GENERAL ELECTRIC REVIEW

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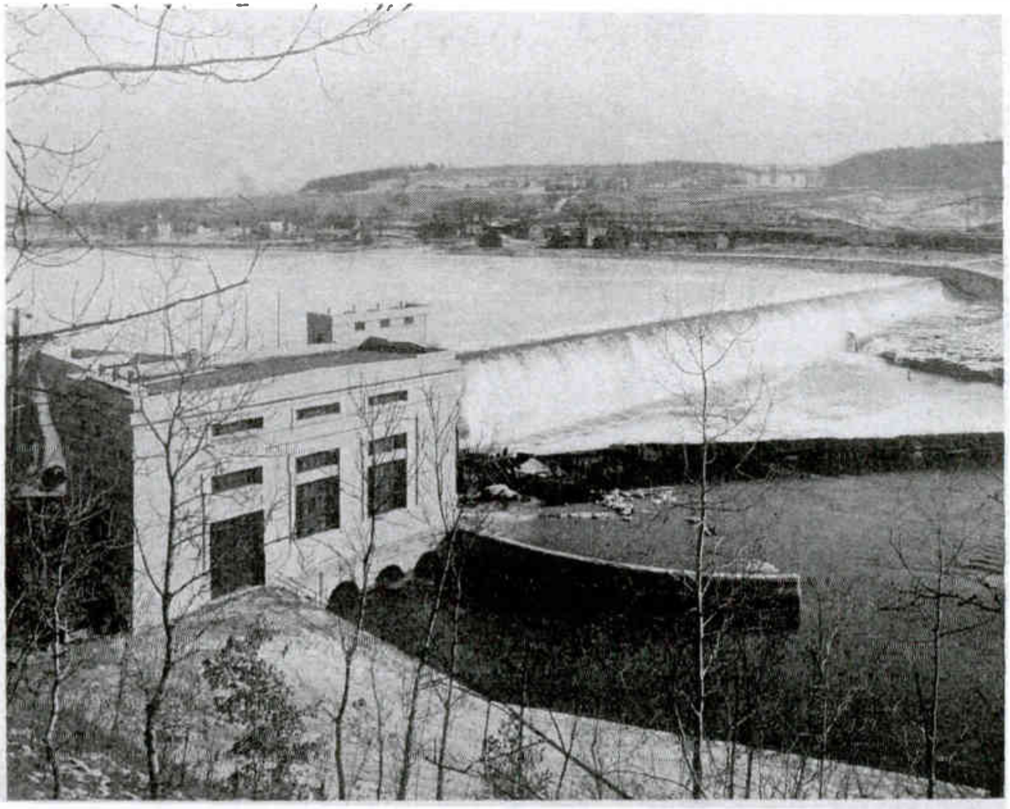
CONTENTS



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

GENERAL ELECTRIC REVIEW

SOME CHEMISTRY OF LIGHT

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

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

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

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

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

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

JOHN B. TAYLOR

THE FLOW METER

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

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

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

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

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

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

For equalizing a load on individual boilers of a battery.

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

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

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

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

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

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

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

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

SOME CHEMISTRY OF LIGHT*

By W. R. Whitney, Ph. D.

Director of Research Laboratory of Schenectady Works

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

I can not tell just when chemistry was first scientifically applied to a study of artificial light. Most cardinal discoveries are made by accident and observation. The first artificial light was not made by design, nor was the first improvement the result of chemical analysis. It is supposed that the first lamps were made from the skulls of animals, in which oil was burned. Herodotus, describing events about three centuries before Christ, says of the Egyptians: "At the times when they gather together at the city of Sais for their sacrifices, on a certain night they all kindle lamps many in number in the open air round about the houses: now the lamps are saucers full of salt and oil mixed and the wick floats of itself on the surface and this burns during the whole night."

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

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

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

Very great advances have been made in the use of fats and oils for lighting purposes, but there is so much of greater interest in later discoveries that we will not consider many of them. The distillation of gas from coal or wood in 1730 was a chemical triumph, and a visit to a gas plant still forms one of the main attractions to the young chemist in an elementary course of applied chemistry. The first municipal gas plant was established in London, just about one hundred years ago. The general plan, so apparently simple to us to-day, was at its inception judged impracticable by engineers.

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

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

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

Various schemes were devised in the early part of the nineteenth century for using gas to heat to incandescence, rods or surfaces of lime, zirconia and platinum. This was not at first very successful, owing to imperfect combustion of the gas. The discovery of the Bunsen-burner principle was made a little later. By thus giving a much higher temperature to the gas flame and insuring complete combustion, new impetus was given to this branch, and the development of suitably supported oxide mantles continued for half a century.

Most prominent in this field is the work of Auer von Welsbach. It was a wonderful series of experiments which put the group of rare earth oxides into practical use and started a line of investigation which is still going on. The Welsbach mantle practically substitutes for the carbon of the simple gas flame, another solid in a finely divided shape capable of giving more efficient light. This allows all of the carbon of the gas to contribute to the production of a hotter flame. But more interesting than the mechanical success, to my mind, is the unforeseen or scientifically unexpected discovery of the effect of chemical composition. By experiment it was discovered that the intensity and color at incandescence of the various mixtures of difficultly fusible oxides varied over a wide range. Thus a broad field for unforeseen investigation was opened, and much advanced chemical work has been applied to this industry. The color and intensity of the light varies in an unexplained manner with slight differences in composition of the mantle. The following are the composition and candle-powers of some sample mantles:

CANDLE-POWER OF MANTLES, RANGING FROM PURE THORIA TO 10 PER CENT. CERIA

No.	Per Cent. Thoria	Per Cent Ceria	Candle-Power
367	100.00	0.00	7
378	99.75	0.25	56
369	99.50	0.50	77
370	99.25	0.75	85
371	99.00	1.00	88
372	98.50	1.50	79
373	98.00	2.00	75
374	97.00	3.00	65
375	95.00	5.00	44
376	90.00	10.00	20
69	La,Zr, Ce	Oxides	30

The methods of making the present mantles were also a part of Dr. Auer's contribution to the art. Suitably woven fabrics are dipped into solutions of the rare earth salts; these are dried and the organic matter burned out, leaving a structure of the metal oxides.

The pure thoria gives a relatively poor light. The addition of the ceria, up to a certain amount, increases the light. This added component is called the "excitant," and as the cause for this beneficial action of the excitant is not known, it is possible that further discoveries along this line will yet be made.

There is hardly a prettier field for chemical speculation than is disclosed by the data on these light efficiencies. For some unknown reason, the change in composition by as little as one per cent. varies the luminosity over ten-fold, and yet more than one per cent. of the excitant (ceria) reduces the light. Besides the temptation to speculation, such disclosures of nature encourage us to put greater trust in the value of new experiments, even when accumulated knowledge does not yield a blazed trail for the pioneer. By giving a discovery a name and attaching to it a mind-quieting theory, we are apt to close avenues of advance. Calling this small amount of ceria an "excitant" and guessing how it operates, is directly harmful unless our guess suggests trial of other substances.

One of the explanations proposed to cover the action of the ceria ought to be mentioned, because it involves catalysis. This is a term without which no chemical lecture is complete. Some think that the special mantle mixture causes a more rapid and localized combustion and therefore higher temperature, by condensation of gas in its material. Others think that this particular mixture permits of especially easy and rapid oxidation and reduction of its metal oxides themselves in the burning gas mixture. The power which catalyzers have of existing in two or more states of oxidation seems to apply also to the ceria of the Welsbach mantle.

Whatever the truth may be, it has been shown by Swinton[*] that when similar oxide mantles are heated to incandescence in vacuo by cathode rays, the presence of one per cent. ceria produces only a very small increase in the luminosity of thoria. It is interesting

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[*] Proc. Roy. Soc.. 66. 113.

