the circuit through the starting coils, thus allowing the lower electrode to fall back to its normal position, retarded by the dashpots. The electrodes remain in this position until for some reason the voltage at the arc momentarily reaches a point sufficiently high to actuate the shunt magnet, when the contacts are once more closed and the cycle of operation is repeated.

When operating at standard adjustments (6.6 amperes—75 to 80 volts at arc) the life of the lower, or magnetite, electrode is from 150 to 175 hours, and that of the upper, or copper, electrode from 3,000 to 4,000 hours. The electrodes used being of the same composition as those used in the standard series luminous lamps, the illuminating efficiency at the arc should be the same; as, however, the lamp carries no reflector, a certain amount of light is directed upward and passes through the globe. The upward rays tend to obliterate finely-defined shadows, and are, therefore, of great value to ornamental street lighting.

It is obvious from the foregoing that a lamp has been designed which, for adaptability, meets the requirements of the simplest or the most elaborate ornamental fixtures. A number of ornamental casings or capitals have been designed that are in keeping with the different styles of architecture, and it is believed that the local lighting companies can procure with little difficulty a complete lighting unit that will meet the approval of the municipal art societies. This has been accomplished without detriment to the operation of the lamp or its light giving characteristics, a specially designed diffusing opal globe furnishing a beautiful secondary source of pearl-white light of high efficiency and low

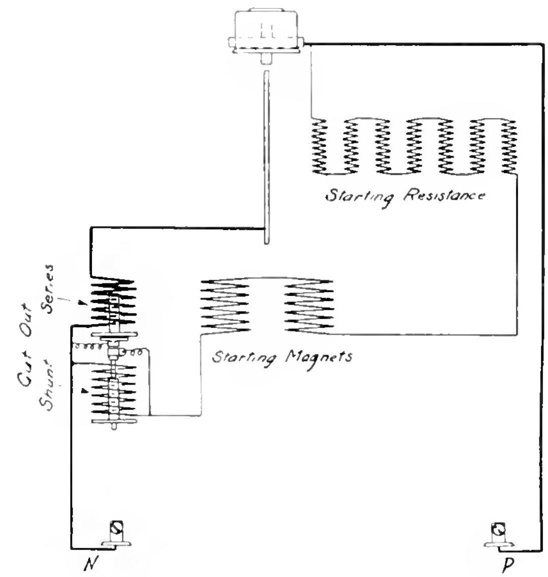

Fig. 24. Connections for Series Luminous Arc Lamp, Inverted Type

intrinsic brilliancy. The result is, that at the extremely low height at which these lamps are placed; viz., 11 ft. 6 in. from the ground, there is a notable absence of glare, and an altogether pleasing effect.

Without doubt this unit will fill a long-felt want, and when installed in accordance with the dictates of modern practice, will overcome that monotony of arrangement which is at present so common with clusters of low efficiency lamps.

THE COMPOSITION AND PREPARATION OF ELECTRODES FOR LUMINOUS ARC LAMPS

By Edward R. Berry

Chemist, General Electric Company, Lynn

This article deals with the chemical composition of the electrodes and the factory processes in their manufacture; including treatment of ores, chemical analysis of raw materials, calculation of percentages of ingredients, grinding, loading of electrodes, and testing.—Editor.

To the average person unacquainted with the details of manufacture, the luminous electrode might appear merely as an iron tube filled with a heavy black mineral substance. It would probably not occur to him that any particular care was required in its manufacture, nor that this same electrode was the result of years of research work, and the expenditure of a vast sum of money in its commercial development.

Chemical Composition

In the luminous electrode the element iron, in the form of an oxide is relied upon as a vehicle or carrier of the current. The iron has mostly been introduced as the magnetic oxide, known to the ancients as the "lode" or leading stone, and to the mineralogist as magnetite. Such a material gives, of itself, a comparatively small amount of light. While the operation of a large number of magnetites has been closely studied, it happens that an American ore, obtained near the shores of Lake Champlain, in the state of New York, has been found best suited. This material is a specially purified ore, and represents, very closely, the theoretical chemical formula of one molecule of ferrous oxide, and one molecule of ferric oxide. Its chemical formula is $FeO\ Fe_2O_3$, and it has a metallic content of about 72 per cent.

Of all the elements which have been tried, research has proved that titanium is of the greatest value as a light-giving element; or, in other words, for the same expenditure of energy, it produces more light in the arc than any other substance which can be used. It is, therefore, mixed or combined with the oxide of iron to increase the luminosity of the arc. The titanium may be introduced as the dioxide (rutile) or it may be introduced chemically combined with the iron, which may give a more even operation of the arc. We have, therefore, by the use of oxides of iron and titanium, a material which will give fair operation, while at the same time possessing wonderful light-giving properties. For increasing the life of the electrode, chromium has been found to possess wonderful properties. As the elements iron and titanium have been introduced in the form of the oxides, chromium should be introduced in a similar form. Of the vast number of chromium compounds which have been worked on, the double oxide of chromium and iron has been found to be the most satisfactory. This material is known as chromite, and has the formula represented by one molecule of ferrous oxide and one molecule of chromic oxide ($FeO\ Cr_2O_3$). As in the case of the other raw materials entering into the luminous electrode manufacture, a very great purity is essential. Research work has proven that the best suited material for this is a chromite from Asia Minor.

Treatment of Ore and Manufacture of Electrode

Even the purest raw ores obtainable do not meet the severe chemical requirements necessary for luminous electrode manufacture. After being received at the factory, therefore, they are very carefully crushed between hardened steel rolls, so spaced as to cause the ores to properly cleave; and after passing a screen of the necessary fineness, the material is passed under the poles of the magnetic separator to lift the ore, as in the case of magnetite, or the impurities, if chromite is being worked on. After this magnetic separation a very good material is obtained. In order to remove the last traces of impurities, the magnetically concentrated ores are now passed over a Wilfley water-table, so adjusted that only material of extreme purity is saved for subsequent electrode manufacture.

Each of the several raw materials, now carefully purified, is placed in tight metal-lined storage bins, fully protected from dust and moisture. A chemist from the laboratory of the electrode department personally attends to the sampling of all the raw materials. After he has obtained a satisfactory sample he assigns to the material which it represents a designating numeral, known as a lot number, by which this particular lot of raw material is distinguished. Such lot numbers are assigned to all of the raw materials as they are received at the factory.

For the analytical and other chemical work, a fully equipped chemical laboratory is maintained, where analyses are made on all of the raw materials and completed mixtures. Not only are the principal elements determined, but the analyses include those elements which are present even to a fraction of one per cent., so that on each of the samples seven or more determinations are made. After the chemical analyses are completed on all of the raw materials, the chemist in charge of such work calculates the amount of each of the several ores from the lot number analyses. A charging form, which is the foreman's authority for loading a mill, is now made out by the chemist. This form specifies the lot number and weight of each of the several raw materials required to bring the resultant mixture to the proper chemical composition, and assigns a numeral by which this charge of mixture is known and which is referred to as a "run number."

It has been found that the best grinding is obtained by the use of pebble mills, all grinding parts being made of a specially hard and tough steel. The foreman, on the authority of the charging form and in the presence of a chemist from the electrode laboratory, proceeds to weigh out the necessary raw materials and to load the mill. After a week of continuous operation the mill is opened, and a sample carefully selected. For testing the quality of grinding, the chemist passes the sample through a nest of standard sieves starting with a 100 gram sample; the weight left on each screen gives the results directly in per cent. In most cases, as the grinding is not exactly right, it is found necessary to continue the operation of the mill until a sample meets the proper specifications. Not only is it necessary that every particle of the mixture shall pass a certain screen, but it is of great importance that the size of the particles be such that the smaller grains will fill the spaces between the larger particles. This may perhaps be best illustrated by imagining an ideal cement mixture, or aggregate, wherein the arrangement of the filling material is such that no voids exist. A very fine and even grinding produces a short life electrode of unsteady operation, due to the light weight and the air which is pocketed in the mass.

The mixture being now properly ground, the chemist instructs the foreman to submit sample electrodes. A sufficient number are loaded under commercial conditions, and samples are taken from these and submitted to the laboratory. Each is carefully weighed, gauged and inspected, then stamped with the number of the run.

Loading and Testing

Thorough trials have proved that the heaviest and best operating electrodes are obtained by what is termed the bumper method of loading. In this process, electrically-welded iron tubes with tightly-fitting steel thimbles at the lower ends, are packed into a machine, which is so constructed and operated that a moving element is slowly lifted several inches, then dropped upon the very heavy base of the apparatus. This downward movement is hastened by heavy springs. During the loading of a standard luminous electrode, about 3000 impulses are delivered by the loading apparatus, during which time the luminous mixture is slowly and evenly delivered to the filling machine.

Half of the electrodes delivered to the laboratory are laid aside for future reference, while the remaining half are operated on a life test for twenty-four hours. At the conclusion of this test they are sent to the photometer department for candle-power tests, where one hundred readings are taken on each of the samples. The electrodes are again placed on life test, where they are operated for forty-eight hours, and a further set of candle-power readings taken. In this manner, several sets of candle-power values are obtained. If the life and candle-power of the electrodes have been found satisfactory, the chemist issues a note releasing the mixture for manufacture and shipment. Only on this release is the foreman allowed to manufacture electrodes from the ground material.

After the electrodes are received from the bumper, they are thoroughly dried in a steam-heated oven at a temperature of 150 deg. cent. for twenty-four hours. The upper end of the electrode is then closed with a moisture-proof and dust-tight seal, and covered with a thin disc of sheet iron to insure perfect contact with the upper electrode when first starting in the lamp. The electrodes are then sent to the inspectors who check the size of each electrode by passing it through maximum and minimum gauges, and the density by weighing, any improperly loaded electrodes being detected on account of their light weight. They are then given a protecting coating of oil, to keep the sheath from rusting and are packed in boxes of five hundred, ready for shipment.

RECENT DEVELOPMENTS IN LUMINOUS ARC HEADLIGHTS

By P. S. Bailey

Assistant Engineer, Arc Lamp Department, Lynn

This article describes the two latest forms of luminous arc headlight, viz., the latest four-ampere lamp and the two-ampere lamp; and, with the article previously published in the May, 1911, General Electric Review, brings the published information on this subject up-to-date.—Editor.

In an article which appeared in the May, 1911, issue of the General Electric Review, the writer briefly traced the evolution of the enclosed carbon arc headlight; and showed

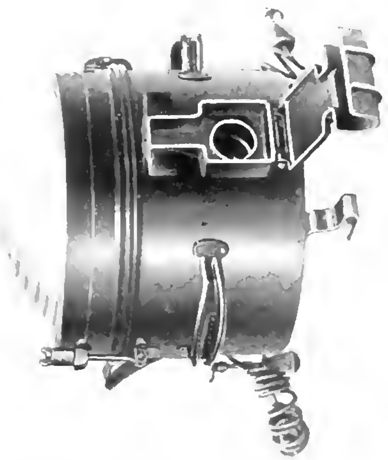

Fig. 1 Four-Ampere Luminous Arc Headlight Showing Interior of Draught Castings

how, as time went on, the increase in speed required for the proper operation of interurban cars, soon necessitated increased track illumination, both for the safety of the public and the protection of the owners. This article then proceeded to describe the various styles of luminous arc headlights which had been developed by the General Electric Company to meet the new demand. Since that article was written, two further types have been developed in addition to those previously dealt with; and it is the author's present purpose, therefore, to describe briefly these two later types, thus bringing the information on this subject up to date.

Four-Ampere Lamp

Considerable progress has been made in the commercial development of the four-ampere luminous arc headlight for street railway service. All standard headlights are now equipped with struck-up casings drawn from one piece of sheet steel. This feature insures lighter and stauncher construction with fewer parts.

A new draught feature composed of a T-shaped, two-part iron casting, assembled at the top of the casing in place of the former circular wind-shield, has been devised. The lamp has also been provided with three baffled intake apertures at the sides and back, near the bottom of the casing. Practically all of the fumes are now removed from the casing interior, the draught having been improved fully 100 per cent. The arrangement is particularly effective when the car is moving, as the air, passing by the ends of the T-shaped casting, tends to create a suction, while new air is admitted through the baffles. Lamps equipped as above have been tested with an air-blast, under 90 lb. pressure, without any deterrent effect upon the arc. The new equipment causes the interior of the lamp to run at a 20 per cent. decrease in temperature as compared with that formerly obtained.

Fig. 1 shows the four-ampere lamp and the interior of the draught casting at the top of the struck-up casing. When closed for normal operation the assembled halves form an appearance somewhat similar to that of the ordinary chimney cowl. The

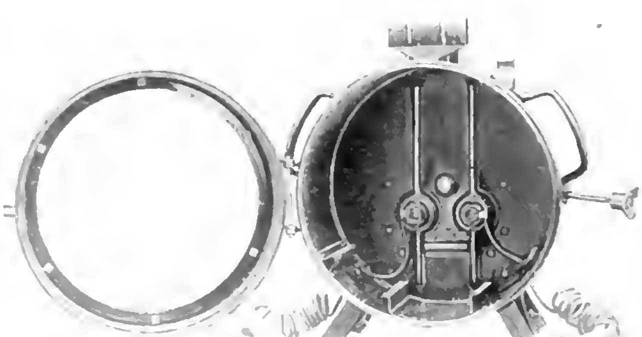

Fig. 2. Interior of Casing Showing Baffle Arrangement for Admission of Air

device may be very easily cleaned. Fig. 2 illustrates the baffle arrangement for the admission of air at either side and at the back of the casing. Fig. 3 gives a reproduction of the semaphore lens type headlight installed on an interurban car.

It will be noted that all the cuts referred to show lamps equipped with a new form of side handle. These handles are so arranged that it is very convenient to lift the lamp up to the supports, which are, as a rule, placed rather high on the ordinary interurban car. It is quite a simple matter to carry the lamp from one end of the car to the other, as there is ample space allowed for the insertion of a heavily-gloved hand, and it is found that the lamp hangs in a satisfactory manner when being carried. These developments, viz., the improved draught castings, the baffled intake, and the side handle features, will be found to add considerably to the general serviceability of these headlights.

Two-Ampere Lamp

There is an apparent demand in certain parts of the country for an arc headlight of comparatively low wattage consumption. Better illumination of the thoroughfares by the use of modern street lighting systems; objection to intense concentration, with regard to the projection of light in densely-populated

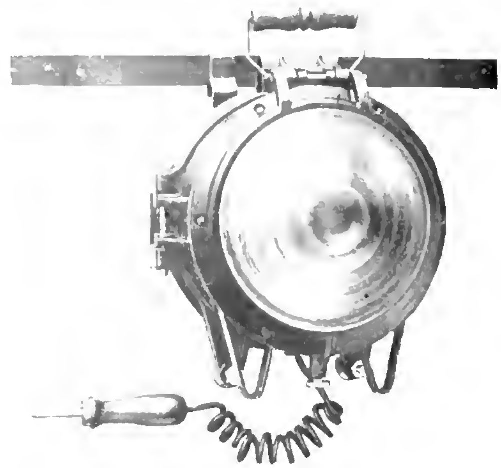

Fig. 4. Two-Ampere Luminous Arc Headlight for Suburban Service

districts; and low speed requirements of suburban service, all tend to create a demand for an illuminant in excess of the ordinary incandescent headlight, but of less penetrative power than the luminous arc headlight commonly used for interurban service. The requirements of some classes of suburban service permit of the design and construction of a lamp occupying approximately one-half the space required for a lamp of the interurban type. Such a lamp has been developed and is now ready for the market, as shown in Fig. 4. The unit is composed of a two-compartment casting, the two chambers being separated and hermetically sealed from each other by a central partition.

The forward compartment shown in Fig. 5, which contains the electrode mechanism, is provided with a cast door holding a standard $8\frac{3}{4}$ in. semaphore lens. This door is hinged at the top, and is also arranged with a catch at the bottom for locking it securely. The upper positive electrode, or anode, is composed of a solid adjustable copper rod; while the lower negative electrode, or cathode, consists of a rolled sheet-iron tube with welded seam, containing the standard mixture commonly used in the series luminous lamps employed for street lighting throughout

Fig. 3. Four-Ampere Luminous Arc Headlight Installed on Interurban Car

the country. The latter is firmly positioned in a cast movable holder, which is mechanically connected to a shaft extending through the central partition of the casing. This shaft is in turn actuated by a clutch mechanism in the rear compartment, and is designed to strike an arc of fixed length. The rear compartment shown in Fig. 6 also contains a single solenoid, operating an armature connected with a substantial clutch which controls the clutch mechanism. Feeding of the lamp is occasioned by the ordinary interruptions of the trolley circuit incidental to regular operation. A hinged rear door is provided which permits of easy access to the mechanism for such adjustments as may be necessary. In regular service the main casing is screwed to this door, thus insuring against tampering with the mechanism by persons not regularly authorized to do so. The rear door also carries a single spring contact, making connection with a single positive lead. The negative side of the lamp is grounded to the casing.

The lamp is furnished in a stationary type for permanent installation

Fig. 7. Two-Ampere Headlight Permanently Attached to Front of Car

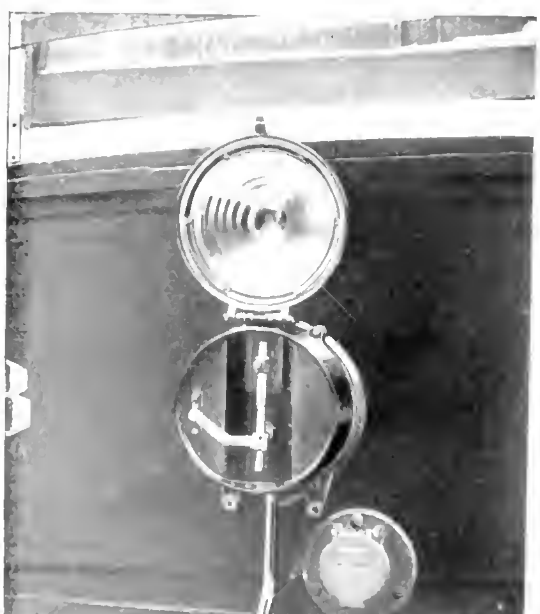

Fig. 5. Forward or Arc Compartment of 2-Ampere Headlight

Fig. 6. Rear Compartment of 2-Ampere Headlight

to either end of the car, or in a portable type, which may be shifted from one end of the car to the other, at the will of the motorman. If desired, lamps can be furnished with a ½ in. conduit for the positive lead with plug attached as in Fig. 5; or the conduit may be dispensed with and the lead brought directly to the contact spring, entering the casing through a compound bushing at the bottom of the back door. The stationary type of lamp mounted on a street car is shown in Fig. 7.

The employment of a two-compartment casing has several distinct advantages which may be enumerated as follows: *First*, the separation of the elements of the clutch mechanism and winding, from the gases and fumes from the arc. *Second*, the comparatively low temperature of the chamber containing the clutch mechanism and the windings, preventing expansion of the metal, and eliminating the danger of injury to the windings from heat radiation. *Third*, the segregation of the elements of the electrode mechanism, permitting of the easy disposition of the fumes through practical ventilation. *Fourth*, the prevention of access to the mechanism by incompetent persons. *Fifth*, the presence of an iron partition, forming a perfect shield which prevents any possible magnetic leakage that might otherwise affect the luminous arc.

The value of a small unit for the particular service above mentioned can scarcely be overestimated. It is a well-known fact, that the space on the dashers of most suburban cars is so congested that a unit occupying a limited space is greatly needed. The moderate depth of casing insures protection in case of collision, as the lamp is shielded by the bumpers on the cars. The lamp should be popular for mining use, due to its staunch and compact construction.

Thus two more headlights have been added to the number of units already developed, completing a line which is now adapted to every class of service.

FLAME ARC LAMPS

By S. H. Blake

Engineer, Arc Lamp Dept., Pittsfield

The article commences with a definition of the open carbon, enclosed carbon, open flame, and the enclosed flame arc lamp. From considering some of the disadvantages of the open flame arc, the author prepares the way for a discussion of the conditions which had to be met in the development of the enclosed flame. He shows how this has been done; and describes standard forms of long burning enclosed arcs, their operating mechanism, etc.—Editor.

Definitions

An open carbon arc is one maintained between pure carbon electrodes, with free circulation of air. The arc is about one-eighth of an inch long, and over ninety per cent. of the light emanates from the incandescent points of the carbons. The arc burns about 10 hours per trim.

An enclosed carbon arc is one maintained between pure carbon electrodes, but within an enclosure having restricted ventilation of air. The arc is about three-eighths of an inch long, and the arc voltage is about double that of the open carbon arc. As with the open carbon arc, over ninety per cent. of the light comes from the incandescent carbon points. The arc burns 120 to 140 hours per trim.

An open flame arc is one maintained between so-called mineralized carbons, i.e., carbons which have mixed in the core, in the body of the carbon itself or in both the core and the body, certain light-giving salts that produce, when raised to the temperature of the carbon arc, a source of light of very high efficiency. As a result of the volatilization of the impregnating salts, fumes are formed with this arc, which deposit mostly above the arc in the form of white powder. With this arc only a very small part of the light comes from the incandescent carbon points, as the arc stream itself is intensely luminous. Most arcs of this kind are operated at the lower points of long thin carbons, inclined towards each other at an angle of about 30 deg. In order to keep the arc from crawling up the sides of the carbons a blow-magnet is generally provided to blow the arc downward, which results in a fan-shaped arc often over one inch in length. This kind of arc is also maintained between vertical carbons arranged co-axially, in which case the arc is from five-eighths to three-quarters of an inch long, with practically all the light emanating from the arc stream. The open flame arc burns about 17 hours per trim.

An enclosed flame arc is one maintained between mineralized carbons, but within an enclosure having restricted ventilation of air. With this arc special provision has to be made to prevent the deposits from the arc fumes from accumulating on the glass enclosing globe. Practically all the light emanates from the arc stream itself as is the case with the *open flame arc*. This arc is extremely sensitive to currents of gases in the enclosing chamber, to stray magnetic fields from the current-carrying parts and from the lamp mechanism itself. It is therefore much easier to control the arc between vertical carbons, co-axially arranged, than between converging carbons. The arc voltage may be run anywhere between 40 and 80 volts (depending, of course, upon the line volts) thereby differing from the *enclosed carbon arc*, which must be operated above 60 volts to get good results. The length of arc is dependent upon the arc voltage and the kind of carbon used, varying from one-half inch under some conditions to one inch and a quarter under others. The arc burns 100 to 120 hours per trim.