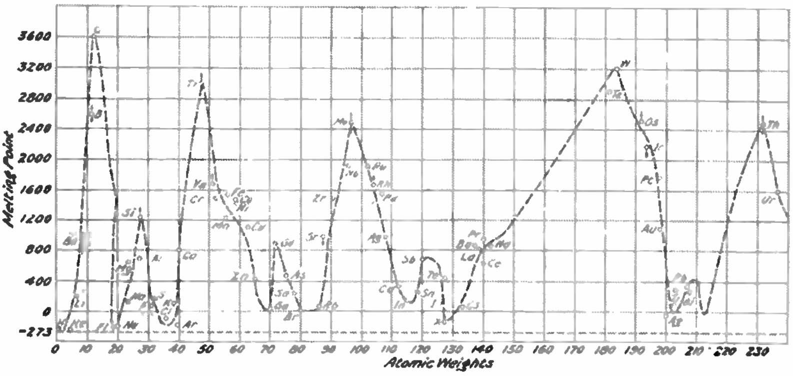
to note that in the gas flame *pure ceria* gives about the same light as *pure thoria*, while in the cathode rays of the Crookes tube, with conditions under which ceria gave almost no light, pure thoria gave an intense white light. These facts, which are still unexplained, illustrate how little is understood in this field.

I will merely refer to the fact that vapors of gasoline, kerosene, alcohol, etc., are now also used in conjunction with the Welsbach mantles. The field of acetylene I must also omit with a mere reference to the fact that the manufacture of calcium carbide was a chemical discovery; and the action of water upon it, producing the brilliantly-burning acetylene gas was another.

Turning now to electrical methods of generating light, we find the chemist early at work. Sir Humphrey Davy and others, at the dawn of the nineteenth century, showed the possibilities which since that time have been developed into our various types of incandescent and arc lamps. We naturally attach Mr. Edison's name to the development of the carbon incandescent lamp, because it was through his indefatigable efforts that a practicable lamp and illuminating system were both developed.

It had long been known that platinum, heated by the current, gave a fair light, but it melted too easily. A truly enormous amount of work was done in attempts to raise the melting-point of the platinum, and the effect of occluded gases, of annealing, of crystalline condition, etc., were most carefully studied, but the results were unsatisfactory. He was therefore led to the element carbon as the next most promising conductor of high melting-point. Edison's persistent and finally successful attempts to get a dense, strong, practical filament of pure carbon for his lamps, is one of the most encouraging lessons to the chemist of to-day.

This history needs to be read in the light of the knowledge of carbon at that time and the severe requirements of a commercially useful carbon filament. It illustrates the value of continued effort when it is based on knowledge or sound reasoning. The search was not the groping in the dark that some of us have imagined, but was a resourceful search for the most satisfactory, among a multitude of possible materials. From our point of view, all subsequent changes in choice of material for incandescent lamp filaments have been dictated by the knowledge that high melting-point and low vapor



tension were the first requirements. If you will consult the curve (Fig. 1) of the *melting-points* of all the *elements*, as plotted against their *atomic weights*, you will see at once that the desired property of high melting-point is a periodic function of the atomic weight. And it is this fact, which was independently disclosed as a general law by Meyer and Mendeljeff, in 1869, that has aided in the selection of all the new materials for this use. You will notice that the peaks of the curves are occupied by such elements as carbon, tantalum, tungsten, osmium, etc., which are all lamp materials.

A study of the laws of *radiation* also soon played a part in incandescent lamp work. The early rough and black filament of bamboo was first replaced by a polished black carbon filament, and later by one which had a bright, silver-gray coat of graphite. A black body at any temperature radiates the maximum possible energy in all wave-lengths. Heated to incandescence, it will *radiate more invisible and useless infra-red rays than any other* opaque material at the same temperature; a polished metal is therefore a more efficient light source than the same metal with a black, or even rough surface. This fact is derived from Kirchoff's law of radiation and absorption, which was early established.

It may seem like penetrating too far into details to consider for a moment the changes in structure and surface which the carbon filament of our incandescent lamps has undergone, but the development of such an apparently closed problem is instructive, because it has yielded to such simple methods of attack. The core, or body, of the carbon filament of to-day is made by some one of the processes based on dissolving and reprecipitating cellulose, such as are used in artificial silk manufacture. The cellulose solution is squirted through a die into a liquid which hardens it into dense fibers. These cellulose fibers are then carbonized by being heated, out of contact with the air, at as high a temperature as possible with gas furnaces. All of this is also merely the application of chemistry which was first worked out in some of the German chemical laboratories.

This plain carbon filament (the result of this simple process), which might have been satisfactory in the early days, would nowadays be useless in a lamp, as its practical life is only about 100 hours at 3 watts per candle. In a subsequent process of manufacture it is therefore covered with a steel gray coating of graphite, which greatly improves the light emitting power. This coat is produced by heating the filament in an atmosphere of benzene or similar hydrocarbons. The electric current which heats the filament is of such an intensity that the decomposition of the hydrocarbon produces a smooth, dense deposit of graphite.

With this graphite-coat the filament now burns about 500 hours. But the simple graphite coat is improved by being subjected, for a few moments, to a temperature of about 3,500° in the electric furnace; the life then becomes about 1,500 hours under the same operating conditions as before. The product of this treatment is known as the metallized filament, because by this last step its temperature coefficient of resistance is made similar to that of the metals; *i.e.*, 0.0037.

With an incandescent lamp containing a platinum wire filament, the intensity of its light is not very great, even when the current is sufficient to melt the wire. A much greater luminosity is produced by a plain carbon filament, and a still greater by the graphite-coated and metallized carbon before they are destroyed. In the case of carbon, the useful life of the lamp depends much more on the vaporization of the material than on its melting-point, and these lamps will operate for a short time at very much greater efficiencies or higher temperatures than is possible when a practical length of life is considered. Thus, besides the physical effect of surface quality, we have evidence of differences in the vapor pressure of different kinds of carbon. It looks as though carbonized organic matter yielded a carbon of much greater vapor pressure for given temperature than graphite, and that even graphite and metallized graphite are of quite distinctly different vapor pressures at high temperatures. It may be interesting to note here that if the carbon filament could withstand for 500 hours the maximum temperature which it withstands for a few moments, the cost of operating incandescent lamps could be reduced to nearly a fifth of the present cost.

It was discovered by Auer von Welsbach that the metal osmium could be made into a filament, though it could not be drawn as a wire. The osmium lamp was the first of the recent trio of metallic filament incandescent lamps. The tantalum lamp, in which another high melting-point metal replaces the superior but more expensive osmium, has been in use six or eight years. This surpasses the carbon in its action, and on running up to its melting-point it shows still brighter light than carbon.

More recently the tungsten filament lamp has started to displace both of the others. At present this is the element which withstands the highest temperature without melting or vaporizing, and on being forced to its highest efficiency in a lamp it reaches higher luminosity; it is similar to carbon and tantalum in that an enormously greater efficiency may be produced for a very short time than can be utilized for a suitable length of life. The inherent changes at these temperatures, distillation or whatever they are, quickly destroy the lamp. The lamp will burn an appreciable time at an efficiency fifteen times as great as that of the common operating carbon incandescent lamp (at 3 watts per candle). In other words, light may be produced for a short time at an energy-cost one fifteenth of common practice, so that there is still a great field for further investigation directed towards merely making stationary those changing conditions which exist in the burning lamp.

While it is generally true that the light given by a heated body increases very rapidly with rise of temperature above 600°, the regularity of the phenomenon is commonly over-estimated. A certain simple law covering the relation between the temperature and the light emitted, has been found to apply to what we call a black body. This so-called Stefan-Boltzmann law states that "the total intensity of emission of a black body is proportional to the fourth power of the absolute temperature." There are, however, very few really black bodies in the sense of the law. The total emission from a hole in the wall of a heated sphere has been shown experimentally to follow the law rigidly, but most actual forms and sources of illumination do not. Most practical sources of artificial light are more efficient light producers than the simple law requires. This may be said to be due to the fact that these substances have characteristic powers of emitting relatively more useful energy as light than energy of longer wave-length (or heat rays). Most substances show a power of selective emission and we might say that an untried substance, heated to a temperature where it should be luminous, could exhibit almost any conceivable light effect. A simple illustration will serve to make this clear: If a piece of glass be heated to 600°, it does not emit light; if some powder such as clay be sprinkled upon it, light is emitted, and the proportion of light at the same temperature will depend upon the composition of the powder. Coblentz has shown, both for the Auer mantle and for the Nernst glower, that the emission spectra are really series emission bands in that portion of the energy curve which represents the larger part of the emitted energy. This is in the invisible infra-red part, and so the laws which govern the emission at a given temperature depend upon the *chemical composition* of the radiant source. Silicates, oxides, etc., show characteristic emission bands.

One of the most attractive fields of artificial light production has long been that of luminous gases or vapors. It has seemed as though this ought to be a most satisfactory method. The so-called Geissler tubes in which light is produced by the electrical discharge through gases at low pressure are familiar to all. The distribution of the energy emitted from gases is still further removed than that of solids from the laws of a black body, and a large proportion of the total electrical energy supplied to a rarefied gas may be emitted as lines and bands which are within the range of the visible spectrum. These lines, under definite conditions of pressure, etc., are characteristic of the different elements and compounds. The best known attempts to utilize this principle are the Moore system of lighting (in which long tubes of luminous gas are employed), and the mercury lamps, which, while more flexible on account of size, are still objectionable because of the color of the light.

It is rather interesting that the efficiencies of all of these various sources of electric light are not nearly so widely different as one would expect from a consideration of the widely divergent methods of light production employed.

From the light of a vapor or gas to that of an open arc is not a wide step, but the conditions in the arc are apparently quite complex and there is a great deal of room for interesting speculation in the phenomena of an arc. Briefly, there are two kinds of arcs to be considered in lighting. One has been in use for a century, the other for a few years only. The first is the successor to Sir Humphrey Davy's historical arc between charcoal points. In this kind of arc the current path itself is hardly luminous, and the light of the lamp is that given by the heated electrodes. In case of direct current it is the anode, or positive electrode, which gets the hotter and gives far the greater part of the light. In this carbon arc, it can readily be seen that the light is emitted by the heated solid carbon of one electrode: this gives a steady source of light, but is not so efficient as an arc in which material in the arc stream itself is the source of light. The arc may be made to play upon rare earth oxides, and these, being heated to incandescence, increase the luminosity, but this has not proved useful. The more common way is to introduce into the carbon electrode certain salts which volatilize into the arc and give a luminous effect. Here cerium fluoride, calcium fluoride, etc., are used, and the color of the arc, just as in the case of gas mantles, may be varied by varying the composition of the electrodes. This is seen in the arc from the carbon electrodes containing such salts.

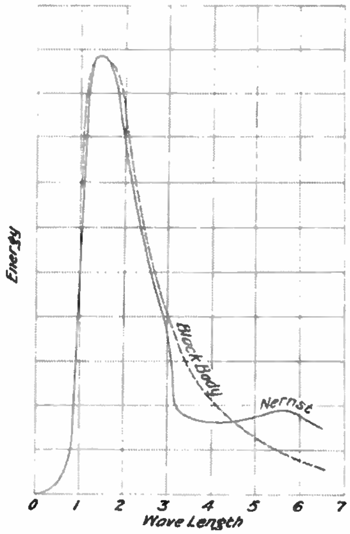


Fig. 2

In the case of the flaming arc, the greater part of the light is due to the incandescent metallic vapors in the space between the electrodes. Substitution of one chemical for another in such flaming arc electrodes has covered quite a wide range of chemical investigation. Salts are chosen which give the greatest luminosity without causing the formation of too much ash or slag. Some compounds of calcium, for example, are practicable, while others are not, though all of these would, under suitable conditions, yield the calcium spectrum. If such salts as calcium fluoride were conductors at ordinary temperature, useful electrodes for flame arcs would probably be made from them. Such conducting materials as iron oxide, carbides, etc., have been used for flame arc electrodes, and a great many of the so-called magnetite arcs are now in use. The electrodes

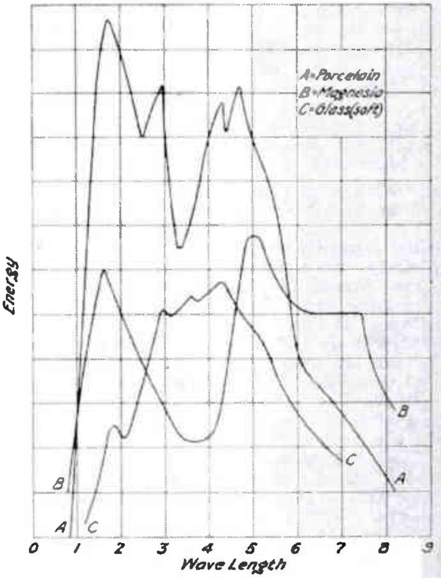


Fig. 3

in this case are largely magnetic oxide of iron, with such other ingredients as titanium and chromium oxides, to increase the intensity of light, to raise the melting-point of the mixture, etc.

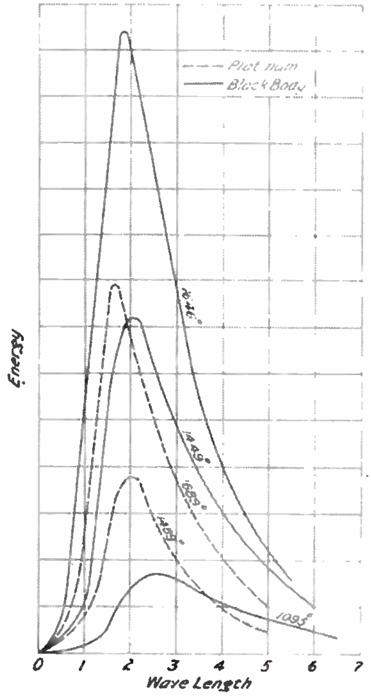


Fig. 4

As will be seen from observing this arc, the light is very white and intense and is generated by the heated vapors of the arc proper. A great many modifications of this arc principle are possible. Titanium carbide and similar substances give characteristic arcs, and some of them are very intense and efficient.

The Nernst Lamp

A distinct species of electric incandescent lamp is that invented about ten years ago by the well-known physical chemist, Professor Nernst. This employs for filaments a class of bodies which are not electrical conductors at all at ordinary temperatures, and which, at their burning temperatures, do not conduct the current as metals and carbon, but as a solution does. This kind of conductivity, the electrolytic, involves electrochemical decomposition at the electrodes, and in the case of the Nernst filaments these otherwise destructive reactions are rendered harmless by the continual oxidizing action of the air. For this reason this type of lamp will not burn in vacuo.

For its most perfect utility the principle of the Nernst lamp seems to require a mixture of oxides, because a single one is not so good a conductor nor so luminous. It uses oxides because these are the most stable compounds known, and it uses the rare earth oxides because they have higher melting-point than other oxides. As the efficiency rises very rapidly with temperature, there is a great advantage in using the most infusible base possible. For that reason, zirconia, thoria, etc., are usually employed.

In this lamp a rod or filament of an oxide mixture, much like those used in Welsbach mantles, is heated by the current, externally applied, until it reaches a temperature at which it becomes a good conductor itself. Here again the peculiar laws of light radiation are illustrated, the light emitted at a given temperature being determined by the nature of the substance. Just as the pure thoria gives a poor light compared to the mixture with one per cent. ceria, so a pure zirconia rod, heated by the current, gives much less light than a rod containing a little thoria, ceria or similar oxide. Work done by Coblentz on the energy-emission of such rods shows the emission spectra, at least in the infra-red, to vary with the nature of the substance. In general, the spectra are not continuous like the spectra of metals and black bodies, but seem to occupy an intermediate position between these and luminous gases, which we know have usually distinct line spectra.

This recalls the subject of selective emission. Coblentz has shown selective emission in the long wave-lengths for a Nernst glower. This is shown in comparison with the emission of a black body, in curve No. 2. The two sources, when compared at the temperatures where they exhibit the same wave-length for maximum emission, differ very considerably in emission in the infra-red, the black body giving more energy at the blue end, and less at the red end of the spectrum.

This is still more noticeable in the curves for such substances as porcelain, magnesia and glass, as shown by Coblentz's curves (Fig. 3).

The curves of wave-length and radiant energy which are shown are, with slight modifications, taken from work of Lummer and Pringshein and of Dr. Coblentz. The curve for the ideal, or black body radiator, gives a picture of the total energy and its distribution over the different wave-lengths. It is the peculiarity of the black body to radiate more energy of any given wave-length than does any other body at the same temperature. Therefore, in case of all substances acting as thermal radiators, the black body will always give the greatest brilliancy. Since this body at the same time radiates a maximum in *all* wave-lengths, it will be surpassed in light *efficiency* by any substance which is a relatively poor radiator in the invisible or non-luminous part of the spectrum.