Just as, seventeen years ago, the enclosed carbon lamp commenced to supersede the open arc lamp in this country, so now the enclosed flame lamp is superseding and replacing the open flame lamp, and for the same main reason, *viz.* cost of trimming. In the case of the old open arc *versus* the enclosed carbon lamp, the total light flux of the former, at its best, is nearly twice that of the latter; but still the enclosed lamp, due to lower cost of carbons and maintenance, more simple mechanism, and better distribution of light, practically superseded the open arc in a period of ten years. The enclosed flame lamp is at no such disadvantage, as it gives as much light as the open flame lamp, watt for watt, while still possessing the other advantages in even a more marked degree.

The open flame lamp has been commercially exploited in the United States for about five years, and although many thousands of them have been sold and are in successful operation today, the lamp has not made a permanent place for itself. The trouble is that it costs too much to instal, operate and maintain for other than display purposes, except where the advantages of its remarkable illuminating qualities predominate over all other considerations. This type of lamp needs careful attention, in the way of trimming and cleaning, to make it give continuously good service year in and year out, and such attention in this country is very expensive.

Roughly estimated, the comparative cost per lamp per year (4000 hours) of trimming open flame arc lamps as against enclosed flame arc lamps, is about as follows:

	Open Flame Lamp	Enclosed Flame Lamp
Hours life per trim	17	100
No. times trimmed per year	235	40
No. outer globes per year	½	½
No. inner globes per year	none	2
Cost electrodes per trim	$0.15	$0.20
Cost labor	$0.04	$0.04
Trimming cost per lamp per year.		
Cost trimming, labor	$9.40	$1.60
Cost carbons	35.25	8.00
Cost outer globes at $0.72	.36	.36
Cost inner globes at $0.25		.50
Total	$45.01	$10.46

The main feature of the enclosed flame lamp is that the carbons are arranged vertically co-axially, instead of converging, as has been the case with most open flame lamps. This arrangement, together with the fact that lamps of the converging carbon type must "feed" carbons downward at the rate of about 1.3 inches per hour, whereas enclosed flame lamps need to "feed" only about one-sixteenth as fast, makes it entirely practical to use a simple substantial solenoid and clutch mechanism for the latter lamp, instead of the complicated differential and clock mechanisms commonly used for controlling the "feed" of converging carbons. This slow "feed" with the enclosed flame is made possible since the electrodes used are much larger in diameter than the small diameter carbons used in the converging carbon lamps; and, due to the enclosing feature, the same volume of electrode burns more than four times as long as it would in the open flame lamp. It has therefore been found quite possible to use to advantage for the enclosed flame arc lamp the simple reliable mechanisms, so thoroughly developed and tried in service for many years, in the various types of enclosed carbon lamps.

If the ventilating openings in the globe, globe holder, ash pan and economizer of an open flame lamp be closed up so as to greatly restrict the free circulation of air around the arc of the lamp, it will be noticed, after a few hours burning, that the inner surface of the enclosing globe has become coated

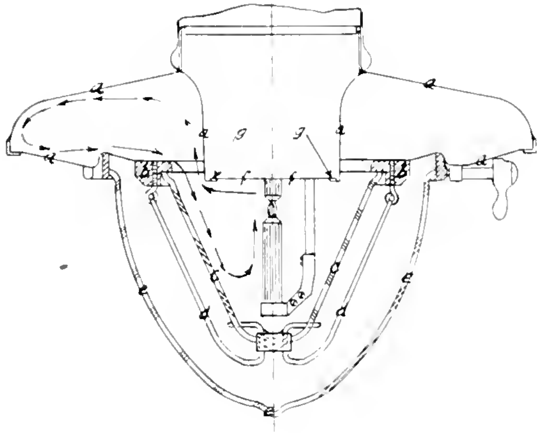

Fig. 1. Sectional View of Long Life Flame Arc Lamp, Showing Method of Ventilation

with white deposit, to such an extent as to greatly cut down the light from the lamp. Not only is the light reduced from this cause; but, due to the fact that the carbon shell of the open flame lamp carbon consumes very slowly without plenty of oxygen, there is not sufficient of the coring material, which gives the arc its high efficiency, to maintain the arc at maximum brilliancy. The arc gradually takes on the appearance of the pure carbon arc, getting short and blue. The short arc does not spread out properly so as to burn off the carbon points bluntly, and the lamp soon commences to flicker and jump very badly.

There were two separate problems to solve, therefore, to secure a long-burning flame arc lamp by enclosure of the arc. The first was to arrange the enclosing chamber so that the fumes from the arc would not condense upon the inside of the enclosing globe and thus reduce the light. The second was to get an electrode that would burn steadily for at least one hundred hours in such an enclosure, giving as much light as is obtained from the short-life open flame lamp.

The way the first problem was solved is shown in Fig. 1. This cut shows a vertical cross-sectional view directly through the middle of the arc-enclosing chamber. The arc shown in the very center of the figure is maintained always in the same position relative to the globe and casing by means of a focussing mechanism. Outline *aaaa* indicates the sheet metal walls of a so-called condensing chamber of comparatively small cubicle content which is made air-tight and with a large surface exposed to the cooling influence of the outside air. Very good results are obtained when the radiating surface of the condensing chamber is about equal to that of the arc-enclosing globe. Part *bb* is a gunmetal cast ring with a very carefully machined surface, against which the truly ground top edge of the inner globe *cc* is firmly pressed by the spring bail *dd*. The outer globe is indicated by letters *eee*. The condensing chamber is securely clamped to the lamp base plate (*ff*), and an asbestos gasket at *gg* makes the joint air-tight.

The only place, therefore, where air can leak into, or gases leak out of, this enclosing chamber, is around the upper carbon where it comes through the lamp base plate. To prevent too much leakage at this point a gas pocket is provided around the carbon to maintain a "dead air" space and thus avoid too much circulation of air and gases around this opening. With this arrangement practically all the white condensation from the arc fumes deposits on the surfaces *aaa* and *ff*. This action is caused by the hot gases rising, striking against the relatively much cooler surfaces, and condensing. The glass globe keeps much hotter than the walls of the condensing chamber, and remains practically clean from deposits even after over one hundred hours burning. The outer globe protects the inner from mechanical injury and from breakage due to rain or sleet striking against the hot glass. When made of opalescent glass, it also acts as a secondary source of illumination.

It is advisable, although not absolutely necessary, to clean out the condensing chamber each time the lamps are trimmed, as the white deposit on the interior of this chamber acts as a heat insulator and therefore interferes somewhat with the proper condensation of the arc fumes.

The second problem was to obtain a suitable electrode for this lamp. Such an electrode must be a conductor that will maintain a good hot arc; while it must also have light-giving salts combined with it in such a way as to be fed uniformly into the arc, and thus produce the characteristically brilliant flame arc. Due to its very high volatilizing point, carbon is the ideal material to use for the base of the electrode. Unfortunately practically all of the salts of high emissivity suitable for use in an electrode are non-conductors at ordinary temperatures.

Fig. 2. Long Life Flame Arc Lamp

Thus the perfecting of an electrode becomes a very difficult development; for there must always be enough light-giving salts in the mixture to insure that the arc will be maintained uniform in brilliancy and color, and still there must not be such an excess of this material as to form non-conducting points on the electrode tips such as would prevent the lamp from starting when cold.

Thin carbon tubes with very large core holes were first tried, the light-giving salts being mixed with carbon dust and a suitable binder for a coring material. Such electrodes were not satisfactory, as the arc would occasionally maintain on the pure carbon shell alone, and the light would get bluish-white and very dim. All the materials to be used in the electrode were then mixed up homogeneously and electrodes squirted in one piece. This method has proven very successful, although great care has to be taken in "mixing" and "firing" such carbons to get them to run uniformly good.

Besides getting these carbons to burn cleanly and without change of color, it has also been most desirable to maintain a high efficiency, keep the arc steady, and insure a life of not less than one hundred hours per trim. One other point which has somewhat complicated the electrode development, particularly for direct current, is the fact that the method made common by enclosed carbon arc practice in this country, of using the stub of the old upper carbon for the new lower, is still continued. By this procedure less than two inches of carbon per trim are wasted, and it is only necessary to supply one long carbon per lamp per trim.

The particular attractive feature of the enclosed flame arc lamp is that it can be made for operation on any commercial circuit (at least 60 volts line on direct current, and not less than 25 cycles frequency on alternating current), and can therefore replace open or enclosed carbon lamps, out-of-doors or indoors, lamp for lamp. The only limitation to this sweeping statement is that on low values of current flame lamps lose considerably in efficiency. The lamp gives surprisingly good results on 25 cycles at 7½ amperes, with 65 to 70 volts at arc.

The external appearance of a long-burning enclosed flame arc lamp is shown in Fig. 2, while Fig. 3 shows the lamp equipped with a 40-inch inverted concentric diffuser. Lamps of this model are standardized for series alternating current (shown in Fig. 4); for multiple alternating current, at any com-

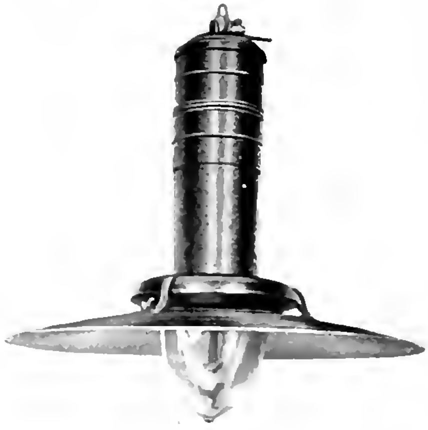

Fig. 3. Long Life Multiple Flame Arc Lamp Equipped With 40 In. Inverted Concentric Diffuser

mercial voltage and any frequency from 25 to 140 cycles (shown in Fig. 5); for multiple direct current 100 to 120 volts (shown in Fig. 6); and for power circuit direct current (with individual external cutout resistances, if desired), two-in-series on 200 to 250 volts, five-in-series on 500 to 600 volts (shown in Fig. 7). The multiple alternating lamps are made with self-contained choke coils for single connection on 100 to 120 volt circuits. For service on 220, 440 or 550 volt, constant potential circuits, it is necessary to operate them from either single circuit or multiple circuit external compensators. No shunt magnets are used except in the case of the series alternating current lamp. The only difference between the power circuit and the multiple direct current lamp is the addition to the former of a regulating weight device which keeps the arc voltages properly balanced when two or more lamps are burned in multiple series.

The mechanisms of these lamps follow very closely enclosed carbon arc lamp designs, except for the fact that a focussing device has been introduced in order to insure steady burning of the arc, and to maintain the arc in the best position for keeping the inner globe clean. The fact that the arc is always at the same point is also of aid in securing constant illumination values. This focussing device consists of a wheel, freely turning on heavy pivot points, with two chain grooves cut on its periphery. The diameters of these grooves are in proportion to the ratio of consumption of the upper to the lower carbons. The groove upon which the upper carbon-holder supporting-chain winds up is made slightly cam-shaped instead of perfectly round, so as to compensate for the weight of the upper carbon which burns away during the burning life of a trim of carbons, thus improving the lamp regulation. This is necessary, as the upper carbon even in an alternating current lamp burns away faster than the lower.

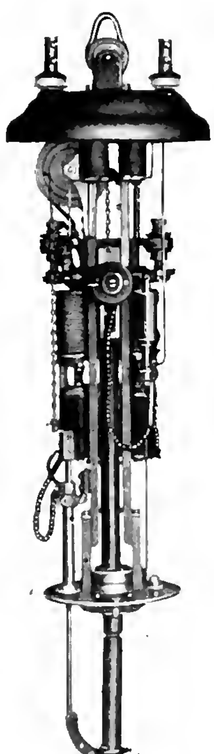

Fig. 4. Series Alternating Current Long Life Flame Arc Lamp

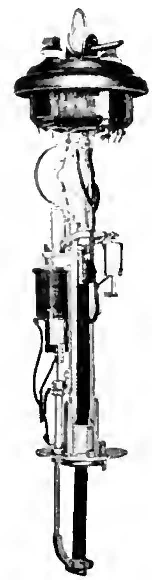

Fig. 5. Multiple Alternating Current Long Life Flame Arc Lamp

A chain guard is placed over the whole wheel, so as to absolutely prevent the chains from falling out of the grooves, or becoming tangled up in any way when lamps are handled. The chain in these lamps is of the safety-link type, made from non-corrosive material, and is extra heavy so as to prevent any stretching in service. The chain is thoroughly "tumbled," so as to remove all burrs and to make it as flexible as possible.

Another feature of this lamp is that the clutch instead of gripping directly upon the carbon, where it would be subject to excessive wear, particularly with carbons as large and heavy as are used in these lamps, is located within a machined opening in the side of the wheel, to which the carbon lifting chains

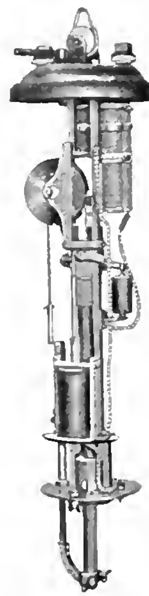

Fig. 6. Direct Current Multiple Long Life Flame Arc Lamp

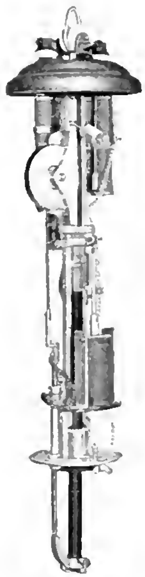

Fig. 7. (Power Circuit) Direct Current Long Life Flame Arc Lamp

are pinned, and upon which they wind up. This clutch has three separate gripping levers, each clamping against the carefully-machined metal surface of the wheel, equally spaced 180 deg. apart; this ensures positive gripping even when subjected to severe vibration. The machined surface is so ample as to practically preclude the possibility of clutch wear. The design and the carefully machined parts of this clutch allow the lamp to "sneak" feed very nicely. The use of the clutch on the wheel, instead of on the carbon itself, also eliminates inaccuracies of "pick up" due to varying diameters of carbons.

As shown in Fig. 1 both an inner and an outer globe are commonly used with these lamps, although the outer globe is not essential for the proper operation of the lamp. Opalescent or clear inner and outer globes can be used in any desired combination. The standard arrangement is clear inner and opalescent outer.

The carbons used in the lamps are homogeneous, 14 inches long and 7/8 inch diameter. Carbons can be supplied for either white or yellow light. It is necessary to renew only one carbon at each trim, the stub of the upper electrode being utilized as the new lower. The life per trim of carbons is 100 to 120 hours with multiple alternating and direct current lamps, and 90 to 100 hours with the series alternating lamp.

An illumination curve, confirming curves and tests already made by the manufacturers, has been prepared by the Electrical Testing Laboratories, New York, showing the distribution of light in a vertical plane from a series alternating 10-ampere enclosed flame arc lamp, trimmed with yellow light carbons, and with clear inner and opalescent outer globes (shown in Fig. 8). The efficiency of the alternating current multiple lamp is 0.28 watts per mean lower hemispherical candle-power, while the direct current lamps give an efficiency of 0.41 watts per mean lower hemispherical candle-power using in all cases clear inner globe and opalescent outer.

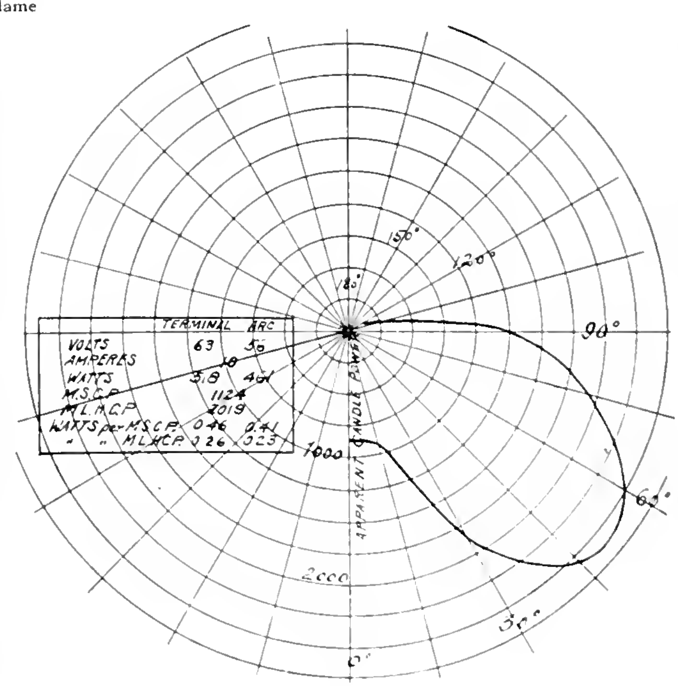

Fig. 8

LONG LIFE ENCLOSED FLAME ARC LAMP

DATA SHEET

	Series A.C.	D.C. 110 Volts Multiple	Power Circuit D.C.	110 Volts Multiple A.C.
Length of lamp	$36\frac{1}{8}$ in.	$39\frac{1}{2}$ in.	$39\frac{1}{2}$ in.	$39\frac{1}{2}$ in.
Approximate weight of lamp	44 lb.	44 lb.	44 lb.	54 lb.
Diameter of globe (outer)	$10\frac{5}{8}$ in.	$10\frac{5}{8}$ in.	$10\frac{5}{8}$ in.	$10\frac{5}{8}$ in.
Size of upper carbon	14 by $\frac{7}{8}$ in.	14 by $\frac{7}{8}$ in.	14 by $\frac{7}{8}$ in.	14 by $\frac{7}{8}$ in.
Gross weight of carbons per 100	75 lb.	75 lb.	75 lb.	75 lb.
Size of lower carbon	$6\frac{1}{8}$ by $\frac{7}{8}$ in.	$5\frac{1}{4}$ by $\frac{7}{8}$ in.	$5\frac{1}{4}$ by $\frac{7}{8}$ in.	6 by $\frac{7}{8}$ in.
Max. and min. term. volt	58–60	100–125	200–250	100–120
Current adjustment	10 amp.	6–6.5	6–6.5	7–7.5
Max. and min. volts at arc	53–55	65–70	65–70	65–70
Outer globe	G.I. 56	G.I. 56	G.I. 56	G.I. 56
Inner globe	G.I. 53	G.I. 53	G.I. 53	G.I. 53

* Lamps will be adjusted for the lowest current specified. Weights given above are approximations only.

Fig. 9. Illumination with One Power Circuit Long Life Flame Arc Lamp

ARC LIGHTS ON THE AMBROSE CHANNEL LIGHTSHIP

By H. V. Allen
Arc Lamp Supply Dept., New York Office

This article gives a brief history of the Ambrose Channel, New York harbor, and describes the installation of carbon flame arc lamps in the lanterns of the lightship that marks the eastern entrance to the channel. The superior penetrating properties of the light from this arc, as well as other features peculiar to the installation are mentioned.—Editor.

Until lately, the successful use of arc lamps on lightships and lighthouses of the government service had been considered impossible: the few experiments carried on by the Department at Washington seeming to indicate, in addition to other objections to this type of illuminant, that the weather conditions were too extreme; although it was recognized that their intrinsic brilliancy and color were extremely desirable qualities.

Fig 1. Ambrose Channel Lightship, showing Flame Arc Lamps on Aftermast

In the early spring of 1910, the subject was given greater attention by several scientists of the Department, especially at the lighthouse depot at Tompkinsville, N. Y. Experiments and tests were begun and assistance was rendered by prominent arc lamp engineers. The work proved to be of unusual interest, as probably no other class of service could be found that afforded greater extremes in operating conditions; to provide successfully for these conditions would insure the ability of the arc lamp to operate under almost any circumstances

The lightship which was thus chosen by the Department for purposes of experiment is easily first in importance of those on the Atlantic coast, if not of the world. It marks the eastern entrance to the Ambrose Channel, named in courtesy of Mr. John W. Ambrose, the originator of the project. This channel, which has been aptly called "the canal at sea," is a passageway five miles long dredged to a depth of 40 feet to allow entrance into New York Harbor of the largest vessels now built.

The undertaking originated in the mind of Mr. Ambrose as early as 1898. Contracts were soon after let for the removal of forty million cubic yards of mud, sand, rock and gravel to form an entirely new and shorter channel to the ocean. Owing to the magnitude and novelty of the engineering problems, however, the contracts were later forfeited. In 1904 the work was undertaken by the government itself, which designed and built especially for the purpose four enormous suction dredges at a cost approximating one million dollars each. The work has now been brought practically to a successful conclusion at a cost approximating four cents per cubic yard for the material dredged, carried out to sea, and dumped.

The channel is marked by twenty-four buoys, those on the starboard side being colored red (entering the harbor) and those on the port side black with white lights for night illumination. A large part of the incoming and outgoing shipping of New York harbor, representing a total tonnage greater than that passing any other spot on the seven seas, now steers its way through this sea canal. Here at the extreme eastern end, as stated before, is stationed the most modern and improved lightship of the government service, officially known as "Ambrose Channel Lightship No. 87," which every vessel is obliged to speak before entering New York harbor.

The power equipment consists of two 7½ kw. marine type General Electric steam engine generator sets, complete with panel boards and all necessary switches for controlling the circuits on the ship.

There are two signal masts, each carrying three lanterns of standard lighthouse design, which are hung in gimbals in order that the plane of illumination may be maintained horizontal regardless of seaway. A vertical type carbon flame arc lamp operating at 110 volts, $6\frac{1}{2}$ amperes, and giving a horizontal maximum candle-power of approximately 4000, is placed in each lantern. The arc is placed at the focus of the lens, which is so located that the light emitted from the arc through a space of 60 degrees is concentrated and passes from the lens with a divergence of about 8 degrees; the result being that a powerful zone of light is projected in a horizontal direction. The three lenses are spaced at equal distances about the masts and are so arranged that at least two of them are visible from any point of view. At a distance of approximately two miles, the two lights merge into one apparent light source. A complete equipment is maintained for eight lamps, although only three are operated at one time. The three lanterns may be simultaneously lowered by a windlass to the deck of the vessel, passing through the roof of a deck-house en route, and are there inspected, cleaned, adjusted, and the carbons renewed at least once a day. In their normal position the lamps are 55 feet above the water line and are visible for a radius of $8\frac{1}{2}$ miles at sea level, 15 miles at an altitude of 15 feet, or twenty-three miles at 50 feet above sea level. The lights are first "picked up" by incoming vessels soon after passing Fire Island.

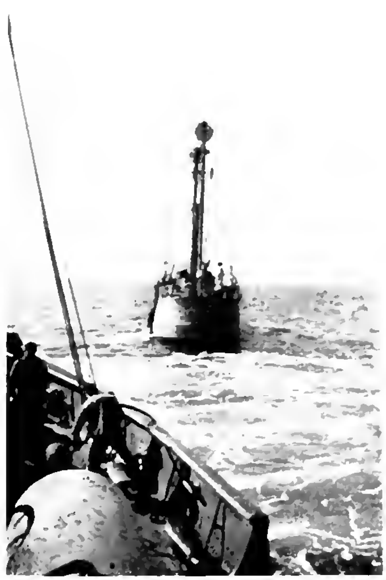

Fig. 2. Fore and Aft View of Lightship

Fig. 3. View from Deck showing the Three Arc Lanterns

The operating resistances of the lamp are mounted in the engine room, care being taken to insure cool operation. A separately driven motor is also placed in the engine room to control the flashing device, which operates alternately a 12 second flash and 3 second release, this being the distinguishing and characteristic flash of the lightship.

Incandescent lamps were used for this service for a long time, but on account of the size of their filaments, it was found difficult to place the light at the exact focal point. A further advantage of the flame arc lamp is found in the light color it emits, experiments having shown that the yellow and white light of an arc has greater penetrating power through fog or steam and can be seen for a greater distance than the light of a tungsten filament. Similar phenomena are readily remarked on any water way traversed by vessels carrying red and green side lights, where the red port light will penetrate to a greater distance than the green starboard light, although at close range the impression of the red on the eye is never so intense as that of the green.

The accompanying diagram showing the deck plan of "Ambrose Channel Lightship No. 87" will give a comparatively clear idea of the arrangement and convenience of the whole vessel. Although the lights on only one mast are kept in operation at one time, the after mast is maintained constantly in readiness, with a duplicate set of lights for emergency use.

The equipment has now been in continuous service for more than a year, during which time some improvements in the lamps have been effected through mutual experiments by the crew of the lightship and the engineers responsible for the installation. Such success has been achieved that steps are now being taken to equip other lightships in a similar manner, with the promise that the carbon flame arc lamp will prove to be the most efficient illuminant for this most trying of all services.

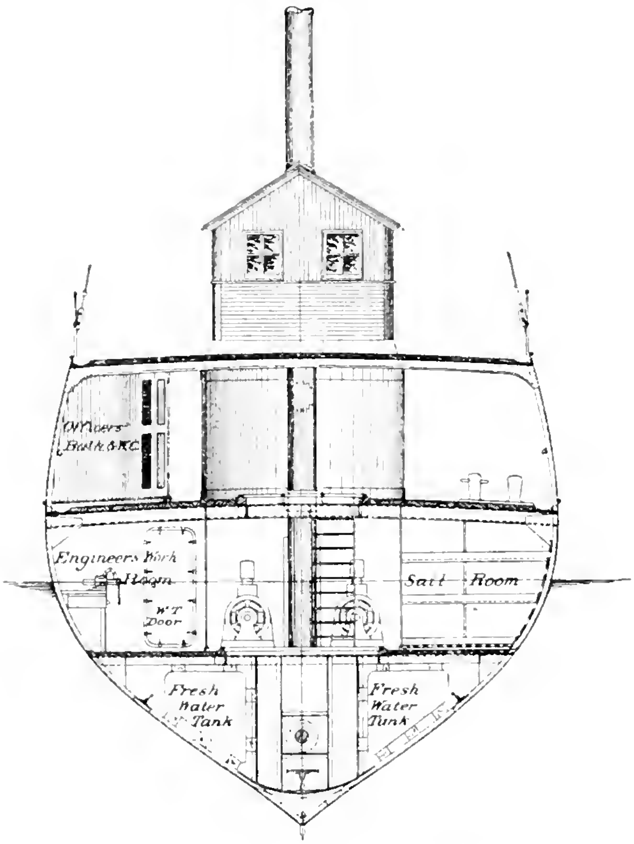

Fig. 4. Section Through Lightship, Showing Location of Steam Engine Generator Sets

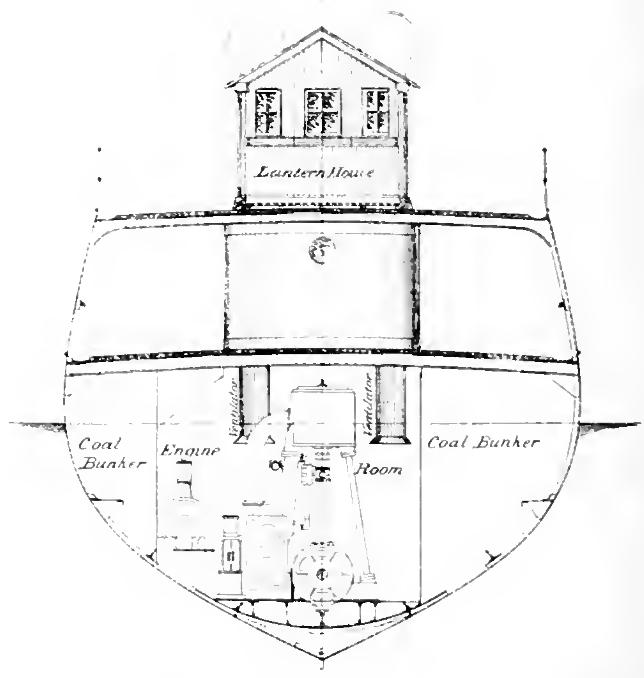

Fig. 4a Section Through Engine Room

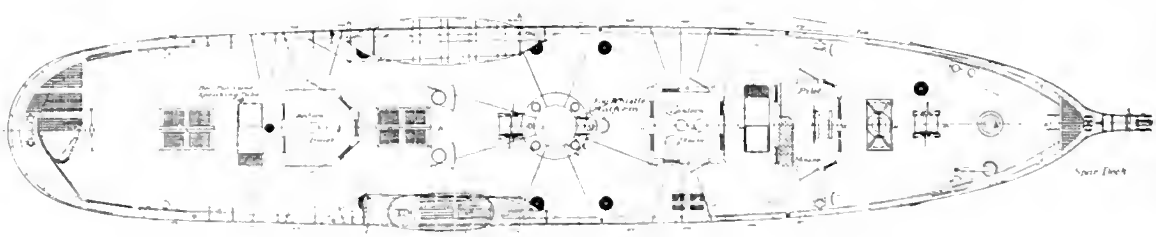

Fig. 5. Deck Plan. Dotted Circles Around Mast Indicate Position of Lanterns

ARC LAMP MANUFACTURE, A DESCRIPTION OF THE NEW ARC LAMP FACTORY AT LYNN

By W. G. Mitchell

Manufacturing Engineer, Arc Lamp Department, Lynn

In these times when so much is being said of scientific management, of close inspection of methods and reduction in costs, it is interesting to record the growth and progress along parallel lines of one of the largest of modern factories. The day of the small mill, at least for electrical products, is over. The unparalleled advantages for research, invention and systematized production that are secured by a large business organization, make it certain that in the future the principal progress in the applied sciences will be the result of co-operative efforts of large business enterprises. The most recent discoveries and scientific applications of the proper principles upon which a modern factory building should be constructed, after a necessary allowance for local and particular requirements are considered, may be gathered from a study of one of the most recently completed buildings of the General Electric Company, and the particular work which is carried on within, for which it was designed.

Fig. 1. Arc Lamp Manufacture. General View of Assembly Department and Machine Shop

THE NEW BUILDING

Building No. 40 of the Lynn Works was begun in August, 1910, and finished in March, 1911. It is 630 ft. long and 80 ft. wide, with two outside towers 40 ft. by 30 ft. It is a three-story building, steel framed and brick filled, with wood floors. Each floor within the building contains 50,400 square ft., and an annex at the south end of the first floor has an additional 5400 square ft., making a total floor space for the building of 156,600 square ft. At present there are about 600 employees in the building; but the different floors are laid out with a view to increased output, and several hundred more employees could be accommodated.

Protection Against Fire

The building is of fireproof construction and as far as possible all the internal fittings and equipment are of fireproof materials. Elevators, stairways and washrooms are in the external towers and these towers are absolutely fireproof, even the floors being of cement. Fire doors protect the openings to stairways and elevators. The building has a first class fire-fighting equipment with high pressure mains and hoses on reels. Fire buckets and sand boxes are placed at close intervals throughout the building. A number of the men employed in the building are members of the company's fire brigade. Regular drills are held. In case of an outbreak of fire, the building could be completely emptied in a very few minutes.

Light and Power

Electric current for lighting and power is distributed from a power plant at one end of the annex on the first floor. The equipment consists of transformers, motor-generators and a switchboard installation with marble panels and all necessary protective devices. The power circuits are three-phase alternating and three-wire direct current. The first and third floors are lighted by alternating current arc lamps and the second floor is lighted by direct current intensified enclosed lamps with a special motor-generator set for supplying the current.

Fig. 2. Arc Lamp Assembly Department

Transportation

Particular attention has been given to the transportation of material to and from the building and during the progress of the work. A standard-gauge track comes in at the north end of the building. All raw material enters here, where it is unloaded, and material for the two upper floors is sent up by the elevator which is close by. The different parts of the work have been so arranged that the material after entering at the north end goes steadily forward until by the time it arrives at the south end, it is completed. Here standard-gauge tracks also run into the building and all material is loaded for shipment. Arc lamps, accessories and all small articles are boxed on the first floor and loaded on the cars.

General Description of Work

Three departments are included in the building. Most of the first floor is given up to the manufacture of gasolene engines and automobile motors, to the plating and polishing room and the shipping department; while about two-thirds of the third floor is occupied by the apprentice department. The remainder of the building is occupied for the manufacture of arc lamps and accessories. In addition to this, a large amount of floor space in other decentralized departments, such as foundries, press department, and screw machine department, is also devoted to the manufacture of arc lamp parts. It is not

Fig. 3. Arc Lamp Casing Assembly Department

intended to describe in this article the manufacture of gasolene engines or automobile motors, nor the working of the apprenticeship department.

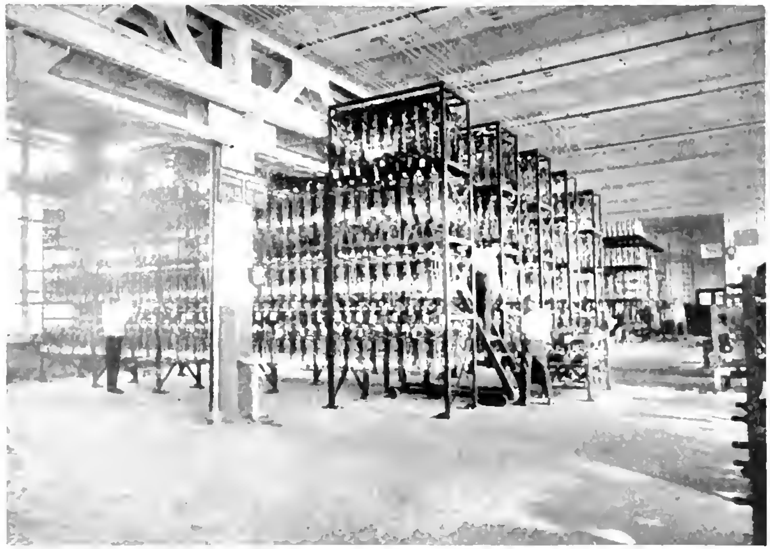

Fig. 5. Arc Lamp and Casing Storage

Employees' Welfare

Careful provision has been made for the comfort and convenience of employees. The three floors all have high ceilings, and as the side walls are almost entirely glass the light and ventilation are all that can be desired. The washrooms in the outside towers are thoroughly lighted and ventilated. Rest rooms, under the charge of a matron, are provided for the female employees; and a mess room has been fitted up in the north tower for assistant foremen who wish to spend the noon hour in the building. Each employee has a separate steel locker.

Fig. 4. Arc Lamp Winding Department

Every precaution is taken against accidents, and a complete equipment is kept on hand for giving first aid in case of injury. This equipment is in charge of men who have had special training and are competent to take care of any ordinary accident. All machine tools and electrical apparatus are very carefully guarded and serious accidents are extremely rare.

Equipment

There are no overhead shafts nor belts, and all machine tools are driven by individual motors, with a resulting gain in efficiency, economy, lighting and ventilation. All small fittings, such as stock shelves, stock and transportation boxes, storage racks and chairs are made of steel, which gives protection in case of fire, and has been found to be more economical than wood on account of its greater durability. Every effort is made to keep off the floors material in process of work; and for this purpose low sheet-iron shelves are provided behind all bench workers, so that material can be kept on these shelves.

THE ARC LAMP DEPARTMENT

The Arc Lamp Department is entirely self-contained in this building. The main offices occupy about 4,000 sq. ft. at the south end of the second floor, and include engineering, drafting, production and manufacturing departments. Adjacent to the offices is the experimental department, occupying about 3,200 sq. ft.

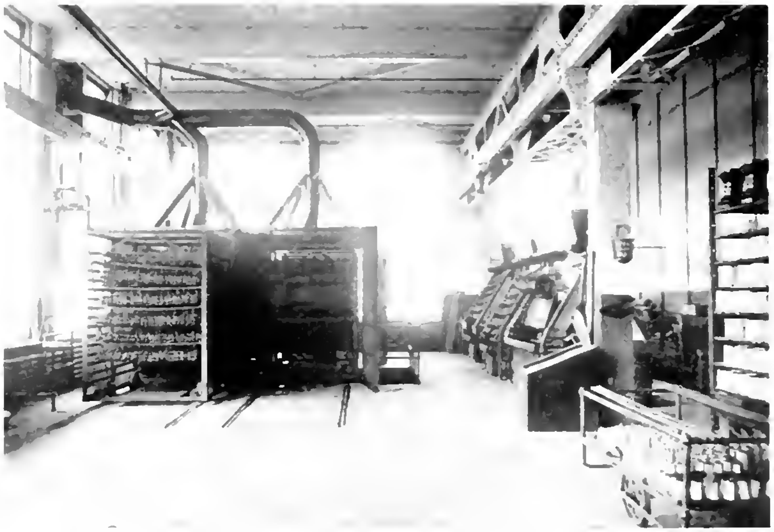

Fig. 6. Japanning Department

Experimental Work

In modern manufacturing it is necessary to devote a large amount of time, skill and money to experimental work, with the idea of improving existing designs and developing new lines of apparatus. This is particularly true of arc lamps where there is a constant demand for cheaper, more efficient, longer burning, and more ornamental types. In this building the experimental department has been very carefully laid out. It occupies the south-west corner of the second floor, where it obtains light from both side and end windows. It is subdivided into three rooms. The model room contains a complete equipment of machine tools, benches and testing stands, so that models of new lamps can be made and tested on the spot. Next to the model room is the special test, which has facilities for making prolonged tests on as many as 40 or 50 lamps at one time. This testing room is entirely separate from the commercial test and is devoted to experimental work. The third division of the experimental department is an exhibition room. This has solid cement walls, and can be transformed, when required, into a dark room for showing lamps in operation in the day time. All standard circuits are wired into this room; samples of all the standard lamps are hung up ready to be put into operation by a push-button switch, so that any type of lamp can be shown without delay. This room is also intended for meetings and consultations. All three rooms of the experimental department have separate marble switchboards and can make use of different circuits without interference.

Manufacture of Arc Lamps

The design and manufacture of arc lamps present conditions somewhat different from those pertaining to machinery in general. Most machines are designed to repeat a certain regular cycle of operations, and moving parts are so arranged that they may receive constant attention and lubrication.

An arc lamp mechanism is not designed for any regular series of operations. Its object is to control an arc which is constantly tending to vary, and the mechanism must do whatever is necessary to overcome this tendency and prevent variation. All parts of the mechanism must be built to stand prolonged exposure to weather, acid fumes and dust, and no lubrication of bearing surfaces is permitted. High electrical insulation must be maintained under very severe conditions.

To meet these requirements, an arc lamp mechanism must be very carefully designed and manufactured. In the manufacture of the lamps a great variety of materials are required, such as iron, steel and alloy castings, punchings, drawn sheet metal and spun metal, as well as electrical windings and insulations. In making use of these materials most well-known manufacturing processes are used; in addition there are many special operations which have been developed in connection with this particular work. Probably the manufacture can be best described under headings of Ordering and Stocking Material, Machine Work, Bench Work, Protective Treatments and Finishes, Inspection and Testing.

Ordering and Stocking Material

Successful manufacturing requires prompt deliveries, and at the same time the smallest possible idle stock. To meet the first requirement, it is necessary to keep on hand at all times, proper quantities of finished lamps ready to send out. To meet the second requirement, it is necessary to keep the bulk of the stock in the form of raw material and partly-finished parts, which can be finished into a variety of different types of lamp.

Three stock rooms are used by the arc lamp department. At the north end of the building is the receiving stock room, where all raw material comes in and is stored until ready to be given out for the different manufacturing processes. By the time the parts are finished as far as possible, without actually putting them into a lamp, they have moved forward about 300 ft. and are then at the finished parts stock room. Here they are held until wanted for assembly into complete lamps. The assembly department is directly opposite this stock room; here the lamps are finished and passed forward to be tested, and are then hung on iron racks, directly opposite the test and close by the elevator which will finally take them down to the shipping department. The three stock rooms are necessary in order to keep the material constantly moving forward and prevent unnecessary handling.

Machine Work

Machining of arc lamp parts includes most standard machine tool operations; but on account of the comparatively large quantities there is plenty of room for ingenuity in connection with jigs, fixtures, and other devices which make for economy and accuracy of the work. One of the most important of the machining processes is the making of dashpots, where great care and accuracy are necessary to ensure the successful operation of the lamp. All material for this work is bought under special specifications, and the inspection and testing of dashpots is carried to a point of very great refinement.

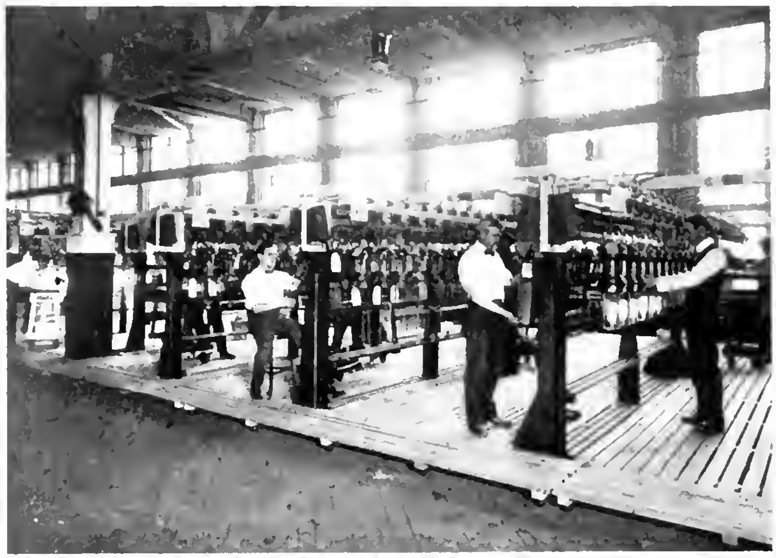

Fig. 7. Part of Arc Lamp Testing Department

In connection with the machine work, there is a tool-makers' department equipped with a complete line of machine tools suitable for doing the very best class of work. Jigs and special fixtures are made in the tool room, the men of which on such work can keep in close touch with the production machining, in connection with the designing of labor-saving devices.

Bench Work

This work includes insulating, winding and assembly of magnets and resistances, and the putting together of a great variety of small parts which are later turned into the finished parts stock room ready to be further assembled into complete lamps. The bench-work is so located that the parts coming from the machine shop pass forward to the benches.

Small brass and copper parts are dipped, and in some cases polished or nickel plated; while large copper parts, such as casings, are usually finished by oxidizing the surface of the copper.

The magnets and insulations require very careful treatment to protect them against exposure to moisture. Insulating material which will absorb moisture is never used without having received a special treatment to render it non-hygroscopic. Magnets, after being wound with insulated wire, are impregnated with a heat-resisting and moisture-proof compound. The operations include preliminary baking to force out all moisture, exhaustion under 30 in. vacuum to remove air, impregnation under high pressure, and subsequent baking at high temperature and pressure to fix the impregnating compound. The result is a coil of great mechanical strength, which will withstand high temperature and which is absolutely moisture-proof. The equipment for this treatment is located in the japan room.

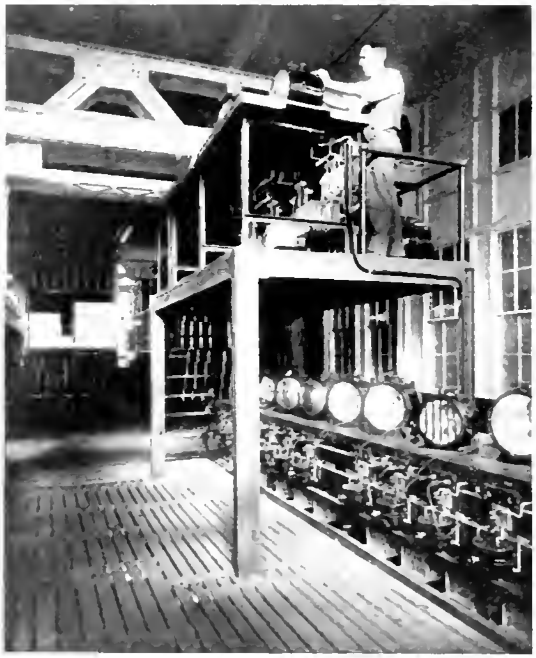

Fig. 8. Testing Arc Headlights

Inspection

Quantity manufactured requires a very rigid inspection system to ensure first-class material and workmanship. The inspection department is one of the most important in the manufacture of arc lamps. Material and workmanship are constantly inspected from the time raw material is received until the finished lamp is shipped. After each process, the inspector punches the operator's piece-work slip to show that he has inspected and approved the piece; without the inspector's approval, neither the work nor the operator's slip can be passed through. This inspection is applied to all parts, and when the lamp is completely assembled it is passed by a mechanical inspector, who goes over every detail and approves the lamp before it is sent to test.

Testing

Each lamp has a thorough commercial test under the conditions specified by the customer. The testing department occupies about 6,400 sq. ft. and is very thoroughly equipped for quick and accurate testing. Lamps are hung on racks so arranged that any circuit may be connected to any rack. In the center of the test is a small individual power plant, with marble switchboards and machines for giving all standard alternate current and direct current circuits. The testers stand on wooden floors supported on glass insulators above the main floor, and every precaution is taken for the safety of men engaged in the work. All lamps are actually operated under commercial conditions and remain on the circuits long enough to show any defect in the manufacture. After all tests are passed satisfactorily, they are given a final high potential test and are then ready for shipment. One of the special features on the arc lamp test is a platform for testing headlights. This is raised to such a height that the beam can be focussed at the other end of the building, more than 500 ft. distant.

Finishes and Protective Treatments

Practically every part of an arc lamp must have a protective finish which will resist severe conditions of outdoor service.