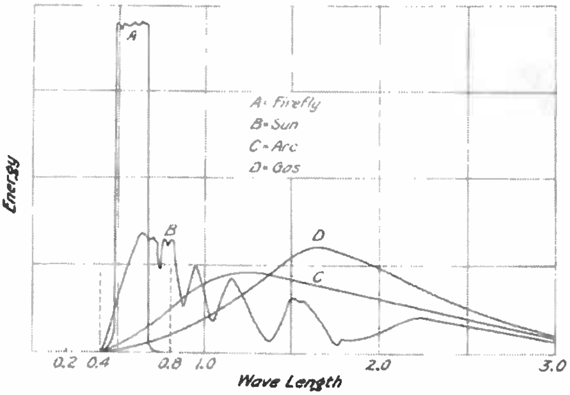


Fig. 5

In the energy curves shown it is to be noticed that the visible part of the energy is practically only that between 0.4 and 0.8 thousandths of a millimeter. Consider the solid lines in Fig. 4 for a moment. These show the emission of a black body at centigrade temperatures noted on the curves. Evidently the energy emitted rises very rapidly with the temperature; *i.e.*, as the fourth power of the absolute temperature. It will be noted also that the point of maximum energy or wave-length corresponding to maximum energy, shifts gradually towards the left, or towards the visible wave-lengths.

It is this rapid shifting of the position of maximum energy which makes the search for substances which can withstand even only slightly higher temperatures of such great interest.

The curves for the black body and for platinum (dotted lines) are not greatly different in general appearance, but the total amount of energy emitted at a given temperature from the black body is shown to be more than for the platinum, and it can be seen that at about the same temperature the platinum is the more economical light source. Professor Lummer has said that at red heat, bright platinum does not radiate *one tenth* the total energy which the ideal black body radiates at the same temperature, and at the highest temperature still less than one half. The deviation of platinum from the black body law is a step in the direction of getting improved light-efficiency without corresponding increase of temperature. This method is practically without limit in its extension, for there seems to be no limit to the forms of energy curves which different substances may possess. The curves are apparently determined not only by physical state, but also by chemical composition of the emitting substance.

In the production of artificial light, the tendency will always be in the direction of increasing the practical efficiency; *i.e.*, reducing the cost of light. We have seen that there is still much room for this. In the case of the kerosene oil lamp we know that much less than one per cent. of the energy of combustion of the oil is radiated as light from the flame. In the case of the most efficient source—the electric incandescent lamp at *highest* efficiency—we are still far from ideal efficiency. A still higher temperature would yield a yet higher efficiency. We do not know exactly how much light might possibly be yielded for a given consumption of energy, but one experimenter concludes that it is about ten candles per watt. Fortunately, it is not now clear just how the chemist is to realize all the advances which he will make in more efficient lights.

No consideration of this part of the subject is complete without a brief reference to the efficiency of the firefly. The source of his illumination is evidently chemical. This much is known about the process:

The light-giving reaction is made to cease by the removal of the air, and to increase in intensity by presence of pure oxygen. It is extinguished in irrespirable gases, but persists in air some time after the death of the insect. Its production is accompanied by the formation of carbon dioxide. These all indicate a chemical combustion process. Professor Langley has shown that such a flame as the candle produces several hundred times as much useless heat as the total radiation of the firefly for equal luminosity. In other words, the firefly is the most efficient light source known. This is illustrated by the energy distribution curves from several light sources taken from Professor Langley's work (Fig. 5). The difficulties attendant upon the accurate determination of the curve for the firefly are so great that we ought not to expect very great accuracy in this case. These curves, which in each case refer to the energy after passing through glass, which cuts off energy of long wave-lengths, represent the same quantities of radiant energy. While the sun is much more efficient than the gas flame or carbon arc, it still presents far the largest part of its energy in the invisible long wave-lengths (above 0.8), while the firefly seems to have its radiant energy confined to a narrow part of the visible spectrum.

COMMERCIAL ELECTRICAL TESTING

Part V

By E. F. Collins
Technical Superintendent
General Electric Company

Commutating Poles

The commutating pole produces the necessary flux for neutralizing the effect of armature reaction, and prevents that shifting of the electrical neutral point between no load and full load which occurs in direct current machines not equipped with commutating poles; and, in addition, aids the current reversals in the armature coils at commutation. To obtain the reversal without sparking, with normal load current flowing, a definite number of ampere turns is required. In many cases, fractional turns are necessary in the commutating field winding; but as only whole turns or half turns are possible for mechanical reasons, a shunt is connected across the terminals of the commutating field winding and adjusted in test to shunt the current in excess of that required. As the electrical neutral does not shift, the brushes are set on the no-load electrical neutral, the adjustments made, and the rocker arm chisel-marked for that setting. Because of this position of the brushes, the machine is sensitive to conditions that under-excite the commutating poles, or make them inactive. Such conditions may cause the neutral to shift, resulting in bad sparking at the brushes or even a flash over, particularly in the case of machines of 500 volts or over.

Consider, for instance, a 300 kw., 500 volt generator, with a heavy german silver shunt across the terminals of the commutating field winding. If the machine is short circuited, the inductance of the commutating field coils forces the instantaneous heavy overload current through the non-inductive german silver shunt and leaves the commutating field without sufficient excitation to neutralize armature reaction. The electrical neutral immediately shifts and bad commutation results. To eliminate this trouble, an inductive shunt is used across the terminals of the commutating field winding, and must always be in circuit when the machine in test is under load. If a short circuit occurs, the inductance of this shunt, being greater than that of the commutating field winding, forces the heavy line current through the field winding and tends to keep the compensation normal for all conditions of load.

Inductive Shunt

An inductive shunt is used on all machines of 500 volts or more, of a normal current rating of 400 amperes or greater. As a test is necessary to determine exactly how much current must be shunted from the commutating field, the inductive shunt is designed with an inductance greater than that of the commutating field winding and with low resistance and ample current carrying capacity. Any additional resistance necessary is obtained by connecting german silver in series with the inductive shunt, the length and resistance of which is varied till an adjustment is obtained that gives practically perfect commutation throughout the whole load range for which the machine was designed.

Location of Electrical Neutral

After a commutating pole machine has been brought to normal voltage at no-load, the no-load electrical neutral must be located. To do this, a fibre brush of the same size as the carbon brushes on the generator in test must be procured. This brush should have two holes drilled through it, each of which will take a No. 12 bare wire; the spacing between the holes being equal to the distance between adjacent commutator bars. The wires should be small enough to move freely through the holes, otherwise they may stick and make poor contact on the commutator, or become wedged and bear on the commutator so hard as to score it badly. One carbon brush should be removed from its holder and the fibre brush inserted in its place, with the two wires in the brush connected to a low reading, or millivoltmeter. With normal volts no-load on the generator, the brushes should be shifted till the instrument needle has passed through the zero point, and then back again until the instrument again indicates zero, to make sure that the actual zero has been found. Pencil mark the rocker arm for this shift and then move the fibre brush to each of the other studs successively, shifting the brushes, if necessary, till zero reading is obtained, and pencil-mark the rocker arm for each stud. If a different shift is required to locate the neutral of the different studs, shift the brushes to a position which is the mean of all the different positions. With the brushes set in the mean position and the inductive shunt properly connected, put on normal load and note the commutation. If commutation is not practically sparkless at normal load and rated overload, take off the load and field excitation, and connect a german silver shunt across the commutating field terminals. If the machine requires an inductive shunt, the german silver and inductive shunts are connected in series. With the total shunt resistance great enough to shunt not more than 10 per cent. of normal load current, full load is applied and commutation noted. The length of the german silver is changed and the commutation is tested until an adjustment has been obtained which gives the best commutation throughout the range of load required. An ammeter is then connected in and the number of amperes flowing through the shunt circuit read and recorded. In case satisfactory commutation cannot be secured, the wiring, spool assembly, pole and brush spacing, air gap, polarity, spacing of equalizing rings, etc., should be checked. If these are all found to be correct, the fibre brush should be used again and the full load neutral of each stud tested. If an appreciable voltage is obtained between adjacent bars, the brushes should be carefully shifted until zero voltage is obtained, and the shunt across the commutating field readjusted. With the best shunt adjustment possible, the fibre brush should be used on each stud, and readings made of the current shunted and the shift of the brushes from the no-load neutral.

If the full-load electrical neutral of one or more studs is found to differ appreciably from that of the others, the commutating pole spacing, brush spacing, and air gaps of those poles and studs which affect the neutral in question should be carefully checked.

When a final adjustment has been obtained on any commutating pole machine of 200 kw. or greater, the fibre brush should be used on each stud and the results with full load recorded.