Japan makes an excellent finish for iron and steel castings and sheet metal, and this finish is very largely used in arc lamp manufacture. The japan room is completely enclosed with cement walls and contains a first class equipment of dipping tanks, draining racks, gas and steam ovens. Articles to be japanned are dipped or painted with baking japan, fired at a high temperature in the ovens, then dipped a second time and again fired. The result is a black glossy finish which will withstand the weather for a long time, and will not flake or scale off. The quality of this work depends entirely upon proper materials and proper temperatures for baking.

Small steel parts are usually finished by galvanizing, either by the hot dipping process or by electroplating with zinc; both of these methods give a very efficient protective coating. This work is done in the plating room on the first floor which is a part of the arc lamp department, although it also does the whole of the plating and polishing work for the River Works.

INTENSIFIED ARC LIGHTING IN THE STORE OF BONWIT, TELLER & COMPANY, NEW YORK CITY

By W. D'A. Ryan

Director, Illuminating Engineering Laboratory, Schenectady

In this issue of the Review Mr. Alfonse Kaufman, associated with Mr. P. R. Moses, consulting engineer of New York City contributes an article under the title "A Good Example of Modern Store Lighting."

Fig. 1. Design of Lamp on First Floor

Fig. 2. Design of Lamp on Second and Third Floors

Mr. Kaufman is very modest in his title. The lighting of the new Bonwit-Teller store is without question the most remarkable achievement in interior arc lighting to date; the color value of the light is excellent, and the artistic and novel treatment is very unique.

It has been common practice to ornament arc lamp casings with composition or papier-mache, which naturally confines the heat. Ample ventilation is rarely provided and the composition frequently cracks or chips.

The Bonwit-Teller casings are cast in bronze and the relief is much sharper and more pleasing than in composition. Ample ventilation is provided and the finish is a rich dark bronze. The ornamentation is highly artistic and the lines are so strong and well proportioned that the units possess a dignity well in keeping with the surroundings.

The designs are by Mr. J. W. Gosling of the Amboy Works, and he is to be congratulated on the results. The general effect is most pleasing and difficult to describe, and anyone interested in modern store installation could ill afford to neglect inspecting this installation before deciding on a lighting system, particularly where color value and aesthetic features are of primary importance.

The watts-per-square-foot is somewhat higher than would be required for equivalent foot candle illumination with Mazda lamps. In this case, however, it is considered that the advantage in color value more than compensates for the slight difference in the cost of operation.

The design of the hanging lamps for the first floor is shown in Fig. 1, while the lamp for the second and third floors is shown in Fig. 2. The construction of the recessed ceiling drum, lamp, dead resistance, and ventilating flues, is illustrated in Fig. 6, on page 613.

The curves, Figs. 3, 4 and 5, page 612, represent a section of each floor, giving the foot candles on the counter levels on the 1st, 2nd and 3rd floors respectively. A remarkable uniformity of distribution is clearly shown. This feature is also emphasized by the photographs of the store.

For additional details I refer the reader to Mr. Kaufman's article.

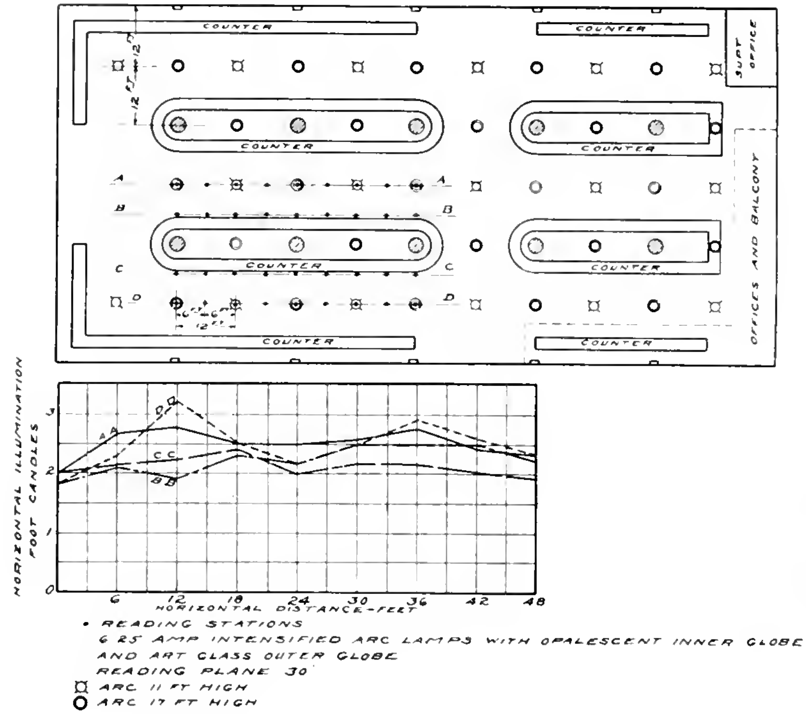

Fig. 3. Diagram of First Floor and Curves Plotted from Illumination Tests

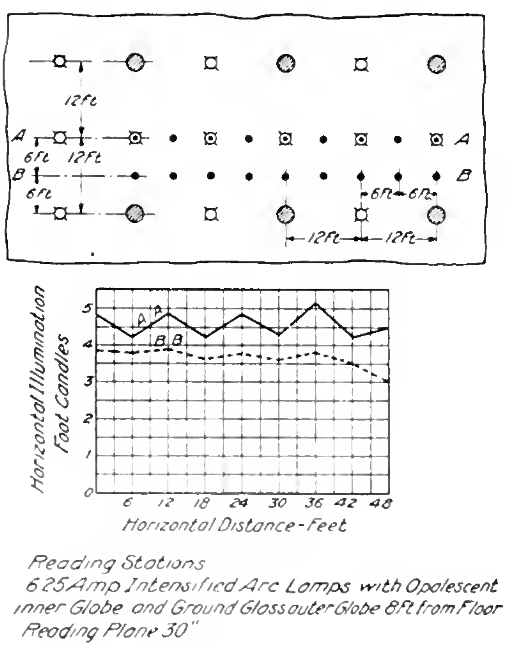

Fig. 4. Second Floor

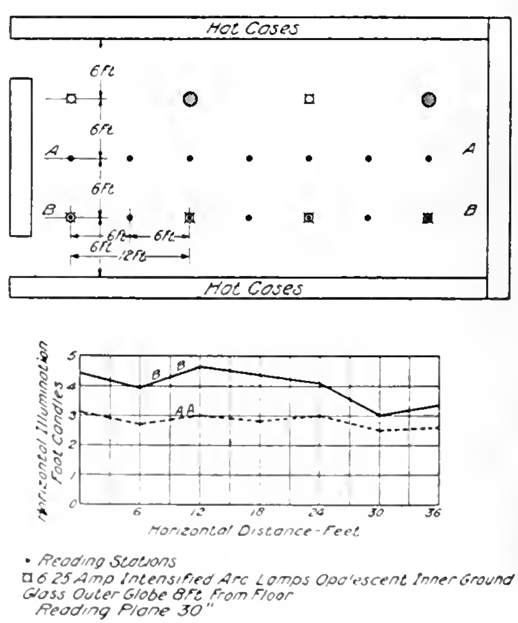

Fig. 5. Third Floor

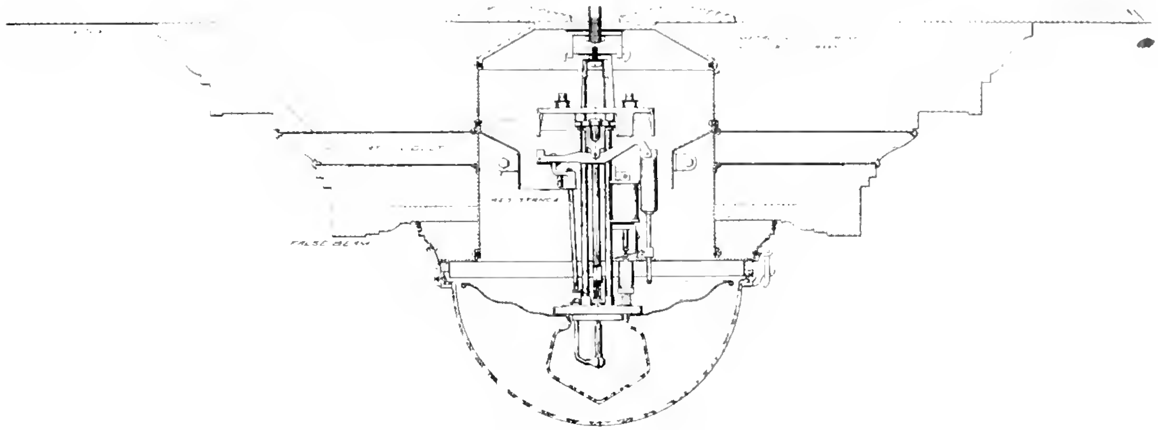

Fig. 6. Sectional Diagram of Recessed Lamp

A GOOD EXAMPLE OF MODERN STORE LIGHTING

By Alfonse Kaufman, Consulting Engineer, New York City

The new store of Bonwit, Teller & Company, located at the corner of Fifth Avenue and 38th Street, New York City, was recently opened to the public for the exclusive sale of women's, children's and infants' apparel.

When purchasing goods of this kind, the customer almost invariably carries the articles to the nearest window for an examination by daylight, for it is a generally appreciated fact that certain colored fabrics, particularly in

Daylight View of First Floor (also, see page 566) shades of blue, purple or green, present a very deceptive appearance when viewed by most kinds of artificial light. For instance, certain shades of purple will appear blue under some forms of artificial light and pink under others. Therefore, when selecting the type of illumination for this store, the matter of color value was given first consideration; it was, in fact, the deciding factor.

A comparison of the light characteristics of the several illuminants in general use will show that the light from the intensified arc lamp most nearly approaches daylight in value. With a knowledge of this fact, the writer, in co-operation with engineers of the General Electric Company, drew up plans and specifications for the use of this lamp as the source of light in the Bonwit-Teller store.

When entering most stores illuminated by arc lamps, the attention of the customer is usually diverted from the merchandise to the long row of glaring lamps. This objectionable feature is also noticeable in some recent installations in department stores where spherical incandescent lamps are suspended from the ceiling in numberless rows; no consideration being given to the selection of glassware to diffuse the light. Each illuminated sphere plays the part of a spotlight to the eye and is very conspicuous. To avoid this unpleasant effect, it is necessary to keep the source of light out of the direct line of vision.

The writer conceived the idea of recessing an arc lamp in the center of each of the false beams forming the bays and, as the ceiling of the first floor is 19 feet high, it was decided to suspend a hanging arc lamp with bronze ornamental casing in the center of each bay. The object of this arrangement was to have the recessed lamps provide the principal illumination, while the hanging lamps, fewer in number, were to serve mainly as ornaments, since the store would have an unfinished appearance without them. In all, twenty-six recessed and seventeen hanging lamps are installed on the first floor. The arrangement,

Night View of Second Floor

as outlined, gives a very uniform distribution, and the light shows the true daylight color of the merchandise. The bottoms of the recessed lamps and of the hanging lamps are respectively 17 ft. 6 inches and 11 ft. from the floor.

The recessed lamps were of special design with two vent ducts terminating in a small register. The coils of the lamp, of which there are four, are placed in a ring of spun copper, forming a ventilating chamber so arranged that the heat causes a current of air to pass through the vent ducts at a fairly high velocity, thus preventing any dust from settling on the plaster ceiling. This has proved to work very effectively.

The selection of the glassware was of great importance, and after many trials a light granite opal glass was chosen for the outer globe, and an opalescent glass for the inner globe. The granite opal glass is not uniform in color, but is of varying density, this giving a very pleasing effect; in fact, the glass diffuses the light so thoroughly that there is an entire absence of the glare so common with ground glassware. A nickel reflector is provided to throw the light downwards.

The lamps were wound specially for about $6\frac{1}{4}$ amperes, in order that higher intensity than that obtained from the commercial lamp might be realized. At first thought the power consumption may be considered high, but the benefit to be derived from having a properly illuminated store is worth many fold the slight cost of the additional power required.

The lamp is supported by a bayonet joint from a cast iron box embedded in the plaster work of the false beam. The lamp is accessible for repairing, and since the outer globe is hinged, trimming is easily accomplished.

The lighting of the other floors is effected by means of intensified arc lamps in bronze casings, suspended from the ceiling by chains in conventional arrangement. In the French room, where evening gowns are displayed, tungsten lamps set in crystal chandeliers and side brackets are used. Carbon and tungsten lamps are used in the display cases and stock rooms. The work tables are lighted with tungsten lamps fitted with reflectors, one lamp for each operator. The show windows are lighted by means of Holophane-D'Olier steel reflectors set alternately at 30 deg. and 15 deg.

The castings for all arc lamps were made by the Amboy Works, Perth Amboy, N. J., and the arc lamps were ma'e by the General Electric Company.

THE EMERGENCY LIGHTING OF THE RUINS OF AUSTIN, PA.

By F. C. Barton

The story of the failure of the Austin dam is still fresh in everybody's mind. In a few minutes a whole township was practically destroyed by flood. An army of men was employed to grapple with the task of extricating the bodies and removing the *debris*. This article describes the emergency lighting plant which was supplied to enable the work to be carried on unceasingly day and night.—Editor.

In the ruins left by the flood which practically wiped the town of Austin, Pa., out of existence, were buried almost eighty human beings. The work of recovery was very difficult and consequently slow, even with the force of 1200 men which worked from early morning till dark. The most difficult problem lay in the searching of the ruins along Main Street. This street ran crosswise of the valley, and the brick buildings on the down-stream side, though badly damaged, withstood the impact of the flood. They stood, not because of their own strength, but by reason of the mass of brick, mortar and other non-floating *debris* thrown against them from across the street. On top of this foundation were piled the collapsed ruins of house after house, all tending to relieve the strain on the standing buildings, rather than augment it. Terrible as was the picture of devastation when the havoc had been wrought, even more striking must have been the sight of the actual destruction during the few minutes in which the flood did its work. Eye-witnesses state that no water could be seen coming down the valley, but that the only thing visible was a wall of wreckage moving rapidly along, carrying on its crest whole houses which rolled and tumbled and broke up like so many toys.

In the overhauling of this mass of wreckage along Main Street, lay the greatest need for haste, for reasons of sanitation, if nothing else. When, therefore, the Health Department engineers realized that the task would take much longer than originally contemplated, night work on a large scale was decided upon, and the offer made some days previously by the General Electric Company was accepted.

"*Oct. 1st.*

An officer of the General Electric Company talked with a person in authority at Austin by 'phone, and offered assistance in the form of a temporary electric lighting plant.

"*Oct. 5th.*

Offer accepted by Dr. Samuel G. Dixon, of the State Department of Health. Lighting apparatus shipped by factory."

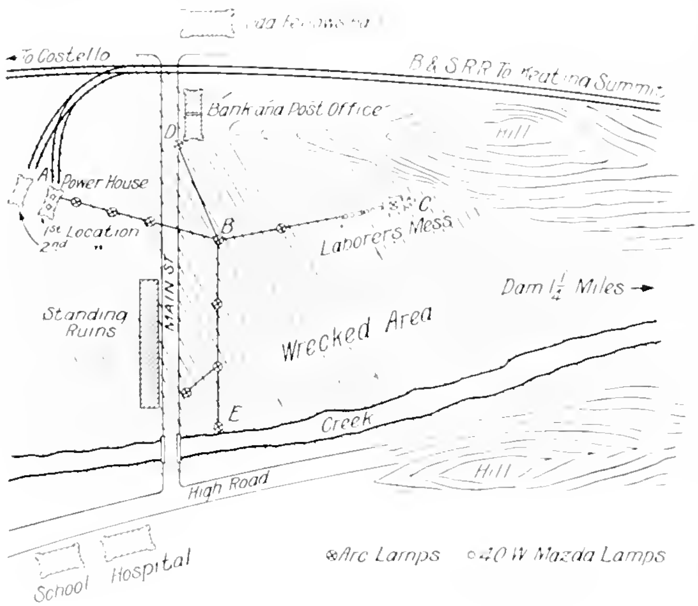

Fig. 1. Wrecked Area Showing Location of Power House

The foregoing extracts from the power house log represent the initial moves by the General Electric Company and by those in authority at Austin, toward the establishment of an emergency electric lighting plant, to enable the search for bodies to be carried on both day and night.

Word was received in Schenectady by 'phone on Thursday, Oct. 5th, that there was urgent need for night work, which could not be carried on without some satisfactory means of artificial illumination. Orders were immediately placed with the Lynn and Schenectady plants for apparatus, which included a standard 10 kw. gasolene-electric generating set, a standard motor-driven cooling radiator, a gasolene tank, twelve 125-volt multiple enclosed arc lamps, twelve 40-watt Mazda lamps, and 5000 feet of No. 8 insulated wire. All of this apparatus left the factories the same evening. The same night the writer also left Schenectady, arriving at Costello about noon the following day. From Costello it was necessary to drive a distance of three miles over a much washed-out road up the valley to Austin. As none of the apparatus had arrived by that time, the afternoon was spent in becoming acquainted with the general disposition of the place, and in selecting locations where lighting could be used to the best advantage. During Friday night most of the apparatus arrived, and on Saturday morning work was really started.

An Erie box car No. 75375 was appropriated for use as a power station, and placed on a siding adjacent to the express car in which the apparatus arrived. Labor being plentiful, the shifting of the gasolene set and other apparatus wanted in the box car was a simple matter. After the transfer was made, the car was pushed down a cleared stretch of track to the position shown in Figs. 1 and 5. At noon on Saturday a construction man from the Philadelphia Office arrived to assist in the work, taking charge of the outside work, including pole lines and arc lamps, while the writer attended to setting up the plant. Certain difficulties were encountered in piping up the gasolene engine, because of the difficulty of securing pipe and fittings; but a brief

Fig. 2. Exterior of Power House

search of the wreckage in the vicinity of the power house never failed to bring to light the desired articles. The poles, as will be seen in Fig. 6 were composed entirely of lumber taken from the wreckage, insulators being noticeable for their absence.

On Sunday morning the system, including eight arc lamps, was ready for operation, but up to that hour no gasolene had arrived. Having foreseen that there might be difficulty in obtaining gasolene, because of the reticence on the part of the transportation companies who handle this commodity, the writer had made a canvass of all of the wrecked automobiles in the vicinity, and had located a supply which would have been sufficient to carry the plant through one night. When, therefore, everything was ready, eight or ten gallons of gasolene were drawn from one wrecked automobile and the system tried out. During the afternoon a barrel of gasolene was brought in to the power house in a special car, as a result of an appeal by the Commissioner to the Railroads. On Sunday night the plant was put in regular operation, and the electrical force, consisting of "the man from Philadelphia" and the writer, moved from the converted passenger car in which it had been sleeping, along with the engineers and two doctors of the Pennsylvania State Department of Health, to "Erie, 75375 Railroad Avenue."

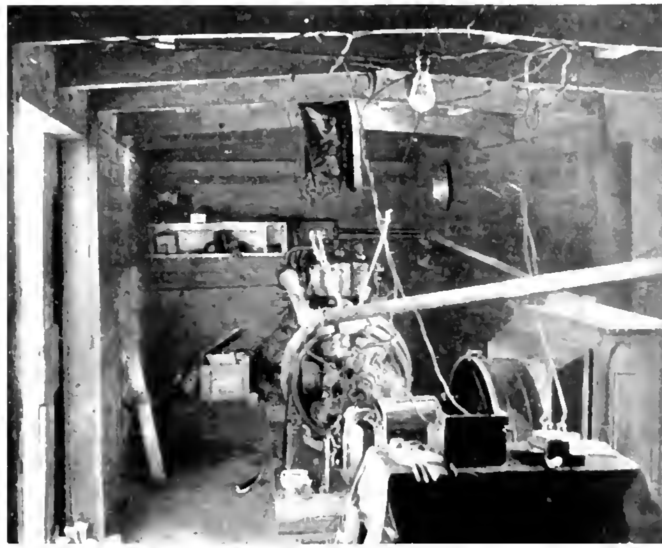

Fig. 4. Interior of Power House

Fig. 3. Partial View of Wrecked Area Showing Laborers' Mess tent in Background

Figs. 2 and 4 show the exterior and interior views of the power house. On Monday a request was received from Dr. Dixon, Commissioner of the Pennsylvania State Department of Health, to light electrically the laborers' mess, which is shown in Fig. 3, and to make certain other changes. These changes added three arc lamps and seven 40-watt Mazda lamps to the equipment, making a total of 11 arc lamps and 9 incandescent lamps. In addition to this, the power house was moved and there were two more poles to set at that end of the line in consequence.

The power house crew worked normally a 24-hour shift, the daylight hours being spent in line construction made necessary by changes in conditions, and the night spent in running the plant, which meant going to bed and sleeping all night. An illustration of the watchfulness of the crew may not be out of place. So excellent were the sounding-board properties of the car sides, that the power-house was not the quietest place in the world. This, however, did not prevent the crew from sleeping; but in the middle of one night an arc light carbon, located with others on a shelf at the far end of the car dropped to the floor, causing both men of the night force to wake instantly. Old construction engineers and others, accustomed to taking their sleep, on occasion, to the accompaniment of various degrees of noise, will probably be able to cap this experience with many of their own.

Fig. 5. The Power House is in the Truck Located near the Center of Picture

The plant was run without a single interruption each night from 5:45 in the evening until 6:45 in the morning, or as near to that time as the crew woke up. From the remarks of Dr. Dixon, his engineers and members of the Pennsylvania state constabulary, the writer gathered that the service rendered by the plant and lights amply justified its being. The state police are mentioned, as in their hands lay the policing of the entire district. This duty they performed most thoroughly; so much so that with the police in the day time, and the combination of police and arc lights at night, a certain valueless souvenir desired by the writer was still reposing, when he left, in the position in which he first saw it. Somehow it seemed that the joke was on the man who made the place so bright he could'nt loot.

A glance at Fig. 1 will serve to show the distribution system. A single pair of No. 8 wires, carrying 3 arc lamps, was run to the distribution center B. From this point the circuit branched in the direction of the bank, the laborers' mess, and across Main street in front of the standing ruins. After the first night's operation it was found advisable to run a second pair of No. 8 wires, paralleling the first pair, from the power house to point B, in order to cut down the line drop. With this last addition the distribution was quite satisfactory.

It is probably unnecessary to make further comment on the serviceability of this "first-aid" generating plant. Without it all work must perforce have been held up during the hours of darkness, all of equal value to the daylight hours, and of which every moment was precious; with it night was turned into day, and full value extracted from every minute by the small army of workmen.

Fig. 6. The Wreckage in Main Street. This View Shows Structure of Temporary Arc Lamp Poles

THE THEORY OF THE MERCURY ARC RECTIFIER

By W. R. Whitney

Director of Research Laboratory, Schenectady

The extended application of the direct current luminous lamp has been responsible for the growth of a contributing industry in the series mercury arc rectifier outfit, employed for changing alternating current to direct current. This article discusses the theory of the rectifier's operation.—Editor.

The mercury rectifier is an apparatus for changing an alternating current into a direct one. Just how it operates might be described by a half dozen different writers in as many different ways. Those who are most interested in the modern conceptions of the flow of current through conductors of metal, might depict the phenomenon of the rectifier to accord with their picture of the current-flow in metals. Another, interested particularly in the production of gaseous ions or conducting particles of gaseous materials, might spend his descriptive talents in picturing the phenomena in the light of studies on localized ionization. Probably a description by anyone would disclose more or less of what is occult to the layman and speculation to the expert. This is because it is difficult to describe any set of physical phenomena without co-ordinating or elucidating them by the use of better known processes. We will therefore try to gradually and imperceptibly slip into a description of the mercury arc rectifier along the path of plain description of simple experiments, without reference to anything speculative.

If an evacuated tube contains two mercury terminals or electrodes and these are connected to a source of direct current, there is, under ordinary conditions of moderate voltage, no visible effect nor flow of measurable current. The entire apparatus may even be heated so hot that the mercury boils and the tube is filled with mercury vapor at high pressure, and yet no appreciable current will flow. In general, then, mercury vapor, hot or cold, has been considered a very poor conductor of current. There is, however, a mysterious something which can make this simple tube, with its two mercury electrodes, a good conductor of the current, and that, too, in one direction only.

Here lies the secret of its use as a rectifier (no matter what the explanation). Barring theory, we may say that having started the current (no matter how), it will continually flow in the same direction, but will cease altogether if an attempt is made to reverse its direction, as by suddenly changing the polarity of the electrodes. This uni-directional flow of current may be brought about by applying an excessively high potential between the electrodes (as by the kick of an induction coil), in which case the current of lower voltage will start and continue flowing, just as though it only needed a kick to start it. It will also flow, if in any way the two electrodes are first brought into contact and then separated while moderate voltage is applied (say 20 or more volts). The greater the distance at which the two electrodes are finally separated, the higher will be the voltage necessary to maintain the current. The simple tube with its two electrodes contains then, when in operation, a portion of the electric current in which we must recognize a single direction. A second current can be superimposed upon the first one if the same polarity be used, while a current of reversed polarity will not pass.

Evidently, then, this is already a rectifier, for if we attempt to superimpose an alternating current on the direct current, then only that portion of the alternating current which coincides with the direct current flowing will pass, and the apparatus will be a sort of check valve for the other wave of the alternating current, just as it was a non-conductor to the direct current until started by the kick. By reducing the original or direct current to a minimum necessary to keep at least some current flowing, then a relatively large current of rectified alternating half-wave can be sent through the tube, and this will show on the previous alternating circuit as a pulsating direct current. Naturally, it is desirable to make use of both halves of the alternating current. This could be done by using two separate tubes, similar to the one described, but it is done more simply by introducing a third electrode into a tube. This makes the apparatus quite similar in action to two of the previous simple tubes, but with one common electrode. This common electrode is the cathode, or the electrode from which negative electricity or negatively charged material would flow if the current consisted of a flow of negative charges or charged particles. It is this cathode, or negative electrode, which is the "essentially different" electrode of the rectifier. For example, one of the two electrodes of our original tube may be replaced by another metal, by graphite, or by practically any other conductor, without apparently affecting the results, but the cathode must be mercury in the practical rectifier.

In practice, most rectifiers are constructed with graphite electrodes for anodes. This permits of a simple form of construction, but is also advisable because of the tendency for one of the electrodes of an all-mercury rectifier to lose its mercury by distillation. For example, in general the anode, just as the crater terminal or anode of the carbon arc, is a point at which much heat is generated. This heat produces a relatively greater rate of distillation of the mercury from the anode than from the cathode; and, except where some special scheme is employed to insure return of mercury properly to both electrodes, one of them will soon run dry and the excessive heat on the sealed-in contact wire will crack the glass. A relatively large surface of iron or graphite is capable of dissipating the energy set free at the anode terminal of the arc without introducing any phenomenon disturbing to the operation of the rectifier.

In practice it is not customary to always keep the direct or starting current flowing through the rectifier, in order to carry the alternating wave. It is only necessary that this carrying or starting current, or its equivalent, should be in existence at each point of time when the alternating current wave of the same direction is near zero voltage; that is, the current must not be allowed to die out completely. This end is commonly accomplished by the use of a reactance coil which discharges through the arc when there would otherwise be no source of potential. This involves the use of two reactances when both halves of the alternating current are utilized. If, now, we examine the current flowing in that part of the circuit which connects directly with the cathode or the mercury electrode of the usual rectifier, we shall find a pulsating direct current, the variable component of which has double the frequency of the original alternating current. If the reactance is so small as to be negligible in its effect on wave distortion, the pulsating current will have practically a simple sine wave form. If the reactance is relatively large, the voltages between the waves will be more or less filled out, so that the resulting direct current will be much more like the usual direct current; that is, without appreciable pulsations.

It should not be assumed that the rectifying principle is confined to mercury. It is so general that practically any arc is a rectifier to some extent, but for practical purposes the components of a rectifier should be permanent, or not consumed as most materials are in arcing. The mercury, being a liquid at ordinary temperatures, condenses and returns to the cathode by gravity in those cases where the current carried actually causes distillation of the cathode. There is a rectifier action, even in a carbon incandescent filament lamp; but here, even for small currents, the loss of carbon at the negative electrode would be great enough to soon rupture the filament. There is rectification, for example, in an arc beween iron and mercury when the arc is run in air at atmospheric pressure, but under this condition only a very short arc can be drawn and maintained, and its irregularity and uncertainty stand in the way of its application. So far, one may say that in the case of the rectifier the material of the cathode is thrown out into the arc-stream and may even constitute it, and that this occurs at the negative electrode and is sufficient for the arc. The anode apparently acts more as a surface to which such conducting material comes, impinges, and gives off energy, apparently kinetic, in completing the circuit. The anode is heated by the action of the current, but does not waste away as does the material of the cathode, because it is made so large as to ensure that neither its vaporizing nor its melting temperature is reached.

In this connection it may be of interest to consider some of the indications which point to a direction of flow of something when electric energy is being transported. We speak of the flow of current through a wire, but do not recognize any flow of material in either direction. The fact that the wire is heated in the process lends aid to the theory that there may be a directed motion of something within the wire. A promising theory postulates negative ions passing within the wire. It would not seem more improbable than the phenomena evidently occurring in aqueous solutions or in gases when these conduct the current. In the case of solutions, an easily demonstrable motion of ponderable material, the electrochemist's ions, always accompanies the flow of direct current, and there is motion of material in both directions — cathode to anode, and the reverse.

In the mercury rectifier there is apparently at least a start of mercury from the cathode, as a necessary concomitant of the arc. As the characteristic color of the mercury arc shows at once throughout the whole conducting path, it is easy to assume the electric current to be carried through such an arc by negatively charged particles of mercury. Any counter current of positive particles in such an arc seems excluded by the fact that the anode does not waste away nor indicate its presence in the arc; moreover, a flow of positive particles would have to meet and oppose a very considerable blast or stream of mercury vapor which flows with great velocity from the hot cathode of the rectifier. It is also worth noting that when by any means an arc is produced in which the permanent graphite or iron anode is made a cathode for any considerable current, then there is a consumption of this cathode, and the arc is one which is characteristic of the material of the new cathode, instead of being a mercury, or greenish arc.

It is not to be assumed that there are as yet any such simple laws connecting the migration of material from a cathode in an arc as the laws of Faraday which apply to solutions. It is only known that the disintegration of the cathode is common, but possibly not essential; it varies with the nature and pressure of the gases present, and is relatively low when compared to electrolytic disintegration or solution.

CONSTANT CURRENT MERCURY ARC RECTIFIER

By C. M. Green

Engineer, Series Rectifier Department, Lynn

Proceeding from the pure theory of the mercury arc rectifier given in the preceding pages, this article deals with the function of the various parts of the series rectifier outfit for commercial arc lighting. Some of the earlier outfits are described. Reference is made to the detail improvements introduced from time to time, and the steps in the evolution of the present-day outfit enumerated.—Editor.

A constant current mercury arc rectifier is a device for obtaining constant direct current, suitable for the operation of series direct current arc lamps of either the open or enclosed type, from single-phase constant potential supply; and the apparatus has been designed for practically all of the commercial frequencies which are in use today. Outfits have been built for operation on 25, 30, 33, 40, 50, 60, 72, 100, 125, 133 and 140 cycles, and for primary voltages, on 50-light sets and above, up to and including 13,200 volts.

In the early days of arc lighting special machines, belt-driven, were developed for this purpose, but due to the nature of the service, the machines were comparatively small and inefficient. In the course of the development of central station practice, alternating current generators have been found to possess a great many advantages over the small constant current machines; and furthermore, the use of alternating current allows transmission of electrical energy over long distances. As a result, a number of years ago it was found advantageous to drive the arc machines by means of induction or synchronous motors with an efficiency between panel boards of from 75 to 80 per cent. The constant current mercury arc rectifier is fa..t superseding the motor-generator set by reason of its many advantages, viz: lower first cost, lower attendance, less floor space and higher efficiency. Furthermore it has the particular advantage of being the first commercial

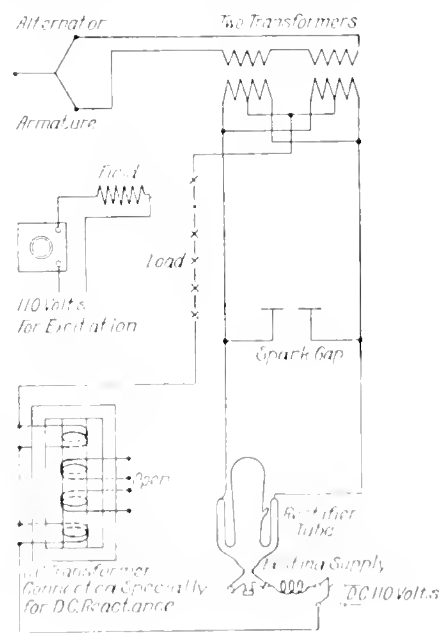

Fig. 1

rectifier, operated from a single-phase supply, capable of supplying a constant direct current

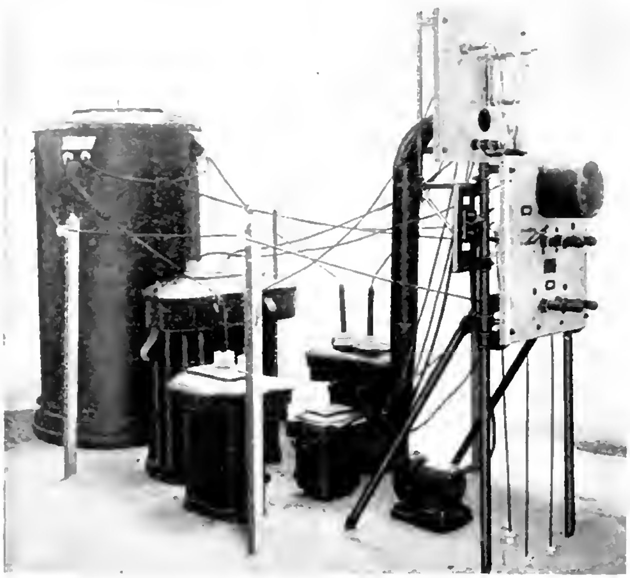

Fig. 2. Early Rectifier Outfit

suitable for the operation of series arc lamps which have been on the market for years.

Commercial Development of the Series Rectifier Outfit

Dr. Whitney, in his article "The Theory of the Mercury Rectifier," has given an excellent description of the phenomena which take place in a rectifier tube and how the alternating current is changed into a direct one. The development of the constant current, or series, mercury arc rectifier followed closely after the first multiple rectifiers were placed on the market for the charging of storage batteries requiring from 100 to 200 volts potential, the tubes possessing more or less of the same general characteristics. The dividing line between the low and high voltage on series tubes seems to come in between 100 and 200 volts load, or in reality in the multiple outfit; the distinction being that on the low voltage tube the anodes are comparatively close to the cathode, and small particles of mercury are almost continually thrown on the anodes by the cathode stream; if the voltage is raised above 200 volts, there is very great liability of flashing from anode to anode. It was necessary, in building tubes to carry high voltage loads, that the anodes should be moved further from the cathode, and the path between anode and cathode made crooked so that particles of mercury could not be thrown from the cathode over to the anode. Furthermore, it was necessary to prevent metallic mercury from dropping on the anode. In other words, the anodes must be kept hot so that mercury will not condense above them and drop on them.

In the multiple rectifier outfits the necessary variation in voltage to take care of the varying loads was obtained substantially by means of taps on a compensator, so as to step up or step down to accomplish the desired results. No insulation whatever was placed between supply and load circuits, the service ordinarily not requiring it. However, for the charging of storage batteries in telephone exchanges, which are used on common battery systems, it has been found necessary to put in an insulating transformer between the supply and the rectifier, so as to prevent disturbances to the telephone system.

The development of the series rectifier outfit consisted mainly in the development of the series rectifier tube, together with special windings, etc., of the constant current transformer, the direct current reactance, and the exciting transformer. The

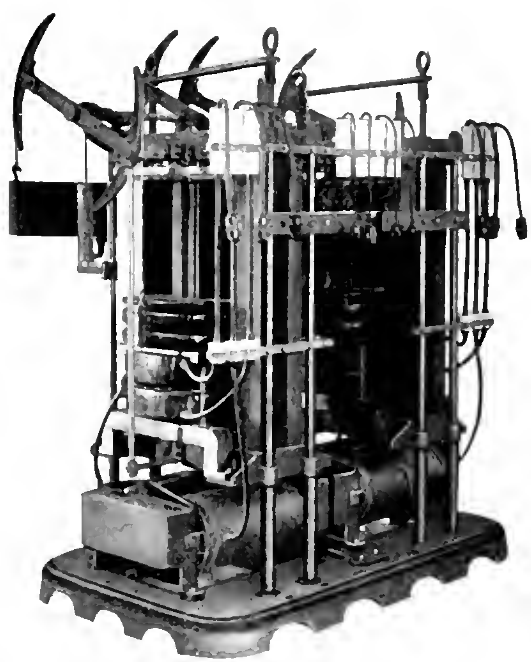

Fig. 3. Early Rectifier Transformer (Casing Removed)

functions of these parts may be briefly outlined as follows:

1. *A constant current transformer* for obtaining constant alternating current for rectification from a constant potential alternating current supply. Variations in voltage and constant current are obtained by varying the relative position of the primary and secondary coils on the core, which also varies the impedance between primary and secondary of the transformer. The lower the load the greater the impedance (coils farther apart), the higher the load the less the impedance (coils closer together) and the higher the power-factor. It was necessary to put additional copper, approximately 40 per cent., in the secondary of the transformer, due to the fact that the total current flowed approximately one-ha'f the time in each half of the secondary winding. For example, on a 4-ampere set the ammeter would show 4 amperes on the rectified circuit; the direct current ammeter would show 2 amperes mean value of current or reactance current in one of the anodes, and the alternating current ammeter would show 2.8 amperes in the same anode, being the square root of the mean square value, or the heating current.

2. *A direct current reactance* used to store up energy during the high part of the wave, and return it to the circuit during the lower part of the wave, the supply coming from energy stored up early in the cycle. During the time the two arcs are running in both anodes the reactance carries the entire load.

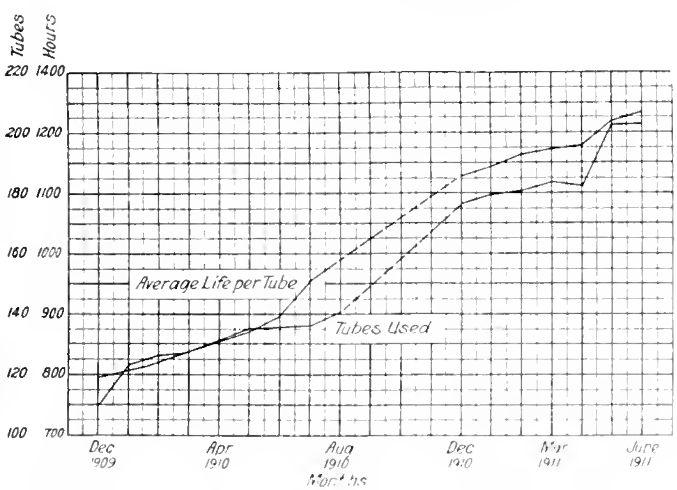

Fig. 4. Curves Showing Increase in Average Life of Tube During Successive Six-Month Periods from December, 1909 to June, 1911

3. *Source of excitation of the tube:* Dr. Whitney in his article mentions two methods of excitation. We selected a method of bringing the electrodes together by means of shaking the tube completing the circuit, and then breaking it, forming an arc and thereby ionizing the mercury in the tube and making the same conductive. It is, however, interesting to note that there is an additional method (not, however, in commercial use) by the use of which the tubes will start up and operate without the tube being shaken, or starting band on same.

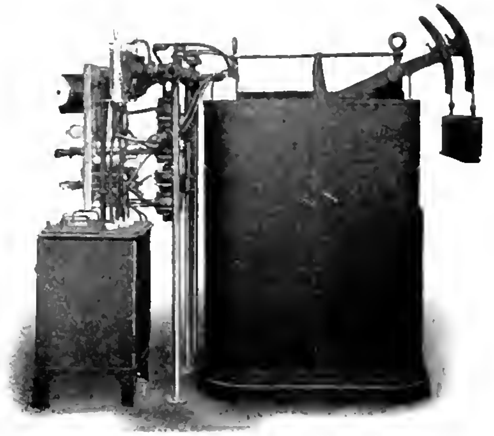

Fig. 5. Later Rectifier Outfit

Tests on the Earlier Outfits

Early tests were made to determine the limits of the rectifier tube, regarding the load which it would carry. 10,000 volts 4 amperes, or 40 kilowatts rectified load, were carried on a tube which was later developed into the present 4-ampere series tube; and 10,000 volts 6 amperes, or 60 kilowatts, were rectified on another tube, which was later developed into the present 6.6-ampere series tube. This load, however, was a resistance load, and not an arc lamp load; and the tests were of short duration, and made under the most favorable conditions, which at that time was not recognized.

Arrangements later were made to obtain 100 magnetite lamps on a single circuit as a load, and the necessary apparatus was put together for the rectifier, consisting briefly of the following parts: one 150 kw., 60 cycle, three-phase, 2200 volt alternator, with field control so that the voltage might be varied as required. Two special testing

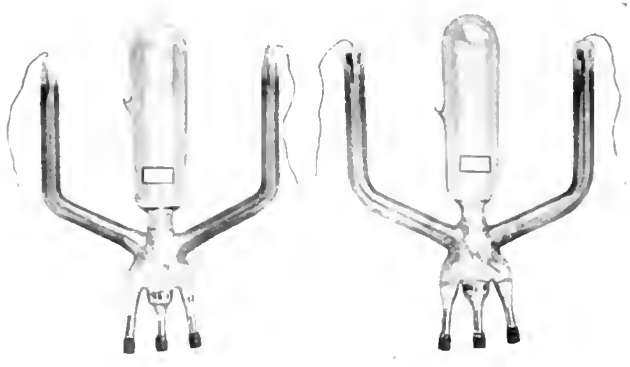

Fig. 6. Tube with Lava Bushing Anode on Left. Tube with Iron Over Graphite Anode on Right

transformers were connected to the alternator, having special connections on the secondary or high voltage side, so as to obtain 6250 volts, 12,500 or 25,000 volts, in accordance with the connection. They were connected up for 25,000 volts on the secondary winding, with tap in the center. For direct current reactance, a double primary and secondary constant current transformer, specially connected, was used as a reactive coil, performing the same functions as the present direct current reactance. The excitation of the tube was from a 110 volt direct current circuit, which was simply used in starting, and was later disconnected. Spark-gaps were placed across the secondary terminals of the transformer so as to limit the voltage to 25,000, which is the approximate amount required for obtaining 10,000 volts rectified load. Several rectifier tubes, which had been built previously, and a small fan motor for cooling the tube, were used. A load of 100 magnetite lamps, connected in series, requiring from 7500 to 8000 volts, and 4 amperes, was carried for eight hours. (Connections of this test are shown in Fig. 1.)

With a view of further developing the apparatus, and encouraged by the above results, several rectifier outfits were designed and built of varying frequencies, primary voltages, voltage capacities or lights, and amperes. The first outfit, rated at 75 lights, 4 amperes, supply 40 cycles 10,000 volts, was built and tested, and shipped to the Research Laboratory, Schenectady, where it was used for several years on tube and lamp test, etc. in connection with the development of the apparatus. A second outfit, rated at 25 lights, 4 amperes, supply 25 cycles 2200 volts, was built and shipped to Baltimore, where competitive tests were made on a General Electric rectifier and luminous lamps, and those of another company. A third outfit, rated at 75 lights, 4 amperes, supply 60 cycles 2200 volts, was supplied to the Commonwealth Power Company, Jackson, Mich., and the apparatus is still in daily use.

Improvements in Design During Commercial Production

From that point on a number of large orders for series outfits have been filled. Numerous changes and detail improvements were effected from time to time, and troubles which made their appearance on test were eliminated in the improved designs. On account of various difficulties which were experienced on test and elsewhere, it was considered advisable to re-design the apparatus

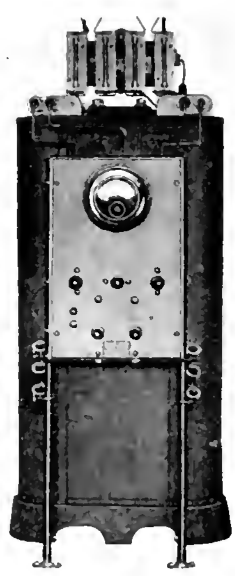

Fig. 7. Combined Outfit. Latest Type of Rectifier Outfit

with a larger margin of safety regarding insulation; and a new line of apparatus was brought out, designed to stand an insulation test of 50 per cent. above what was previously called for. In other words, the insulation test on a 50-light outfit was increased from 30,000 to 45,000 volts. In the case of another order, the two alternating current reactances were combined on a single core, thereby cutting down the number of parts. Another design resulted in combining in a single casing the constant current transformer, the direct current reactance and the two alternating current reactances, and the apparatus was designed for an insulation test of 45,000 volts (50-light outfit).