In general, shunting current from the commutating field will shift the load neutral of all studs away from the no-load neutral by the same distance. Shunting less current will shift all neutrals toward the no-load neutral. Where possible, all adjustments should be made with the brushes on the no-load neutral, and the brushes should be left permanently in that position. The rocker arm of all commutating pole machines should be plainly chisel marked, when the final adjustment has been made. When satisfactory commutation has been obtained, a heavy load should be thrown on and off suddenly and a record made of the resultant commutation and general behavior of the machine. If the machine has an inductive shunt, and flashing or violent sparking is produced by throwing a heavy load on and off quickly, readjusting the air gap of the inductive shunt should be tried.

With a given winding on the core, the inductance of the shunt may be varied by changing the gap, and the relative inductance of the shunt and commutating field winding be thus adjusted. If the current in the shunt circuit quickly falls to zero when a heavy load is thrown off by tripping the breaker, and the brushes show sparking, there is too little inductance in the inductive shunt and its air gap should be decreased. The air gap should be adjusted to give the minimum sparking when the machine is operating with a highly fluctuating load.

Baking Commutator

To bake the commutator on a commutating pole machine, the brushes should never be shifted under load to produce sparking and heating. They should always be shifted at no-load to insure against setting them beyond the safe limit of no-load commutation, thus preventing flash-over should the load be suddenly removed. When baking a commutator, it should also be remembered that the armature must not be short circuited through the commutating pole winding, as in this case the majority of machines will build up as series generators and the armature current cannot then be controlled.

DIRECT CURRENT MOTORS

The connections and wiring of all motors should be carefully examined, with particular reference to the field. At starting, the speed of the machine must be carefully followed with a tachometer, and the circuit breaker immediately opened if the speed rises above the prescribed limit.

With the starting rheostat or water box in the off position, the terminals of the rheostat or box must be attached across the open main switch, with the circuit breaker closed; the lower terminal being attached first. The field switch should then be closed and the pole pieces tested with a piece of iron for excitation. The resistance across the main switch should then be gradually cut out and, if the speed is all right, the main switch closed.

If the motor runs above normal speed the wiring should be carefully examined to see that the field is connected across the circuit. Sometimes by mistake the field is connected across the main switch; in which case as soon as the starting resistance is cut out the field current falls rapidly and the motor speeds up excessively. To test for wrong connection, read volts field during starting and, if the field is wrongly connected, the volts field will drop as the starting rheostat is cut out.

If a potential curve cannot be taken on a motor with a multiple wound armature by running it as a generator, a "motor potential curve" may be taken by the following method: The machine is run as a motor with the field self-excited, the field current is held constant, and a constant voltage is applied to the armature, using only two adjacent sets of brushes on the commutator. A careful reading of the speed is then taken. The brushes on the next pair of studs should be placed on the commutator, and the speed again taken with the same voltage and field current as before; this procedure being repeated for all pairs of adjacent brushes. For a direct current generator, the speed should vary directly with the voltage if a potential curve is taken as described. This method should never be employed unless it is impossible to drive the machine as a generator, as it is very difficult to read the tachometer sufficiently accurately.

With no load, normal voltage, and full field, a speed reading is taken, the brushes being shifted so that when full load is on, the speed is not less than 5 per cent. below nor more than 2 per cent. above normal speed. At the end of the speed run the machine is loaded, the brushes shifted if necessary, and the commutation noted.

On compound wound motors, a shunt is adjusted across the series field to give a speed within 4 per cent. of the correct speed at rated load. Speed curves and running light should be taken with the series field disconnected.

Running light should be taken at hot full load speed.

Commutating Pole Motors

The electrical neutral on commutating pole motors is determined by shifting the brushes until the same speed is obtained in both directions with the same value of field current. This position of the rocker arm is marked. In double speed motors of this type, the neutral should be obtained at the high speed.

Machines sometimes hunt with full commutating pole field, thus preventing the location of the neutral from being obtained. In this case, the field current should be slightly shunted, even if commutation is affected. Good commutation is rarely obtained in the unstable condition.

In testing motors sent out as single units, of which the direction of rotation is not known, the electrical neutral should be located by shifting the brushes at no-load, till a position is found that will give the same speed in both directions of rotation. The fibre brush method should not be used. To perform this test quickly, reversing switches are used in the series and shunt field circuits. Care must be taken, when shifting the brushes, to avoid a dangerous rise of speed.

When the proper no-load shift has been found for full commutating field, normal load is applied and the commutation and speed noted. If the speed has increased under load or the commutation is not sparkless, a german silver shunt is used across the commutating field and adjusted for commutation, the speed for each change in the shunt being noted to ascertain whether the speed is decreasing under load. When the final shunt adjustment is obtained, a speed curve reading is taken and the speed and commutation in both directions of rotation, at no-load, full load and whatever overload is required are recorded. At the conclusion of all tests required, while the machine is hot, a hot speed curve covering the same range of load as used in the cold curve is taken. In the case of two-speed machines, this curve should be taken at both speeds. Additional no-load and full-load readings should be taken at full field. If a falling or constant speed is obtained, and commutation is satisfactory, no shunt is necessary; otherwise, a shunt must be placed across the commutating field and adjusted to give these speeds.

Commutating pole variable speed motors must have the shunt in the commutating pole field adjusted for the highest rated speed. Speed curves and running light tests should be made at both speed limits.

Shunt wound variable speed motors have the brushes set for commutation at the speed limits. Speed curves and running light tests should be made at both of these speeds.

Some compound wound variable speed motors are not designed to run light; consequently, before starting, the smallest load the motor is designed to carry should be ascertained. Commutation should be adjusted at the various speeds, series full field readings being taken and the speed carefully recorded. Speed curves should be taken at the different speeds; also running light, with the series field disconnected.

STANDARD EFFICIENCY TESTS are made by the method of losses.

Employing the same nomenclature as that used in calculating the standard efficiency of direct current generators, a motor efficiency is calculated as follows:

$C_4 = C_L - C_6$

Watts input $W_A = C_L V_L$

W_1 = Core loss taken from the core loss curve corresponding to $V_L - CR$

Then $\Sigma W = W_1 + W_2 + W_3 + C^2_4 R_4 + C^2_4 R_5 + C^2_6 K_6 + (C_6 V_L - C^2_6 R_6) + C^2_8 R_8 + C^2_9 R_9 + C^2_{10} R_{10} + C^2_{11} R_{11}$

as before.

Watts output $W_b = W_a - \Sigma W$ and

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

Since motors are always rated according to horse-power output

$$H.P. = \frac{W_b}{746}$$

If, as in the case of direct current generators, only a running light is taken and it is desired to combine the resistances of the series and commutating pole fields with their respective shunts and to combine the losses in the shunt field and rheostats, then

ΣW = Running light $+ C^2_4 R_4 + C^2_4 R_5 + C_6 V_L + C^2_L R_{SF} + C^2_L R_{CF}$

In the case of shunt motors

ΣW = Running light $+ C^2_4 R_4 + C^2_4 R_5 + C_6 V_l$

The remarks made under the subject of direct current generators in reference to the calculation of brush friction, brush contact resistance and hot resistances, as well as to *all other* efficiency calculations, apply in the case of motors.

It will be seen from Fig. 23 that motor efficiencies are plotted with amperes line as abscissæ and per cent. efficiency and horse-power output as ordinates. The horse-power curve should be produced to intersect the axis of X at running light *amperes line*.

For NORMAL LOAD HEAT RUN the machine is run under load until it has reached constant temperatures, and these are then recorded. All series field shunt adjustments must be made to give the required regulation at the specified load.

For OVERLOAD HEAT RUN the machine is brought to normal load temperatures and the required overload is then applied for the specified time and the temperatures recorded.

Direct Current Series and Railway Motors

The principal type of series motor is the railway motor. Other types, however, are built for use with hoists, air compressors, pumps, etc. As all these motors are designed for intermittent service, the test, unless otherwise specified, is a one hour run at full load, with the brushes set on the neutral point. The load must *never* be taken off a series motor unless the armature circuit is first opened, otherwise the motor will run away. For the same reason a series motor should always be started under load. All running light tests must therefore be made with the field separately excited.