Quite recently the design of the apparatus was again radically changed, the various parts of the apparatus, except the panel board, being brought together, mounted on a common base and enclosed in a single casing, which simplified the installation, and materially reduced the floor space and cost of installation (see Figs. 7 and 8).

The parts in question were the constant current transformer, the direct current reactance, the exciting transformer, the tube tank, the static dischargers and the indicating lamp.

Of the foregoing, the function of the first three items has already been dealt with. With regard to the remainder, it may be pointed out that the tube-tank contains the necessary holder, etc. for holding the rectifier tube, so that it may be removed readily in case of trouble and a new one substituted. The tube-tank is also provided with a nickel-plated brass coil for circulating the water for the purpose of cooling the oil. The static dischargers are connected between the anode and cathode of the tube to protect the tube and other parts of the apparatus from electrical strains, which may occur under certain conditions, as for instance, when the tube is started up when it is cold. This effect is usually noticed with old tubes. The function of the indicating lamp is to burn under normal operating conditions, and go out if the circuit should go off for any cause, or the cathode spot jump over into the starting anode.

With such a rapid development of any line of apparatus and the building of them in such large quantities, it is natural to expect that certain difficulties would be experienced, which would only appear after the apparatus was in commercial service for an appreciable period of time. Certain outfits developed trouble due to cool weather, static discharges occurring from the anode to the cathode of the rectifier, while in hot weather the tubes would not operate. The matter was carefully investigated and the transformers were re-built, an additional section added to the panel board, and the outfits changed from

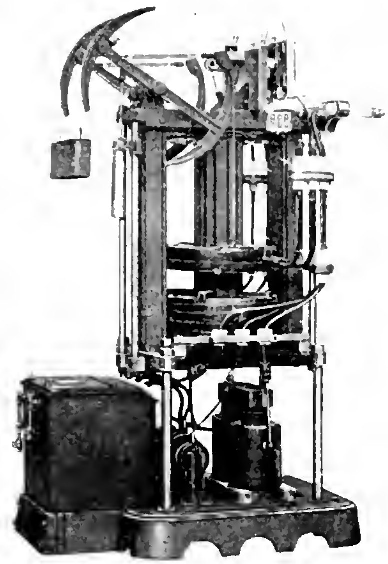

Fig. 8. Combined Outfit. Latest Type of Rectifier Outfit (Casing Removed)

single-tube to two tubes in series. After this the operation was entirely satisfactory.

It was also observed that the rectifier tubes on relatively high loads were more or less sensitive to temperature changes; and with a view of still further improving the

Lights	Method of Cooling	No. of Stations	No. of Tubes	Total Hours Run	Average Hours Run	Maximum Hours Run
50	air	5	33	22194	672	4333
50	oil	12	64	116325	1817	7562
75	air	2	42	47982	1142	3203
75	oil	2	21	83154	3959	6387
Misc.	oil and air	3	48	41387	862	
Total		24	208	311042	1495	

system, the method of cooling the tubes on the new outfits were changed from air, which was originally used, to submerging the tube in oil, the oil being water-cooled. Data have been gathered from a number of central stations, and it is very interesting to note the comparative hours run of the tubes in service in air and oil on 50-light single-tube, and 75-light two tubes in series sets. The table on page 625 gives these particulars up to January 1, 1911.

These figures are interesting and show that a great advance has been made in changing the method of cooling the tubes from air to oil. Furthermore, the gain is so great that there is no question but what a number of stations using air-cooled tubes could change over to oil-cooled tubes, and pay for the cost of change in the reduction in tube renewals and improved operation inside of a couple of years. There have been built outfits for air-cooled tubes requiring, in round figures, 300 tubes in service nightly, and oil-cooled tubes about 1200 in service nightly, or a total at the present time of about 1500 tubes.

It is an endless task to get tube reports from all stations. In fact, a number of stations have never sent in any; but from the number of panel boards and tube tanks which have been supplied during a number of six-month periods and the tube shipments during the same period, it is very interesting to note the rapid falling off of the number of tubes required per outfit supplied. Furthermore, there is every reason to expect that there will be still a further reduction in the number of tubes required per panel board and tube tank which have been supplied, through improvements in the method of manufacturing the tubes and operation of the system.

Six Months Period	No. of Panel Boards and Tube Tanks Shipped to End of 6-Months Period	No. of C.C. Tubes Shipped per 6-Months Period	No. of Tubes per Panel and Tube Tank Shipped
July to Dec. 1909	721	2449	3.4
Jan. to June 1910	940	3758	4
July to Dec. 1910	1229	3688	3
Jan. to June 1911	1482	3705	2.5

Anodes of the Iron Over Graphite Type

Experiments with the punched iron anode tubes, having iron over the graphite, instead of the ordinary lava bushing above graphite anode, were made some years ago, and they showed up satisfactorily. Our percentage of production of this type of tube has been gradually increased, life test in various installations having shown conclusively that they give better results than the lava bushing type. At the present time approximately 75 per cent. of the constant current rectifier tubes are manufactured with punched iron-over-graphite anode, and 25 per cent. of the lava-bushing type, both kinds of tubes being packed in the same box for shipment.

Experience has shown that series rectifier tubes are sensitive to temperature changes, and the greater the load on a tube the narrower the range of temperature over which it will operate satisfactorily. In certain instances of tubes operating unsatisfactorily the lowering of the air or oil temperature from 3 to 5 deg. Fahr. would produce satisfactory results. A number of stations have made a particular study of the best operating temperature of oil or air for their tubes, with a view of obtaining the very best operating conditions and tube life; and by so doing they have very greatly increased their tube life, improved their service, and reduced the cost of their tube renewals.

The foregoing will give some idea of the various steps in the evolution of the latest type of series rectifier outfit as designed for the modern series arc lamp systems. Much could be written with regard to a number of detail improvements; and further reference to some of these will be found in Mr. W. E. Carpenter's article on page 627, in which a number of cuts are shown illustrating the shaking magnet, tube carrier, drip-pan, tube bracket, oil-circulating device, tube closet, etc., as used in various installations.

THE STATION OPERATOR, THE LUMINOUS ARC LAMP AND THE SERIES MERCURY ARC RECTIFIER

By W. E. Carpenter

Engineer, Supply Department, Philadelphia Office

This article has been written primarily for the instruction of operating men in charge of luminous arc installations, including the lamps and rectifier outfit. It contains instructions for tests which can be carried out in cases of service trouble, the procedure which is followed to remedy the trouble, and pointers in regard to the handling, storage, etc., of rectifier tubes. The most valuable part of the paper is a selection of questions and answers on the operation of the system, compiled by an operating engineer.—Editor.

THE STATION OPERATOR

This important adjunct to the successfully operated central station plods along, in the majority of cases, with, unfortunately, but scant recognition; and is given, as a general rule, but little or no credit for his assistance in the progress of electrical science. It is all very well for engineers with almost unlimited data at hand to design electrical apparatus; for our great factories with their vast facilities to manufacture this apparatus; for the testing organizations to make all the tests which the electrical engineers can devise and for the selling organization to exploit its sale. But when all is said and done, it is the poor, insignificant, and often officially unrecognized, station operator who deserves a great share of the credit for its ultimate commercial success.

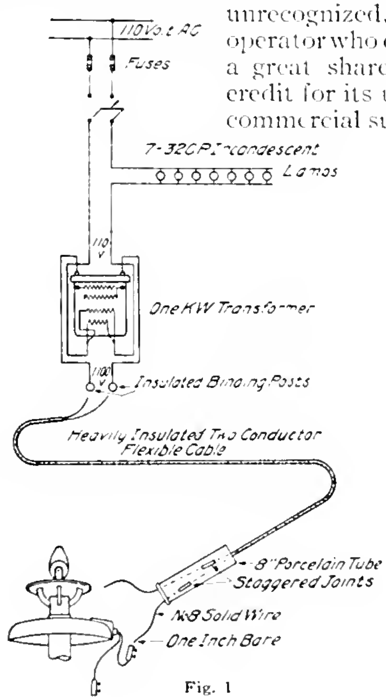

Fig. 1

In the following article, therefore, the writer has endeavored to illustrate a few of the many ways and means employed by operators to discover causes of trouble and some of the remedies for them. This, the writer believes, will not only make interesting reading; but, while possibly some of his readers may recognize their own methods, others may obtain some points of value for use in their own particular field.

At this point it may be well to mention that the great slogan of all operators is: *there must be no interruption in the service.* Therefore all operators of electrical machinery, in no matter what field, are invariably on the lookout for trouble; and this being the case, are continually devoting their energies to locating possible causes for trouble, and eliminating them before such causes can result in any impairment of the service.

THE LUMINOUS ARC LAMP

A complete description, pictures and diagrams of connections of this lamp appear elsewhere in this issue, and may be readily referred to for an explanation of any particular point.

As a general rule the first thing an operator looks at when trying to locate the cause of any operating difficulty with any electrical apparatus is the insulation. This is particularly so in the case of arc lamps, and many operators have arranged a simple, cheap and very efficient method of testing the insulation. This is illustrated in Fig. 1. The ease and quickness with which insulation defects may be located by its use, as well as the small risk to the operator, have brought the device into popular favor.

All operators appreciate the risk involved in an endeavor to work on arc lamps while operating, or while the circuit is alive; and they therefore almost invariably desire that all current-carrying parts of arc lamps be thoroughly insulated from the lamp frame and casing. Very frequently we hear it remarked that, with lamps thus insulated, the lineman can detect a live cross on the arc line from the presence of static on the casing; thereby oftentimes locating line troubles before damage results to the arc current generating machinery.

The next thing is to determine whether or not the continuity of the several circuits within the lamp has been impaired; first, by a superficial examination to see that there

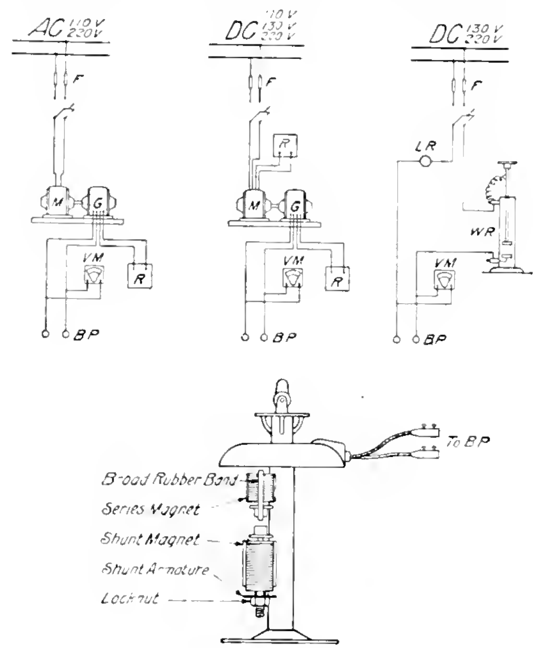

Fig. 2. Cutout Test

M, motor
G, generator
R, rheostat
F, fuse
L.R., 16 c-p. lamp resistance
W.R., water rheostat
B.P., binding posts
V.M., voltmeter

are no burnt-out magnets or bad contacts; and second, by a more careful examination with a magneto or low voltage current. These points determined, the adjustments in like manner receive careful consideration.

The adjustments of the series luminous arc lamps are, fortunately for the operator, very few; there being only three main adjustments, two mechanical and one electrical, in the following order:

First. Mechanical, the alignment of the electrodes.

This is accomplished by first loosening the screw on the roller guide of the movable clutch rod, to which is attached the lower electrode holder. The lower electrode holder may then be moved sidewise, by the amount necessary to align the electrodes.

Second. Mechanical, adjustment of the arc length.

This is determined by adjusting the stop for the lower clutch. This stop may be raised for increasing the arc length, or lowered for reducing it. Many operators have concluded, from observations covering a long period of time, that the best results for a 75 volt arc are obtained with an arc length of $\frac{17}{32}$ in. on the 4-ampere lamp and $\frac{21}{32}$ in. on the 6.6-ampere lamp. This distance is measured between the electrodes after the lower electrode has dropped back into its normal position; care having first been taken to push the lower electrode upward until it has lifted the upper electrode its full distance of travel.

Third. Electrical, the adjustment of the shunt armature to determine the point, in arc voltage, at which the lamp should cut out.

This is accomplished by raising or lowering the shunt armature on a threaded stem, which is provided with a lock-nut to prevent change in adjustment during operation. To make this adjustment while the lamp is in normal operation on the circuit, has been found to be inconvenient; if so made the adjustment is unreliable and consequently very unsatisfactory. As a consequence, operators have made use of methods shown in Fig. 2.

The first thing necessary is to obtain direct current of at least 130 volts. For motor-generator sets one-sixth horse power is plenty large, for the reason that only the shunt magnet, which requires only a fraction of an ampere, is to be energized; and further, that it is not desired to operate the arc. The generator should be provided with an adjustable resistance or rheostat in the field circuit, so that a range of voltage from 90 volts to 130 volts may be obtained.

The method by water-rheostat has been used in several instances, and accurate results obtained; but the rheostat needs frequent cleaning and adjustment, so that it is not quite so convenient or reliable for emergency service as the motor-generator set method, and the latter has therefore been more frequently used. The operators have used in some cases two small motors, one as a motor and the other as a generator, fastened to a two-inch board with their shafts coupled together. The principal recommendations for these methods are reliability, accuracy of test, compactness, convenience, low first cost and negligible maintenance. One operator in particular, being of an ingenious nature, has installed his little motor-generator set on a shelf under his work-bench, and has closed it in like a small cupboard. On opening the door, the binding posts and the flexible leads, for connecting between the binding posts and the lamp, are found hanging on a little hook. The motor switch is just inside the door. On a shelf, secured to the door by a bracket, is the voltmeter all connected in, and on a nail beside it is a broad rubber band. The door of this miniature testing outfit, being only 12 in. wide by 14 in. high, is indicative of the compactness of the equipment.

Adjusting the cut-out on the series luminous arc lamp by either of these methods becomes a pleasure, and by practice has frequently been reduced to such a science by the operator that the adjustments are made and checked in what has seemed to the writer an almost incredibly short time. The general method of procedure is as follows:

The lower electrode is first removed; then the broad rubber band is placed around the series magnet and upper cut-out contact. This holds the upper cut-out contact in the position it normally assumes while the arc is burning. This rubber band also acts as an insulator between the cut-out contacts when the lower contact is lifted by the shunt magnet; thereby preventing a short-circuit on the generator, where motor-generator set is used, or a short-circuit on the line, where water rheostat is used. In this latter case the insertion of the lamp resistance (Fig. 2) is an additional safeguard. The direct voltage is varied by resistance "R" in the generator field, from 90 volts (at which point the shunt magnet becomes weak enough to allow the armature to drop and assume its normal position) to 130 volts, this giving sufficient range to enable the operator to adjust the shunt armature so that it will be lifted, thereby bringing the cut-out contacts together at any predetermined point between. The majority of operators have found that the best results are obtained where the cut-out is adjusted to close at about 120 volts, the test being made when the shunt magnet is cold. If this test is made when the shunt magnet is hot, as, for instance, after the lamp has been operating for some time, the adjustment should be made at about 125 volts.

It was amusing to the writer to notice on the door of the cupboard of the ingenious operator above referred to, a prominent printed sign which read "*Where is the rubber band*?" On being asked "Why the sign?" the operator apologetically remarked: "One day I forgot the rubber band and left it on the lamp. Result, a burnt-out shunt magnet." Just below this was another sign which read "*Is the lock-nut tight?*" The reason for the question is obvious but illustrates the care exerted by operators to avoid trouble.

The present universally satisfactory results obtained in operating series luminous arc lamps is due to the particular attention which operators have paid to the details of the lamps, and to the avoidance of difficulties which might result from scanty attention to such points as the following:

1. Lamp jumping, frequently resulting from broken, chipped or loose-fitting globes.

2. Broken or loose flexible connection strip from the upper electrode to the upper electrode box, causing lamp jumping, welding of electrodes and consequent outage, to say nothing of the possibility of burning out magnets or insulations.

3. Too tight, too loose or broken flexible connection cable to movable clutch rod. If too tight the result is short arc or welding of electrodes. If too loose, the cable may come in contact with the lamp frame, resulting in burnt-out insulation; or it may come in contact with other current-carrying parts, thereby short-circuiting the arc and causing outage. If broken it may cause either of these difficulties, burning of the clutch rod or lamp jumping and its consequent results.

4. Binding of lower clutch, which might interfere with the proper feeding of the electrodes.

5. Spiral spring on the lower clutch too weak. Might cause short arc.

6. Lower electrode holder bail removed or lost out, possibly allowing the lower electrode to drop out.

7. Trip rod bent against the upper electrode box, thereby short-circuiting the arc.

8. Cut-out contact flexible lead binding; thereby preventing the cut-out from performing its proper function, possibly resulting in burnt-out magnets or insulations.

9. Badly-pitted upper electrodes. This might be the result of operating the lamps at reversed polarity, or with the electrodes not properly aligned, or from attempting to operate them over too long a period.

In this connection it has been found advisable not to turn the upper electrodes over, thereby operating the arc on the opposite end, until all the life desired or available has been obtained from the first end. It appears that if an electrode, which has been operated in one position for about six months, is reversed—thereby allowing the current to flow through it in the opposite direction and causing the arc to be operated from the opposite end—the rate of oxidizing of the electrode is materially increased and the life consequently much shortened. Therefore if upper electrodes, after having been operated for a period, are found to be burned away more on one side than on the other, and the electrodes are found to be properly aligned, it is advisable to turn the upper electrode around, thereby putting the high side on the opposite side of the arc, rather than to turn the electrode over and thereby shorten its life. This side burning of the upper electrode will, however, very rarely occur, except possibly as the result of some local conditions such as the electrode not being properly aligned, or the lamp operated at reversed polarity, etc.

The series luminous arc lamp requires for its operation direct current; and since it has been the general tendency of central stations to get away from motor-generator sets or belted arc machines, it became necessary to devise means for obtaining a uni-directional series current direct from an alternating current source of supply. The result of exhaustive investigations has been the series mercury arc rectifier outfit.

THE SERIES MERCURY ARC RECTIFIER

The series mercury arc rectifier outfit, being in a class by itself and of comparatively recent design, is not very well known, especially among station operators. During the process of its development the engineers have been very ably assisted by the operators, who have kept close watch of the performance of the rectifier, have noted its peculiarities, and oftentimes have suggested means for overcoming or avoiding in the future difficulties already experienced. Operators generally have found so many and such varied peculiarities attending the tube and its operation, that many questions have been asked and much instruction given as to their operation and the general care that should be given them in order that the best results may be secured. This instruction has been given verbally, by letter or instruction book; and yet there is apparently still quite a field for questions which might be asked in connection with this apparatus. For the benefit of operators who may read these pages, the writer has secured the following list of QUESTIONS AND ANSWERS, which were compiled by one of our most studious operators from instructions which he received from time to time.

QUESTIONS AND ANSWERS

Luminous Arc Lamps

Q. How would you adjust the arc length on a 4-ampere series luminous arc lamp?

A. By moving the stop on the guide rod.

Q. How long should the arc be?

A. On a 4-ampere lamp it should be $\frac{17}{32}$ in when the lower electrode drops back into position.

Q. What should be the length of the arc on the 6.6-ampere series luminous arc lamp?

A. The arc should be $\frac{21}{32}$ in.

Q. How would you adjust the lamp to get the $\frac{21}{32}$ in. arc on the 6.6-ampere lamp?

A. By moving the lower clutch stop as on the 4-ampere lamp.

Q. At what voltage should the cut-out close?

A. At 120 volts.

Q. What would happen if lamps were operated at reversed polarity?

A. The upper electrodes would burn up rapidly, lamps would jump badly and give very little light.

Q. How often should globe and reflector be wiped off?

A. At every trimming.

Q. How often should lamp chimney be cleaned?

A. At each trimming if weather is fair; not when raining or snowing.

Q. What will cause a lamp to jump or feed too fast?

A. Globe not fitting well against the canopy.

Q. When a lamp is brought in for repair, what voltage should be used in testing the insulation?

A. One thousand volts alternating current.

Q. How should cut-out adjustment be made?

A. As per the accompanying sketch (see Fig. No. 2).

Q. In adjusting the cut-out, at what voltage should you start on the shunt magnet?

A. At 90 volts.

Q. How high should this go?

A. Until it raises the shunt armature thereby closing the cut-out contacts.

Q. How should this armature be adjusted?

A. By raising or lowering the disc of the armature on the threaded stem.

Q. At what voltage should the armature rise?

A. At 120 volts.

Q. How often should upper electrodes be inspected?

A. Every few months.

Q. For what are the upper electrodes inspected?

A. To see if they are burning squarely.

Q. If not, what should be done?

A. They should be turned ***around***, not ***over***.

Q. To obtain the best light distribution and operation of the lamps, what should be done?

A. The upper electrodes should be maintained so that the lower edge is even with the outer edge of the reflector.

Q. What will cause flashing on the circuit?

A. Badly-burned or imperfect upper electrodes.

Examining Tubes

Q. How would you tell that the vacuum in a tube is good?

A. By the sharp click heard when the mercury is moved about in the tube.

Q. If the vacuum is good, what will the mercury do?

A. Entirely fill the cathode and starting anode chambers.

Q. If there is little or no vacuum, what will happen?

A. Bubbles will appear in the mercury in the cathode and starting anode chambers.

Q. What should be done before placing a tube in service?

A. See that all leads are in good order and, when tubes are turned right side up, see that no mercury is left around the anodes or seals.

Q. How many new tubes should be kept on hand?

A. Two tubes for each tube operating.

Installing Tubes

Q. What should be done in installing new tubes?

A. See that the three flexible leads, at the bottom, connecting to the starting anodes and cathode, are looped away so as not to come in contact with each other.

Q. In what manner should the flexible leads, to main anodes, be set?

A. They should be arched up as an inverted letter "U" so that when the tube is moved in shaking there can be no strain on the glass where the lead leaves the tube.

Q. What might happen if the flexible anode leads came close to the glass?

A. There is danger of puncturing the tube at this point, particularly if started up cold or started direct on the arc circuit. *Tubes should be operated as per instructions.*

Drying-out Tubes

Q. How high should the direct current go on short-circuit on a 4-ampere outfit?

A. To between 5.5 amperes and 7 amperes.

Q. How long should new tubes be operated on short-circuit?

A. One hour at least.

Q. What should be done after new tubes have been operated one hour on short-circuit?

A. The operator should, if possible, pick up the arc circuit by operations Nos. 6, 7, 8 and 9. (See operating instructions.)

Q. Why should all new tubes be run on short-circuit for one hour before attempting to operate the lamp circuit with them?

A. To be sure that there is no mercury left in the vicinity of the anodes which might cause puncture.

Q. What should be done with a tube which has been dried out, if it should be accidentally turned upside down?

A. It should be dried out again.

Q. What should ordinarily be done with tubes in regular service?

A. Tube should be operated on short-circuit for from 5 to 10 minutes before putting on the load.

Q. Can a tube be started directly on the load?

A. Yes; if it is found necessary to do so.

Q. How would you start a tube directly on the load?

A. By separating the C.C. transformer coils to the normal running point and then shaking the tube. The lamp circuit should pick up without much fluctuation.

Installing Protectors

Q. What should be done when tubes will not operate on the load?

A. They should be cleaned or static protectors applied.

Q. How many protectors should be used on a tube?

A. Two; one over each anode. Glass bushings should *never* be omitted.

Keeping Records

Q. What should be done when a shipment of tubes is received?

A. The tubes should be unpacked and carefully examined as to their condition.

Q. What should be done with the tubes which are apparently all right?

A. They should be dried out and placed in the tube closet for future use.

Q. What should be done with the record of this examination?

A. Copy should be sent to the proper District Office of the General Electric Company and marked for the attention of the engineer keeping in touch with rectifier systems.

Q. What about daily runs of the tube?

A. Record should be accurately kept so that the life of the tube can be definitely determined.

Q. What about static protectors?

A. Notation should be made on record sheets of the date they are applied.

Q. What can be determined by keeping record of the date the static protectors are applied?

A. The life with and without the protectors.

Operating Tubes

Q. How should the rectifier outfit be started up for regular run?

A. As follows:

1. See that the water supply is O. K. and that the oil temperature is between 60 and 90 deg.
2. Put in the short-circuiting plug.
3. See that the transformer coil is latched up.
4. Close the exciter switch and shake the tube.
5. Put in primary plugs or switch, at the same time shaking the tube.
6. If the tube has started O. K. and the pilot lamp is burning let down the rope to the balance weight (if rope is used) and see that the coil is unlatched.
7. Put in the arc line plugs.
8. After running five minutes on short-circuit, pull the short-circuiting plug and, if necessary, help the moving coil down to its normal running position.
9. Maintain the oil temperature as nearly uniform as possible. A little practice will determine the best operating temperature for each individual tube. This temperature varies with different tubes but is generally found to be between 75 and 85 deg. Fahr.

Q. How should the apparatus be shut down?

A. Proceed as follows:

1. Open the exciter switch.
2. Pull out the primary plugs or switch.
3. Pull out the arc line plugs.
4. Pull up and fasten the transformer coil.
5. Cut off the water supply.

Q. What should be done when the tube is to be started on short-circuit?

A. The coils of the C.C. rectifier transformer should be separated, as far as possible, to avoid the exceptionally heavy rush of current which would follow attempting to start up on short-circuit with the transformer coils together.

Q. How can an operator tell when a circuit is open?

A. By the pilot light going out.

Q. How could the operator tell when the spark had jumped from the cathode to one of the starting anodes?

A. By the pilot light going out and there still being current shown on the ammeter.

Q. How could the operator get the spark back?

A. By shaking the tube; the pilot lamp should then immediately light up.

Q. Why should the operator run the outfit on short-circuit for from 5 to 10 minutes in starting up each night?

A. To warm up the tube.

Q. What effect does this have on the tube?

A. It has a tendency to reduce the amount of static which may be on the tube or apparatus.

Q. What will cause an increase of static?

A. It is oftentimes increased by inductive kick, due to current fluctuation.

Q. What might cause surges on the line?

A. The tendency of the circuit to open in the tube.

Q. What will the static, brought in on the direct current line, sometimes cause?

A. Discharges in the tube from cathode to starting anode, or from anode to anode, or across the static dischargers.

Q. What will happen when this occurs?

A. The spark may be carried over into one of the starting adodes, and should be carried back by shaking the tube.

Q. How long should the tube be run on the exciter only in starting up nightly?

A. Not over one minute.

Q. How is the water supply controlled?

A. By needle valves operated at the discretion of the operator.

Q. For what is the thermometer in the tube tank used?

A. To determine the temperature of the oil.

Q. How is this temperature regulated?

A. By the water supplied through the needle valves.

Q. How is the thermometer held in place?

A. By a tube, supplied for this purpose, secured to the top of the tube tank.

Q. What might cause a tube to flash or puncture about the anode leading-in wires?

A. Too high or too low an oil temperature.

Q. In what other way will too high an oil temperature affect the life of a tube?

A. Shorten the life by reducing the vacuum.

Q. Why is it better not to disturb the tube, by shaking, while it is operating all right?

A. It might cause static and cause the tube to flash or puncture.

Q. What should be done if the tube flashes out?

A. Shake the tube. In the majority of cases, if the tube is all right, it will pick up the load immediately.

Q. Why should the exciter switch be pulled off before shutting down?

A. To reduce the arc when the primary plug or switch is pulled out.

Q. What might be the trouble if a tube, which runs all right on short-circuit, will not carry the load?

A. The vacuum in the tube may be low, the tube may be too cold, or the dashpot may be too stiff.

Q. What may be done to get the circuit going?

A. Leave the short-circuiting plug out; put in the arc line plugs; put in the primary plugs or switch; pull up the moving coil of the C.C. transformer to the normal running position, and then shake the tube.

Q. What kinds of oil are used in the dashpots?

A. About one-half cylinder oil and one-half No. 6 transil oil.

Q. When should the dashpot be adjusted?

A. After adjusting the balance-weight for the desired arc line current.

Q. How should the dashpot be adjusted?

A. With the valve closed; have the mixture of oils such as to allow the moving coil of the C.C. transformer to drop its full length of travel in 2¼ seconds.

A. How often should this adjustment be checked?

Q. At least as often as once a month.

Q. What should be done before checking this adjustment?

A. Move the coil up and down several times to thoroughly mix the oil in the dashpot.

Q. What might occur if the dashpot were too stiff?

A. It might cause surging on the arc line, flashing of the tube or cause the tube to drop the load.

Q. What should be done if the floating coil on the C.C. transformer floats to within 1 in. of the stationary coils, when the transformer is operating on the 80 per cent. connection?

A. Change the primary connection to full load.

Q. What is the cause of the current in the arc lamp circuit fluctuating more, for a short time, just after starting than during the balance of the run?

A. The resistance of the arc on the series luminous lamp is somewhat higher at starting than after the lamps and electrodes become warmed up.

Q. What could be done to stop a tube flashing?

A. Steady the rocker arm on the C.C. transformer, or lower the oil temperature, or put on the static protectors.

Q. What would be the result if the circuit were overloaded?

A. The tube might start flashing or drop the load.

Q. What would be the result if the balance weight on the C.C. transformer were too heavy?

A. The arc line current would be low.

Q. What would be the result of a tube flashing when the exciter is in?

A. The rectifier would continue to operate, but might cause electrodes on lamps to weld, or the tube to puncture.

Q. What would be the result of a tube flashing when the exciter is out?

A. The tube would almost invariably drop the load.

Q. What can be done to release the mercury from the inner walls of the tube?

A. Wash the tube with warm water and *Bon Ami*, or place it in a box and raise the temperature to about 250 deg. Fahr.

Q. How should the tube be handled in cleaning?

A. In a vertical position so as to avoid having to dry out the tube on short-circuit again before putting on the load.

PRACTICAL POINTS IN THE HANDLING OF RECTIFIER OUTFITS

Many and varied have been the experiences of operators in charge of outfits; from finding tubes of apparently so high a vacuum that they will not carry their full rated load, to finding tubes which, having apparently failed, have been resuscitated, either by being given a rest of varying periods, or by the application of the static protector.

The Static Protector

The principle of the static protector is well explained in the following, quoted from an authority on this subject: "The principle on which the static protectors on mercury arc rectifier tubes operate is the same as that on which the ground wire over the transmission line protects; i.e., in the interior of a perfectly conducting body no electrostatic field can exist, and thus no static discharge or disturbances. In the rectifier, during the positive half-wave, the anode is connected by the arc stream with the mercury cathode, the glass walls, etc., and the potential throughout the anode space is thus uniform and positive. During the negative half-wave the current cannot pass; the anode thus is open-circuited, strongly negative, but the glass walls, residue mercury vapor, drops of condensed mercury vapor, etc., are left positive from the preceding half-wave. Very strong static attraction thus exists between the anode and the residual mercury vapor and condensed mercury drops.

"Such positive mercury vapor or mercury drops, statically attracted by the negative anode, fly against it, are instantly evaporated by the red-hot anode, negatively charged by their contacts, are thereby thrown off, and thus form a beginning of a vapor blast from the anode, that is, a reverse arc; or in other words, cause the rectifier to 'strike back', and thereby short-circuit and melt the tube. Therefore the anode arms of the rectifier tubes are kept at a higher temperature than the rest, so as to keep mercury vapor and especially condensation of mercury away from them.

"The static protector, connected to the anode lead, encloses the anode and the whole space surrounding it by a metallic conducting shell. They thus are in the interior of a conducting body, and therefore no electrostatic field can exist at or near the anode; that is, the attraction between anode and mercury which causes sparking, disappear.

"When the rectifier tube gets older, its vacuum gets poorer, and gases are produced, probably largely carbon monoxide. During a period of rest, these gases are occluded by the graphite anode. At the time of starting the rectifier (by putting voltage on it), and during the negative half-wave, the static repulsion between the occluded gases and the graphite anode which occludes them, drives out the gases and thereby momentarily forms a gas cushion in front of the anode; and during the next, or positive, half-wave, the mercury vapor cannot reach the anode because of the gas cushion. The circuit then opens suddenly, and more or less severe electrostatic discharges occur, which endanger the life of the tubes, until ultimately it fails to start altogether.

"When enclosed by the static protector, however, no static repulsion exists, as the anode is in the interior of a conducting shell, the gas cushion thus does not form, and the rectifier starts all right; while the gases occluded by the anode are given off only gradually by its rising temperature, and collect in the condensing chamber, without interfering with the operation of the tube. When the rectifier tube gets old, static protectors are necessary, as without them tubes cannot be operated and they therefore must be used."

While there may be "no apparent theoretical reason why static protectors, which make an inoperative tube operative, should not keep a tube from becoming inoperative, if used from the beginning" and while there may be no apparent reason "why they should not be used from the start, and tend to keep the tube from beginning to fail, instead of waiting until it has apparently failed and then resuscitating it;" yet it has been the general experience of all operators that if protectors are used on new tubes the percentage of immediate failures is much larger than if new tubes are placed in service without them. Thus we find operators using the static protectors only when tubes will not operate without them.

The Static Discharger

The second protective device designed to improve the service was the static discharger. The general tendency of all alternating current apparatus to be affected by surges on connected lines is well known; but the ultimate point in electrostatic voltage thus reached is oftentimes difficult to determine. As the effects on the insulation of the apparatus are sometimes disastrous, it was early determined that the series rectifier outfit, in view of the peculiar phenomena incident to rectifying an alternating current as in this apparatus, should be protected by some device which would, if not limit the amount of surge, at least cause this static to be discharged and dissipated into the atmosphere at a predetermined point, and thereby prevent it from piling up to the point of breaking through the insulation to ground.

The general effect of the application of the static discharger has been apparently to increase the life of the tubes. All operators therefore, are very careful to see that these static dischargers are in good condition at all times; that they are clean, properly adjusted, and have no loose connections, cracks, or ridges in the resistance sticks.

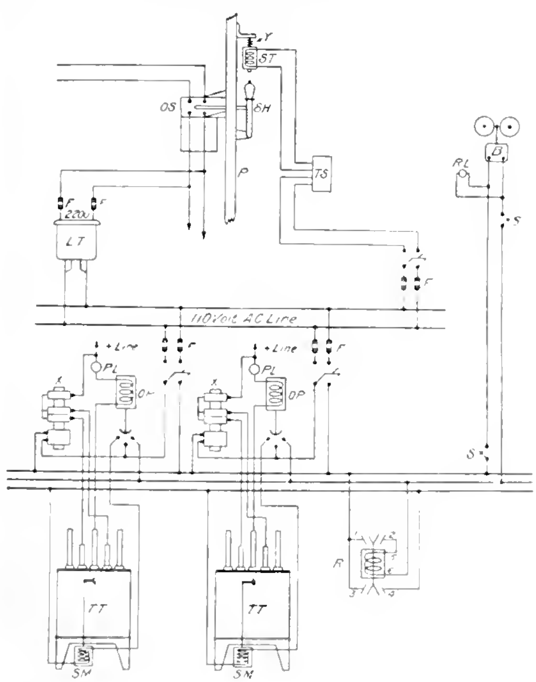

Fig. 3. Accessories

- B, bell
- F, fuse
- R, relay
- S, switch
- P, panel
- X, exciter transformer
- Y, spiral spring
- O.S., oil switch
- O.P., operation indicator
- L.T., lighting transformer
- T.T., tube tank
- S.T., solenoid trip
- S.H., switch handle
- S.M., shaker magnet
- R.L., red lamp
- P.L., pilot lamp
- T.S., time switch

Various Automatic Safety Indicators

The pilot lamp has been supplied on all outfits that are equipped with oil-immersed tubes and is so arranged as to perform two functions: First, if the tube should drop out, the pilot lamp would also go out; second, if, due to some peculiar tube phenomena, the line current, which normally passes out through the cathode or center bottom terminal of the

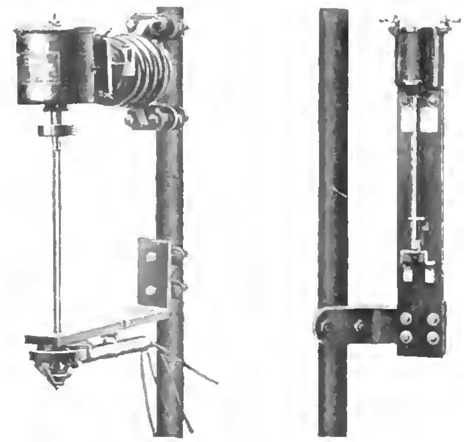

Fig. 4. Underload Series Relay and Operation Indicator

tube, should pass out through one of the starting anodes and thence through the exciting transformer, the pilot lamp would go out. In either case the operator would notice that the pilot lamp had gone out and that the outfit needed attention. The action of the pilot lamp is noiseless, and if the operator were engaged at a distance from the rectifier switchboard the going out of the pilot lamp might easily escape his attention. To avoid this possibility, many operators have installed operation indicators, shown in Fig. 4 and connected as shown in Fig. 3, having a bell and red lamp connected thereto, to notify the operator in the event of the rectifier needing attention. The results obtained from the use of the operation indicator with the bell have well repaid the additional expenditure.

There are still other cases where the operator has even less time to devote to the rectifier outfit, and where it is necessary to provide additional protective devices to insure increased reliability. To meet such a demand, the automatic relay and the tube-shaking magnet (the latter shown in Fig. 5) have been developed. These are connected as shown in Fig. 3 and operators report very good results.

While the automatic relay and shaking magnet will operate in a very satisfactory manner, and assist, when necessary, in keeping the outfit operating, yet, in the event of the absolute failure of a tube, the operator must of necessity install another tube. To notify the operator of this necessity, the bell and red lamp may be installed as shown in Fig. 3. Operators who have used these signals report very satisfactory results.

There are of course isolated cases where outfits are operated without an attendant, except at starting and shutting down. Few of these, however, have taken advantage of auxiliary devices to the extent practiced by two operators I know, who have also installed a time switch, as shown in Fig. 3, to automatically shut down the outfit at a predetermined time. Two such operators have installed the bell in their sleeping room, in one case several blocks from the substation, thereby materially assisting them in giving the outfit prompt attention in cases of necessity.

Fig. 5. Tube Tank Equipped with Shaking Magnet

Other General Rules Which Should Be Observed

The rectifier tube, being the most important factor in the successful operation of the series rectifier system, deserves to receive and does receive the closest care and attention from operators; as is well illustrated by the series of questions and answers given above. There are therefore a number of points which, as a general rule, are observed by operators. Among them the following are of chief interest:

As soon as a new consignment of tubes is received they are examined, prepared for service, placed in a location convenient for immediate use, and a detailed report is made of this examination and test. Thus the operator knows the exact number of tubes which he has on hand, available for service.

The placing of the tube in the tube-carrier, as shown in Fig. 6, is given especial attention. The flexible anode leads are arched up well away from the glass, at the same time allowing free movement of the tubes. The same care is exercised in installing the static protectors; care being taken to ensure that the glass bushings are in their proper places between the protectors and the tubes.

The general practice of all central stations is to keep accurate record of the performance of all electrical machinery; and thus we find the station operator keeping accurate record of the series rectifier tubes. The temperature of the oil in the tube tank is taken at regular intervals, in order that any sudden change in the condition of the water supply, such as abnormally high temperature or absolute failure, may be immediately determined. The room temperature and the temperature of the water supply are, in many cases, made a matter of record for comparison or checking, or for general information, and have been found to be very valuable for reference purposes. The duration of the operating periods is also made a point of record; so that all interested parties may know the exact number of hours of service obtained from each individual tube.

It is generally conceded that the best operating results may be obtained from the tubes when the temperature of the oil in the tube tanks is maintained from 80 deg. to 85 deg. Fahr. Locations have, however, been encountered where the temperature of the circulating water is, during certain periods

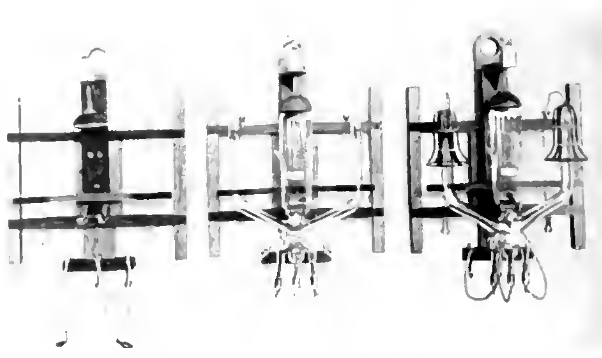

Fig. 6. Tube Racks

of the year, so high that from 90 deg. to 92 deg. Fahr. oil temperature is about the best which can be obtained. To meet this contingency an oil-circulating device, shown in Fig. 7, has been installed. Operators of these devices have determined that the oil temperature may be lowered from 6 to 8 deg. by their use, and a decided improvement in the operation of the tube has resulted.

Many operators pay particular attention to the condition of the tubes. They examine them from time to time, clean them and dry off the mercury from inside the tube. In cleaning the tubes *Bon Ami* is most frequently used, as this apparently gives the best results in washing off the brownish deposit precipitated from the oil. When cleaning the tubes operators are careful not to allow the mercury to get out of the cathode chamber; realizing that should any mercury be allowed to come into the vicinity of the anodes, it would be necessary for the tube to be operated on short-circuit for a period of time (generally about one hour) to vaporize that mercury, and prevent the tube breaking down on being placed in service. To dry off the mercury from the inside of the tube, the tube is generally placed in a small box

Fig. 7. Oil Circulating Device for Series Tube Tank

to which external heat may be applied for a few hours, raising the temperature to approximately 250 deg. Fahr. In steam plants several operators have placed the tube in an open-front box, placing the open front against the boiler wall, and have obtained very good results after leaving the tube in this location over night. Increased reliability

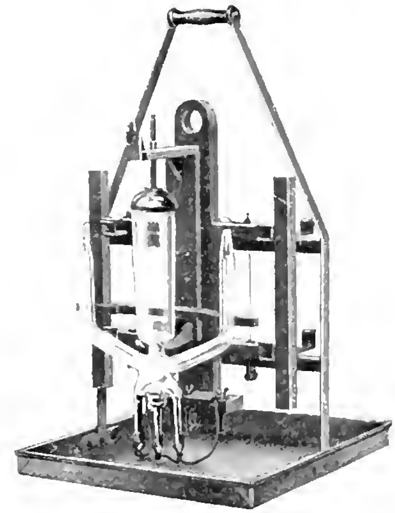

Fig. 8. Rack and Drip Pan for Handling Tubes

and improved operation have invariably resulted from cleaning tubes.

The Effect of Load on Life

Outside the mechanical details of manufacture of the tube and certain peculiar tube

Fig. 9. Bracket for Holding Tubes While in Storage

phenomena, the two most important conditions affecting the average life of series rectifier tubes are the temperature at which they are operated, and the load operated on them. Assuming that tubes are operated at the universally conceded best operating oil temperature of 85 deg. Fahr., the load becomes the main consideration. The maximum amount of luminous arc lamp load which can be operated successfully from a commercial standpoint, on a single 4-ampere series rectifier tube is, approximately, 50 lamps. Beyond this point the average tube life drops very rapidly. Inversely as the number of lamps operated from a single tube is reduced, the average life is increased very rapidly. In view of the fact that, to a certain extent, the life of the tube becomes a limiting feature in connection with the installation of a series rectifier system, all central stations have been very desirous of seeing this average tube life increased. In many cases they have reduced the number of lamps on the circuits to accomplish this end.

To meet this condition, that is, the necessity for obtaining increased average tube life and yet permit of maintaining 50 lamps on the circuit, a number of stations have installed 50-light outfits operating two tubes in series instead of only one tube. The results obtained have been very gratifying. The increased tube life, resulting in a saving in the yearly cost of tubes, more than compensates for the installation of the extra tube.

The drip pan, shown in Fig. 8, for handling the tube to and from the tube tanks, has met with the unqualified approval of all operators who are using them. This makes a very convenient method of handling the tubes. It is neat in appearance, substantial in construction, and not any larger than is absolutely necessary. A number of different designs of tube closet have been developed by station operators for the storage of series tubes and accessories. The tube bracket, shown in Fig. 9, is being used by many operators with very satisfactory results.

A tube closet, similar in design to that shown in Fig. 10, has met with the approval of many station operators and apparently does not detract from the general appearance of the station. This is equipped with tube brackets and is arranged to accommodate the drip pan. It is also provided with shelves for holding the extra pilot lamps, fuses, static protectors, record sheet, etc.