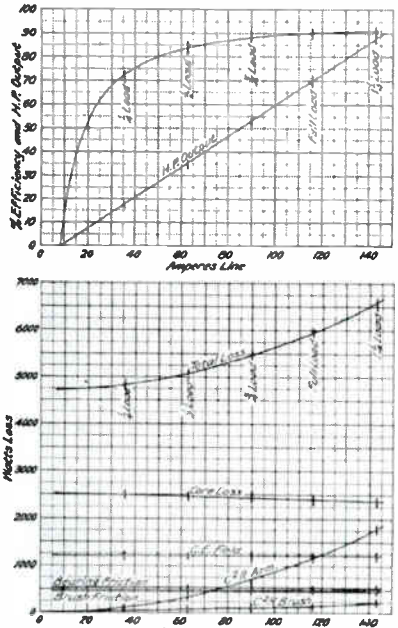


Fig. 23
Efficiency and Losses on a 70 h.p., 6 Pole, 850 R.P.M. 500 Volt D.C. Motor
(Plotted to values of Table IX, February REVIEW)

As the tests on railway motors are very complete and the general method applies to tests on any series motor, those on railway motors will be discussed more or less in detail. Hot and cold resistances must be taken on all railway motors and high potential applied both while the motor is cold and hot.

GENERAL TESTS consist of sufficient preliminary tests to warrant engineering approval or disapproval for production. It is impossible to definitely define the heading, since the tests may include only a few minor tests, or they may include complete and special tests. For instance, it may be necessary to make slight changes in either the construction or design of a standard motor in order that it may meet special requirements. After these changes have been made, tests are conducted to make sure that the motor will meet such conditions satisfactorily. These tests are included under general tests, and if after completion they are found to be satisfactory, engineering approval is given for the production of the machine in question.

COMPLETE TESTS consist of special tests, thermal characteristics, commutation and input-output. With the exception of commutation, the other tests under this heading will be considered separately.

Commutating tests on series railway motors should be made by holding normal voltage and operating the machine at loads varying from 33⅓ per cent. to 200 per cent. normal load.

On series commutating pole motors, interruption tests are taken. These tests consist in opening and closing the motor circuit while the machine is running at various loads and speeds. The machine should stand such tests without arcing over at line voltage as high as 125 per cent. normal. The loads are varied from 33⅓ per cent. to 200 per cent. normal. Mill motors are tested for commutation by suddenly reversing the direction of rotation under various loads.

Development tests consist of general tests and special tests, and are made when an entirely new type of machine is being developed.

Special tests consist of speed curves, core loss, and saturation tests.

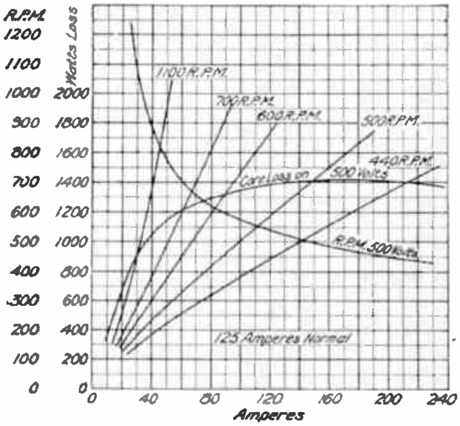


Fig. 24

Core Loss and Speed Curve of a 50 H.P., 500 Volt Railway Motor

In taking a speed curve two similar motors are placed on a testing stand and the pinion of each is meshed in the same gear mounted on a shaft. One motor drives the other as a separately excited generator and is run loaded until the motor is heated to about 50° C. rise. The speed curve is then taken on the motor rotating in first one direction and then the other, the voltage being held constant. The resistances of armature and field should be measured both before and after taking the curve.

Core loss should be taken by the belted method, as on any other machine, except that the test should be made at about five speeds. (Fig. 24.) The lowest speed should correspond to about 175 per cent. full load amperes (taken from speed curves) and the highest at about 200 per cent. full load speed. During this test the machine is separately excited.

A saturation curve may be taken on a series motor just as on any other machine by separately exciting the field. Saturation curves at different speeds may be obtained from data taken during the core loss test.

The speed curves, core losses and saturation are calculated as previously explained. The speed curves and core losses should be plotted on the same sheet against amperes line as abscissæ and revolutions per minute and watts as ordinates. From these two sets of curves another curve can be developed, which will give the core loss of the motor at any speed or current.

The thermal characteristic should be obtained by making a series of heat runs at varying current values for a sufficient time to get a temperature rise of 75° C. All runs should be made at the same constant voltage, the current value for each run varying from 50 to 150 per cent. normal. If a sufficient number of heat runs are taken on a sufficient number of motors of the same class, type and form, the horse-power rating for 75° C. rise may be obtained for any length of run from one-half hour to continuous running. Before starting a heat run, cold resistances and temperatures should be taken. After the motor has run continuously for the specified time, with all covers off and all openings unrestricted and with amperes and volts held constant, it is shut down, hot resistances measured and all temperatures taken. The results of the thermal heat run should be plotted, one curve for armature and one for field, against times in hours as abscissæ and degrees centigrade rise as ordinates. Lines should be drawn through zero and the plotted points corresponding to the different loads, the intersections of these lines with the line of 75° C. rise giving the respective values of time that the motor takes to attain 75 degrees rise with that load. From these curves another curve should be plotted with time as abscissæ and amperes load as ordinates. This is an ampere-time curve for 75° C. rise. On the same sheet on which the ampere-time curve is plotted, a curve should be drawn with time as abscissæ and horse-power as ordinates, the horse-power being calculated from the standard 75° C. characteristics. (Fig. 25.)

In taking a load running test, as in the speed curve test, two motors are geared together on the same shaft (Fig. 26), one running as a motor at the rated voltage and full load current and driving the other as a separately excited generator. The separately excited field of the generator is in series with the motor field, thus giving normal full load excitation. The armature of the generator is

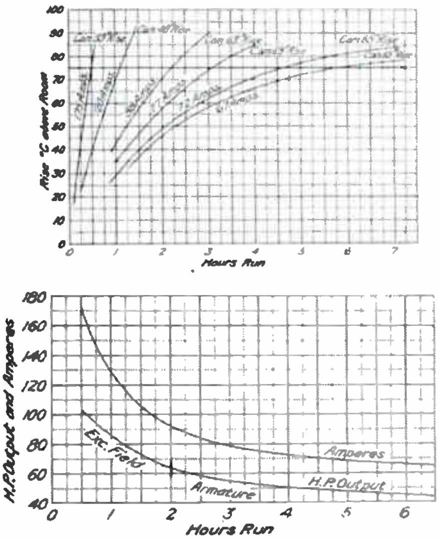


Fig. 25
Thermal Characteristics of a 75 H.P., 600/1200 Volt Railway Motor

connected to a water box, the resistance of which is varied until full load on the motor is obtained. The run is made for one hour, after which temperatures are taken.

Resistances are measured and high potential applied both before and after the test and before starting. The speed should be checked in both directions of rotation.

One out of every fifty of all types of motors should receive the one hour load run. All 600 volt commutating pole motors, with the exception of those receiving the one hour load run, should be run under load for ten minutes in each direction of rotation. Other motors the characteristics of which are well established should receive "commercial tests".

Commercial tests consist in running a motor light for a short period. It is the practice to run four motors in parallel, the fields being connected in series and separately excited by a current equal to the full load current of the motor. (Fig. 27.)

With normal voltage held constant across the armatures, the motors are run light for ten minutes in each direction of rotation, readings of speed, and armature and field currents being recorded.

With rated voltage across the motors, tho fields should be weakened until about twice normal speed is attained. Under these conditions the machine should be run in each direction for five minutes, the same readings as listed above being taken.

Resistance measurements and high potential tests must be made before and after this test.

Care must be taken that the resistance and speed at 25 degrees C. come within the prescribed limits already mentioned.

On all series motors, *with the exception of railway motors*, standard efficiency tests are made by the method of losses and the calculation of the efficiency is identical with that for any other motor. In this case, of course, amperes armature equal amperes line.

In making an input-output test the motors are geared and connected as for the load heat run and are usually run under full load for one hour up to ordinary working temperatures to get the bearings in good running condition. Before the load is put on, careful measurements of the armature and field resistance of the motor and of tho armature of the generator are taken by the drop in potential method. Three different measurements should be made of each, with as many different values of current near normal load current.