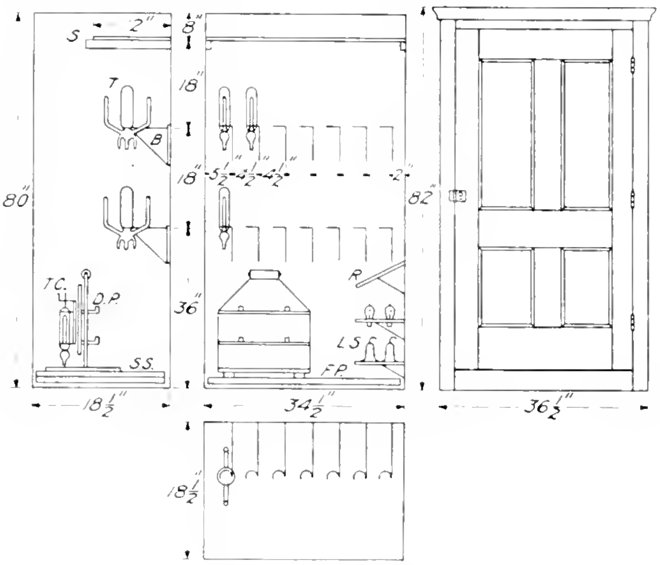

Fig. 10. Tube Closet

Not drawn to scale. All are inside dimensions, except view showing door

R, roof to keep oil from dripping on lower shelves
S, shelf for papers
T, tube
L.S., lower shelves
B, tube supporting bracket
D.P., drip pan
T.C., tube carrier in drip-pan
F.P., floor pan to catch oil drippings
S.S., supporting strips, 1 in. by ¼ in. iron

CONSTANT CURRENT TRANSFORMERS

By Howell H. Reeves

Arc Lamp Supply Department, Schenectady

This paper outlines some of the methods used in series alternating current lighting systems for maintaining constant current from a constant potential supply, the most efficient being the series reactance, which varies the load in such a manner as to maintain constant current. This variable reactance in the constant current transformer is obtained by two or more coils, movable with respect to each other. The principle of its operation is then discussed in detail.—Editor.

The object of this paper is to point out the position of the constant current transformer in the practical problem of street lighting and show some of its characteristics. In order to do this, however, some consideration must be given to the various lighting systems in use.

When electrical energy is transmitted over long distances or when large areas are supplied from a single advantageously located power plant, we must for the sake of economy generate and transmit alternating current. Alternating current multiple lamps may be operated through suitable constant potential transformers from the current supplied by such a power plant. However, if direct current multiple lamps are used rotary converters or motor-generator sets are necessary to produce the desired low voltage direct current. The multiple lamp is not of much importance in street lighting, because of the increased line material necessary and its low efficiency. The latter is due to the volt-ampere characteristic of the arc

$$e = e_0 + \frac{k(l+l_1)}{\sqrt{i}}$$

where e_0, k, and l_1 are constants of the terminal material, i the current, l the arc length, and e the arc voltage. From this it follows that an arc cannot be operated

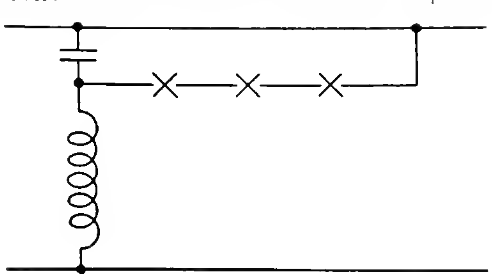

Fig. 1

directly on constant voltage supply but must have a steadying device inserted in series, that is, a device in which the voltage drop increases with the current, so that the total voltage consumed by the arc and the steadying device increases with increase of current, thus limiting the pulsations of current. This steadying resistance in direct current arcs or reactance in alternating arcs consumes power.

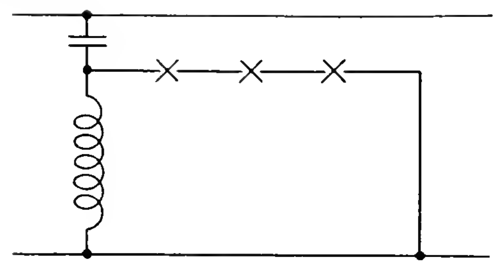

Fig. 2

Arc lamps for use on constant current circuits, that is, circuits in which the current is kept constant by the source of power supply, such as the constant current transformer or arc machine, require no steadying resistance or reactance. Direct current series lamps necessitate a constant current transformer in connection with a rectifying equipment. Alternating current series lamps may be operated on circuits where the current is maintained at a given value by any of the various devices for transforming the constant potential supply to constant current. This transformation can be accomplished by means of inductive reactances or combinations of inductive and condensive reactances; e.g.

(1) An approximately constant current can be maintained by a constant inductive reactance inserted in series with an alternating current, noninductive circuit, so long as the resistance of the circuit is small compared with the series reactance. The current, however, is maintained constant only at a great sacrifice of power-factor. Allowing a current variation of five per cent. from no load to full load and assuming a four per cent. loss in the coil, the power-factor is only thirty per cent. and a coil of three and forty-five hundredths (3.45) kv-a. rating is required for every kilowatt of constant current load. As seen from the low power-factor

the impressed voltage must be extremely high compared with the load voltage.

(2) A constant condensive and an equal constant inductive reactance connected in

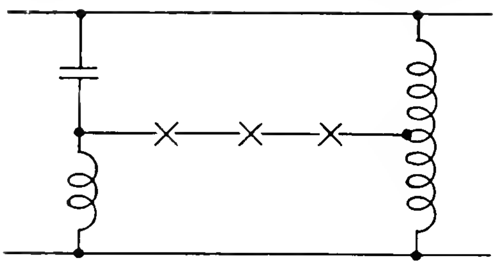

Fig. 3

series across a constant potential supply will maintain constant current in any circuit connected to the common point between the reactances. The other end of this circuit may be connected to either of the constant potential lines, in one case shunting the condensive reactance (Fig. 1) and causing the main current to lead, and in the other, shunting the inductive reactance (Fig. 2) and causing the main current to lag; or it may be connected to any point of a compensator bridging the constant potential circuit (Fig. 3). The power-factor in this case is about seventy-four per cent. and 3 kv-a. capacity in reactance is required for every kilowatt of constant current power.

(3) The "T-connection" or "resonating circuit," consisting of two equal inductive reactances connected in series in the constant potential circuit with a condensive reactance equal to the two inductive reactances connected from the middle point of these across the constant potential circuit, gives constant current in a circuit shunting the condensive

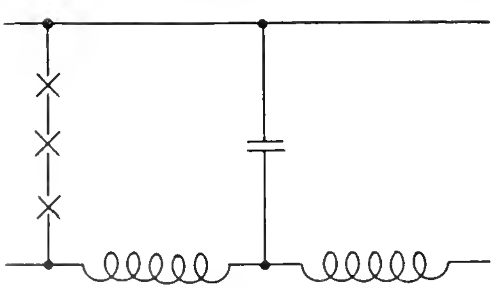

Fig. 4

reactance and one of the inductive reactances. (Fig. 4.)

With the "T-connection" (Fig. 4), a reactance of 4 kv-a. rated capacity is required for every kilowatt of constant current power, although the power-factor is good.

(4) The "monocyclic square," consisting of two inductive and two condensive reactances connected in series-multiple across the constant potential circuit, the two similar reactances being opposite each other, gives constant current in any circuit connected to the diagonal of the square opposite the points of connection to the constant potential circuit.

The monocyclic square (Fig. 5) requires 2 kv-a. in reactance for every kilowatt of constant current power, the full load efficiency being 94.3 per cent. and the power-factor 100 per cent. for non-inductive loads.

One great disadvantage of all of the above systems is their lack of flexibility, the maximum voltage on the constant current circuit being fixed by that of the constant potential supply. The prohibitive feature, however, in the last three, at least, is the high cost of the condensive reactance and its great weight.

The most efficient method of producing constant current from constant potential supply and at the same time maintaining a sufficient value of power-factor and allowing flexibility in secondary voltage is by means of a series reactance which changes with the load in such a manner as to keep the current constant.

This variable reactance is obtained in the constant current transformer by means of two or more coils, movable with respect to each other.

In constant current transformers for series incandescent street lighting, the primary coil is stationary while the secondary is suspended from a rocker arm, to the other

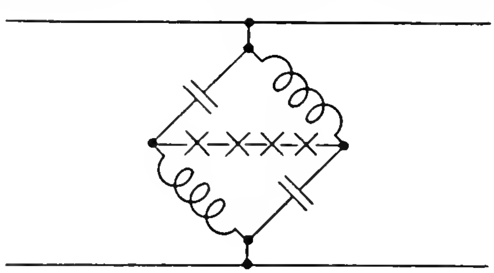

Fig. 5

end of which weights are attached. These weights together with the magnetic repulsion between the coils counterbalance the weight of the secondary coil. At full load the coils should be from one to two inches apart, and as the load falls off the tendency for the current to rise due to the decreased resistance of the secondary circuit is offset by the separation of the coils. The separation of the coils is caused by the greater repulsion of the increased magnetic flux, due to the momentarily increased current in the secondary coil. With the coils farther apart more of the magnetic lines of force from the primary coil go out between primary and secondary as leakage flux, and the e.m.f. induced in the secondary is decreased in proportion to the fall in the secondary load, thus maintaining the current at a constant value. The series inductive reactance, which varies with the load, is independent of frequency, impressed voltage and character of load.

Constant current transformers for incandescent circuits are designed so that the coils will separate sufficiently to maintain constant current even when all of the lamps are out of the circuit; in other words, they regulate from full load to no load. The arc transformers also regulate from full load to zero. The center of curvature of the weight sector arm is adjustable, as is also the amount of balancing weight, thus allowing the transformer to be adjusted for operation at any current within 7½ per cent. of the normal rated value. They may be operated on any primary voltage within 5 per cent. of the normal rated value, and will regulate within 1/10 ampere either side of normal. Arc transformers are designed in 6, 12, 25, 35, 50, 75, and 100 light sizes, while those for incandescent circuits are made in 3, 5, 10, 15, 20, and 25 kw. capacities.

By means of suitable connections from the secondary the total number of lamps may be operated either in a single circuit, or if

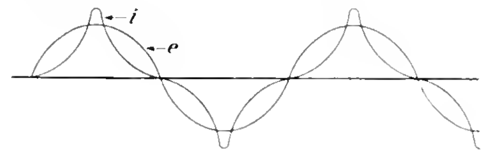

Fig. 8
e, Voltage Wave; i, Current Wave

desired in two multi-circuits, in a manner similar to the well-known method employed on the Brush series dynamos of large capacities. Owing to the high secondary voltage of constant current transformers commonly employed for street lighting the 15 kw. transformer is the largest size recommended for single circuit secondary. By adjusting the cam-shaped segment from which the counterbalancing weights are suspended, it is possible to regulate the arc transformer so that the current will increase or decrease as the number of lamps is varied between 1/3 load and full load. The curves in Fig. 6 show the range of regulation that can be obtained by varying the adjustment of the cam supporting the regulating weights.

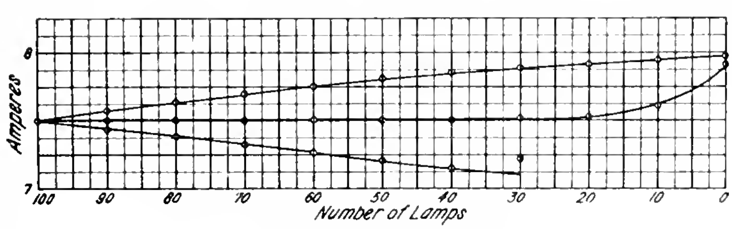

Fig. 6. Range of Current Regulation

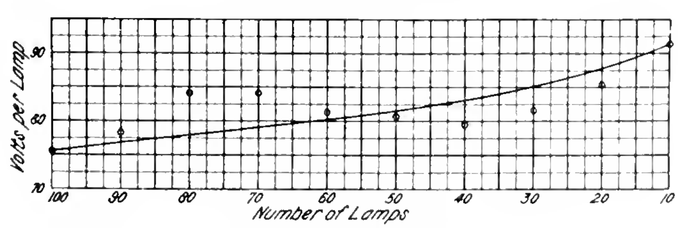

Fig. 7. Increase in Voltage Across Lamp with Decrease in Number of Lamps; 100 Lamp Transformers

The early tests showed that when the transformers were adjusted for constant current over a wide range of load the arc lengths of the lamps varied, depending upon the number of lamps in the circuit. The voltage across the terminals of the individual lamps was approximately 10 volts higher at 1/4 load than at full load, although the current was the same in both cases. The results of a test on a 100 light transformer made to show this effect is given in Fig. 7.

It has been found that by varying the adjustment of the transformer, constant voltage or constant wattage can be maintained at the terminals of the individual lamps for various loads. The current, however will vary, increasing as the load increases. This is due to the fact that the alternating arc can not be represented by a constant effective resistance, but has an effective resistance varying periodically with the current strength and with a double frequency. The apparent resistance of the arc is very high at small currents, low at large currents, and varies almost inversely at a rate proportional to

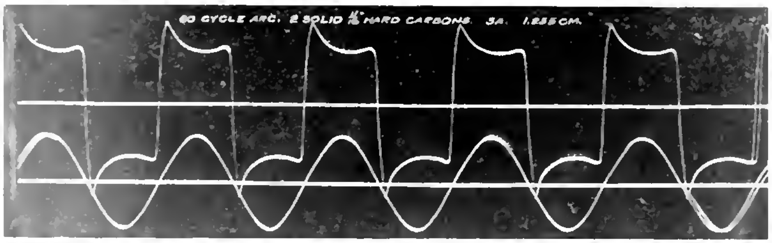

Fig. 9. Upper Curve, Current; Lower Curve, Voltage

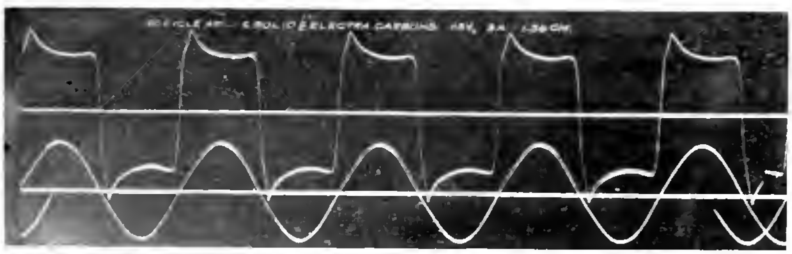

Fig. 10. Upper Curve, Current; Lower Curve, Voltage

the current strength. In consequence thereof, if the current passing through an arc lamp follows in value a sine wave, the potential difference cannot be a sine wave, but is less near large values of current and greater near small values of current, that is, becomes double peaked; and if a sine wave of potential difference is impressed upon the arc, the current cannot be a sine wave, but is less near small values and greater near larger values of potential difference, that is, becomes single peaked. Fig. 8 shows the theoretical shape that the current wave in the arc would assume if a sine wave of voltage were to be impressed on the arc. Fig. 9 is an oscillogram showing the voltage and current for two solid hard carbons, $\frac{11}{16}$ in. in diameter, where the arc length is 1.255 cm. and the current 3 amperes. Fig. 10 is an oscillogram showing the voltage and current for two solid soft electra carbons, $\frac{1}{2}$ in. in diameter, where the arc length is 1.36 cm., the current 3 amperes, and the arc voltage 113 volts.

In a constant current transformer with primary and secondary coils close together, the internal self induction is relatively small at full load, and the secondary e.m.f. wave is almost the same as the primary; that is, assuming a sine wave of impressed e.m.f., the secondary potential difference is sinusoidal, and thus the secondary current is peaked. At light load, however, the primary and secondary coils are widely separated and the internal self induction of the transformer is very high. Thus through the effect of self induction in suppressing the higher harmonics, the secondary current is maintained closely resembling sine shape, and in this case the secondary potential difference becomes double peaked.

The iron armature in the series magnets of the arc lamps is worked at a high flux density, consequently, the saturation of the iron is approached at high values of current. As these are higher in the peaked than in the sine wave, the former do not cause proportional increase of flux in the core. Hence for the same effective value, the current of peaked wave form will cause the series magnet to give a smaller pull than it would if the current were a sine wave.

As the load becomes lighter and the current approaches a sine wave, as already stated, the pull of the series magnets increases and the electrodes are drawn farther apart, causing the arc voltage to rise. In the meantime, if the secondary current has remained the same, the watts per lamp would be greater on light load then on full load. In order to keep the wattage per lamp constant with changes of load the transformer is adjusted so that the secondary current will automatically fall as the load is decreased. On incandescent circuits the resistance is constant and consequently the transformer can be adjusted for constant current.

Two important advantages of the constant current transformer over the ordinary variable series reactance (constant current regulator) are that the former transforms the supply voltage to the desired secondary load voltage (either up or down) and also insulates the lighting circuit from the generating system. This separation of the lighting circuit from the distributing and generating system is absolutely necessary for safety, and when regulators are used can only be assured by employing in addition thereto constant potential or insulating transformers. As the constant current transformer is used with alternating current series arc and incandescent lamps, and in the case of direct current lamps in connection with a rectifier, its importance in street lighting systems is at once noted. It does not lend itself quite so readily to theoretical investigation and discussion as the constant potential transformer or some of the rotary machines, but in the every day service of the public it fills a place and performs a task that may well be coveted by much larger or more complicated mechanisms.

MATCHING COLORS BY ARTIFICIAL LIGHT

By R. B. Hussey

Illuminating Engineer, Arc Lamp Department, Lynn

This article describes an artificial illuminating outfit which reproduces almost exactly the light values from a clear north sky. This consists of an intensified arc lamp with a combination of diffusing glasses for reducing the amount of red, orange and violet rays.—Editor.

Until quite recently the only requisite of an artificial illuminant to receive consideration was the quantity of light. Other points were unthought of, and it was merely a question of getting as much light as possible for a given amount of energy. In keeping with the rapid progress in other lines of engineering development, the demands made within the last few years on the lighting industry have multiplied many times. Now not only the quantity of light is considered, but its steadiness, distribution, color, etc., are equally matters of great importance. As the human eye by nature is best adapted in general to natural light, or daylight, the ultimate goal in the matter of color is, and always will be, daylight. Although this natural standard is constantly varying through quite wide limits both in intensity and color, it is what we are accustomed to and to which we constantly refer in discussing and comparing all forms of artificial light. A light is said to be white if it seems to approximate some form of daylight.

In common practice the enclosed carbon arc lamp has been spoken of as the daylight lamp, and has been usually employed in all cases where any attempt has been made to distinguish or work with colors when daylight has not been available. Its general color effect is good, and much nearer to daylight than any lamp of the incandescent class; and where properly handled, using sufficiently high intensity, the results obtained have been fairly satisfactory. In cases where this was not sufficiently accurate, it nevertheless represented the best available artificial light source, and nothing could be done but wait for suitable daylight.

There has been, however, a constantly increasing demand for an accurate daylight-giving illuminant, by the use of which colored goods of any hue would not be appreciably distorted from their daylight values, and under which colors might be matched with results identical with those which would be obtained under the best daylight. Inasmuch as the whole range of color must be considered, such an illuminant must be correct, or, in other words, equivalent to daylight throughout the entire range. Such a lamp cannot be expected to have a high efficiency, nor is this of the greatest importance as the lamp is not needed for the lighting of large areas. Its greatest value at present is apparently to provide a suitable illumination, both as to intensity and quality, over a comparatively small area, where the finest and most accurate color work can be done. Such a lamp has an advantage over daylight, in that its color and intensity remain constant, while daylight constantly varies with the weather and time of day, a matter of a few minutes frequently making a very great difference in the apparent color value.

With this growing demand in mind, much work has been done recently in an endeavor to produce lamps that will give the desired light effect. One of these devices, using a standard enclosed arc lamp, has recently been developed. The so-called intensified arc lamp was selected as a unit with which to work, since its light is steady, well distributed for the particular purpose, and of sufficient intensity. A careful examination of the spectrum of this lamp reveals the fact that the red and orange are somewhat in excess, while the well known "carbon lines" in the violet considerably accentuate that portion of the spectrum. In other words, to bring this light to our standard-daylight, it is necessary to reduce the amount of red, orange and violet, without greatly weakening the color in the middle of the spectrum. No single color of glass has been obtained with the correct selective absorption to produce this desired result; but after considerable experimenting, a combination of several colors of glass was obtained that would give a light of almost exactly the same value as that from an almost clear north

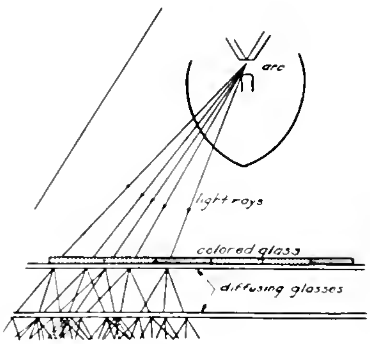

Fig. 1

sky; and, since this is what is commonly used for color work of the highest accuracy, this combination is used.

Instead of allowing the light from the arc to pass through the different colors successively, which would necessarily result in a large amount of absorption, the different colors are arranged side by side in strips or small pieces, and diffusing glass used to mix the light (see Fig. 1). As can be readily seen, if the proportions of the different colors or the relative sizes of the pieces are varied, almost any desired modification of color within certain limits can be obtained to answer particular requirements. The pieces of colored glass may be cut small and placed between two layers of clear diffusing glass, and the light will properly mix. If the pieces are made larger, it is necessary to separate one of the diffusing glasses from the other by a distance of 1 in. to 2 in. in order to get good diffusion.

This arrangement of colored glasses, forming the color screen, is made up in the form of a circle about 16 in. in diameter, and is placed in the large end of a conical hood which is attached to the casing of the lamp. This hood surrounds the inner globe and is given a reflecting surface, so that the light from the arc is transmitted and reflected down through the color screen, while at the same time the direct rays are kept from the eyes of the user. (Fig. 2 shows the general appearance of lamp and hood.) With an outfit such as has been described the worker in colors or colored goods can continue his work all day and all the evening if necessary during rush seasons, with the assurance that his lamp is accurate and constant, and that what is done with it will be the same as if done under the best of daylight.

The practical uses of such a lamp are many. In the winter time every dyehouse or color-printing establishment can match or select colors for only a few hours in the middle of the day and then only on pleasant days. A long spell of cloudy weather in a busy season becomes a serious matter in such lines of industry. With two or three of these lamps at hand the work can be continued regardless of the weather and with exactly the same results from day to day. Many other applications might be mentioned, such for instance as the tobacco industry, where a very close selection of tobacco by color is required, and for which ordinary illuminants having a predominance of yellow and red are valueless. At ribbon counters, silk goods counters, and other places in department stores, it is found that the close matching of goods is very difficult under the best of ordinary lighting conditions, and frequently impossible owing to insufficient and poor quality of light. In such places a few special

Fig. 2. Intensified Arc Lamp Arranged for Matching Colors, Showing Screen Lowered

color matching outfits should be installed in convenient locations, where prospective customers can at any time take goods to be matched against samples with the assurance of accurate results.