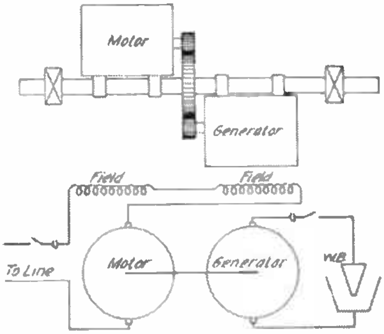


Fig. 26
Connections for Load Running Test on Railway Motors

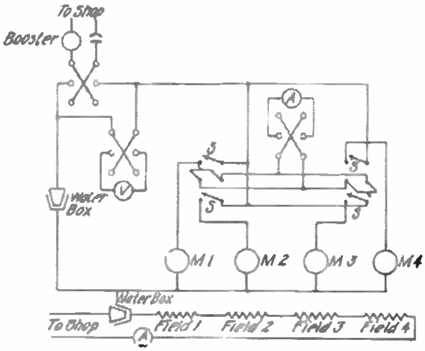


Fig. 27
Connections for Running Light on Railway Motor

Holding normal voltage constant, 12 or 15 different loads ranging from as low as possible to 150 per cent. load should be put on, the direction of rotation being such that the motor tends to lift from its bearings. Readings at each load should be taken of the amperes, volts armature and speed of the motor, and amperes and volts armature of the generator. The direction of rotation should then be changed and several check points taken in speed and amperes, after which the machine should be shut down and hot resistance measurements made.

Table X and Fig. 28 show the method of working and plotting the data obtained from the input-output test. Unless otherwise specified, the tractive effort and miles per hour are calculated for 33 in. wheels. The formulæ used are:

$$\text{Miles per hour} = \frac{\text{R.p.m.} \times \text{diam. of wheels in inches} \times \pi}{\text{Gear ratio} \times 1056}$$

$$\text{Traction effort} = \frac{\text{Amps.} \times \text{volts} \times \text{efficiency} \times 252}{\text{Miles per hour} \times 500}$$

The gear ratio is that between the gear and pinion.

From these characteristics new ones should be plotted, as shown in Fig. 29, the C^2R being corrected for 75° C.

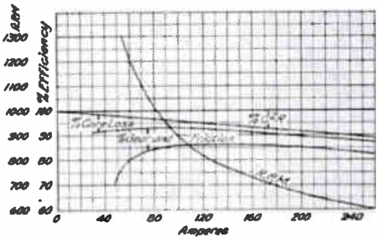


Fig. 28
Input-output Curves for a 75 H.P., 600 Volt Railway Motor

TABLE X

SPEED, TRACTIVE EFFORT AND EFFICIENCY OF A 100 H.P. 600 V. RAILWAY MOTOR

INPUT		C^2R %	Core Loss %	Gear + Friction %	Efficiency %	Miles per Hour on 33" Wheels Gear Ratio 3.35	Tractive Effort
Volts	Amps.						
000	40	1.7	5.3	30.0	63.0	45.0	170
600	60	2.5	4.1	14.0	79.4	35.4	407
600	80	3.3	3.4	9.0	84.3	29.6	687
600	100	4.2	3.0	7.5	85.3	26.2	084
600	120	5.0	2.6	6.5	85.9	23.8	1310
600	140	5.9	2.3	5.7	86.1	22.5	1615
000	100	6.7	2.1	5.0	86.2	21.3	1900
600	200	8.4	1.8	5.0	84.8	19.5	2630
600	240	10.0	1.5	5.0	83.5	18.1	3350
600	280	11.7	1.3	5.0	82.0	17.2	4040

Resistances at	75°C.
Armature	.107
Exciting Field	.076
Commutating Field	.050
Brush Contact	.017
Total	.250

TABLE XI

INPUT-OUTPUT OF A 100 H.P., 600 V. RAILWAY MOTOR

Motor	Volts	600	600	600	600	600
	Amps.	60.5	94.0	134	178	249
	R.P.M.	1216	935	790	700	610
	Watts Input	36300	56400	80400	106800	149200
	C²R { Arm. + Brushes + Exc. Fld. + Comm. Field	935	2260	4590	8100	15800
	(A) = Watts − (C²R)	35365	54140	75810	98700	133400
	(A) − (Core Loss + Fric.) = Output	29382	48180	69410	90755	123150
	Efficiency	80.9	85.4	86.4	85.0	82.5
Generator	Volts	602	592	580	551	522
	Amps.	38.5	70	105.5	144.5	203
	Watts	23151	41400	61150	79390	106000
	C²R { Arm. + Brush + Comm. Field	248	820	1860	3420	6900
	(B) Watts + C²R	23399	42220	63010	82810	112900
	(A − B) ÷ 2 = Core Loss + Friction (1 Mach.)	5983	5960	6400	7945	10250

Resistances		Motor	Generator
	Armature	.1082	.1015
	Exciting Field	.0792	—
	Comm. Field	.0522	.0492
	Brush Contact	.0170	.0170
	Total	.2566	.1677

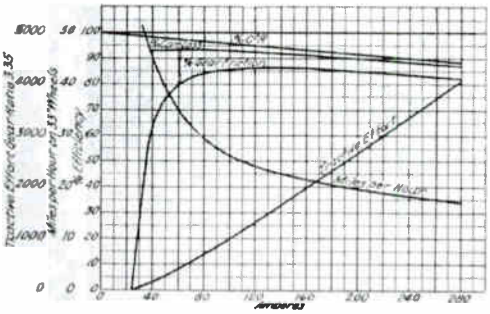


Fig. 29

Speed, Tractive Effort, Efficiency on a 75 H P. 600 Volt Railway Motor

rise, and the gear loss assumed as 5 per cent. at full load. If the gear loss derived from test has to be changed at full load, it should be changed in the same ratio throughout the curve. (See Table XI.)

Cooling off tests are made by running the motor under full load, with covers off, for one hour, shutting down and reading temperatures as the machine cools down. For the first hour after the machine is shut down, the temperatures of the following parts are read every fifteen minutes: armature, commutator, field, frame, air in the motor, and room. After the first hour temperatures should be taken every half hour until the temperature of the hottest part is not more than 25 degrees C. above the surrounding atmosphere.

The results of the cooling off test should be plotted to time as abscissæ and degree C. rise as ordinates. The curves for armature, field, commutator, frame, and air in the motor, should all be plotted on one curve sheet.

THE JOHNSONVILLE HYDRO-ELECTRIC DEVELOPMENT OF THE SCHENECTADY POWER COMPANY

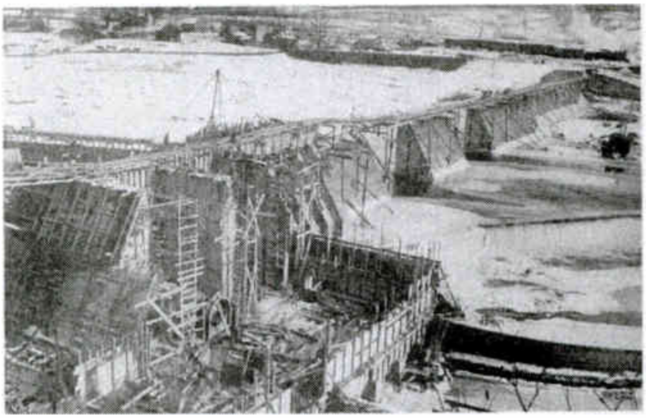
By John Liston

The rapidly extending use of electricity, especially in industrial applications, together with the high efficiencies now obtained in water wheels and generators, have combined to stimulate the development of those water powers affording either high heads or great volume wherever they have been found to be within practicable transmission distance of large centers of population.

As the field for the construction of larger hydro-electric plants becomes restricted, the small power station utilizing low or variable heads and designed either as an auxiliary to the larger plants or for the independent generation and distribution of electrical energy, becomes of increasing importance to the engineering fraternity.

In the Eastern States where the larger power sites have been to a great extent either developed or pre-empted, the construction of small power stations is already becoming an important factor in the future of hydro-electric development.

The Johnsonville power station on the Hoosic River is located at one end of a spillway dam constructed primarily to provide additional storage water for a larger power house at Schaghticoke, N. Y., which was described in the April, 1909, issue of the General Electric Review. The Schaghticoke plant utilizes a head of 150 ft. for generating 12,000 kw., which is transmitted on twin circuit steel towers at 30,000 volts, three-phase, 40 cycles, to Schenectady, N. Y., a distance of 21 miles.



General view of dam and power station during construction, showing turbine casing installed in north flume

Some water storage is secured by the dam at Schaghticoke, back of which an area of 145 acres is flooded, giving a capacity of 44 million cu. ft., but the main reservoir is at Johnsonville, as indicated above. The relative location of these dams and that of the transmission line connecting the two stations is shown in Fig. 4.

The pond back of the Schaghticoke dam is sufficient to hold one day's supply of water and insure the operation of the plant at any load factor, but does not provide sufficient storage capacity to carry the plant over periods of low water. It was therefore decided to construct another dam, at a point about 5 miles up the stream. This dam is located at Johnsonville, N. Y., about 15 miles northeast of the city of Troy, the drainage area of the Hoosic valley back of this point being about 550 square miles. The new dam backs the water up stream for a distance of 5 miles to the town of Buskirk, thereby flooding an area of 850 acres and giving an additional storage capacity of 332 million cu. ft. This, added to the pondage originally provided, gives a total available water storage capacity of 376 million cu. ft., or sufficient to supply a flow of 250 cu. ft. per sec. continuously for a period of 20 days.

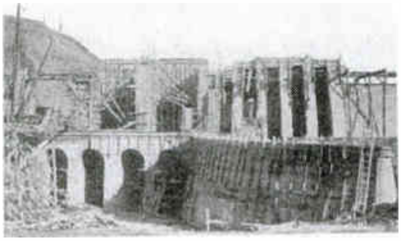
The Johnsonville dam (see Fig. 1) runs approximately north and south at right angles to the flow of the river, and is located just above an earlier timber dam which was formerly utilized for power to drive a local mill. In exchange for the cession of riparian rights, the mill has been provided with motor drive and receives current from the new generating station.

The development comprises a power house and sluice gates located on the north shore at the end of a spillway dam which extends to the south shore and ends in a heavy masonry abutment. This abutment is extended up

High water during construction, showing water passing over the unfinished sections of the dam spillway

Fig. 1
General plan of masonry construction at Johnsonville

stream from the dam for a short distance in a straight line, while below the dam it curves towards the center of the stream, thereby deflecting the water from that portion of the south shore immediately below the dam and protecting the bank from erosion at that point, even in times of maximum flood. In this way it prevents injury to the mill buildings, which are located 120 feet below the new dam and beside the old crib dam already referred to.



Tail race and sluice gate diverting wall during construction

The north shore of the river is clay hard pan but the dam rests on bed rock, undercut for its entire length. The south shore, however, is covered to a considerable depth with soil, and in order to prevent seepage around the end of the dam, a concrete core wall 180 ft. long was constructed, running on bed rock from the abutment at the end of the dam back to the high ground, as shown in Fig. 1. The core wall has a maximum height of 25 ft., and is covered by an earth embankment.

The dam is made of solid concrete and is built up in eleven sections with expansion joints every 50 ft.; it is of the ogee type with a total spillway length of 530 ft., a maximum height of 40 ft., and its greatest thickness at the base, of about 30 ft. Both the height and thickness of the dam diminish near the south shore where the river bed is higher.

The surface of the reservoir can be raised 3 ft. by means of flash boards, the crest of the dam being provided with brass tubes sunk 6 in. into the concrete and serving as sockets for the flashboard rods.

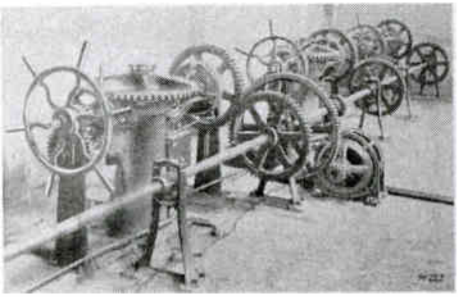
At the north shore end of the dam, 4 sluice gates and an ice chute are located. The sluice gate masonry is of concrete having a maximum thickness of 38 ft. at the base and provided with heavy buttresses on the down stream side.

The gates are of cast iron and are ordinarily operated through gearing by a 10 h.p. motor, which is coupled to one gate at a time by means of an automatic selector cut-out and a mechanical clutch.

To prevent injury to the apparatus the motor is controlled by a panel board located in the power house and equipped with circuit breakers and reversing contactors, so that when a gate strikes bottom the motor is automatically cut out of circuit. Handwheels are provided for use in the event of injury to the motor, and all the gate controlling mechanism is housed in a concrete chamber which caps the gate masonry and is at a sufficient elevation above the crest of the dam to prevent injury during floods.

The gate openings are 6 ft. by 9 ft. each, and with the reservoir full their combined capacity is 8000 cu. ft. per sec. The gate masonry is grooved for stop logs so that the openings may be shut off and the gates inspected or repaired.

Between the sluice gates and the power house is a log and ice chute, having its sill 3 ft. below the crest of the dam; when not in service it is closed by means of 2 sets of stop logs set in side grooves. Running diagonally up stream from the ice chute to the north shore is a deflecting curtain wall about 160 ft. long, under which are 3 submerged openings that admit the water to the forebay. The top of this wall is 3 ft. above high water, and the inlets are 5 ft. below the crest of the dam and 2 ft. below the



Sluice gate operating mechanism

sill of the ice chute, so that floating ice, logs and other debris are diverted to the ice chute. The forebay portion of the wall has to withstand ice pressure from both sides, and is therefore reinforced in both vertical faces and braced by two reinforced concrete beams spanning the triangular shaped forebay and tying the deflecting wall to the retaining wall which supports the clay hard pan bank of the north shore.

View looking up stream showing finished power house and sluice gate masonry

The water from the forebay, after passing through screens and gates and under a curtain wall, enters two flumes, each 20½ ft. wide, 27½ ft. long, and 35 ft. high; the walls of which are of reinforced concrete 4 ft. thick, and designed to withstand the thrust of the water with both flumes full, or one full and the other empty. The reinforcing is carried back to the north shore retaining wall on one side and to the dam on the other, in order to give the necessary stability. The curtain wall over the intake gate is located directly across the intake and supports the upper part of the flume gate framework; it is 3 ft. thick at the top and extends downward from the deck of the flume for 17 ft.

View looking down stream, showing dam equipped with flash boards and intake to forebay

The flume gates are made of structural steel, each approximately 18 ft. high and 21 ft.

wide; they operate in angle iron seats set in the concrete sides and owing to their great size have additional support in the form of two steel beams for each gate, which extend vertically from the floor of the flumes to a concrete girder at the bottom of the curtain wall. Each gate weighs about 7 tons and is raised or lowered by means of two steel screws connected to a pair of handwheel operated hoisting stands at the top of the flumes. In order to facilitate the raising of the gates, 24 inch by-pass valves are used to first fill the flumes and thus balance the water pressure.

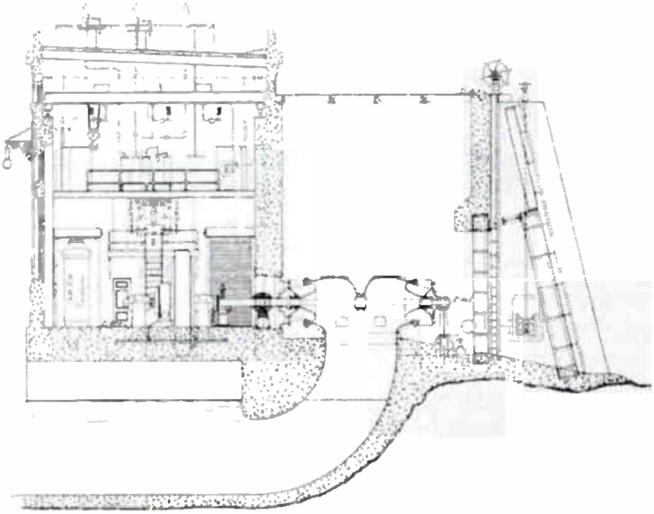


Fig. 2. Sectional view of power house and flume showing compact arrangement of the equipment

As the Johnsonville dam is primarily intended to store water for the Schaghticoke power house, it is evident that the auxiliary power plant at the dam must frequently work under widely varying heads, and the turbines are therefore designed to operate under heads ranging from 24 ft. to 39 ft.

In each flume there is mounted a 57 inch double runner reaction turbine of the horizontal Francis type, as shown in Figs. 2 and 3. The wheels discharge into a common draft chest located between the runners and the amount of water which is admitted to the wheels is controlled by wicket gates mounted in a ring around the runners and operated by a common rotating shaft which is geared to the governor in the generating room.

When operating under a 35 ft. head the turbines develop 3000 h.p., and when the water is drawn down to a 24 ft. head the output is reduced to 1750 h.p.; the speed, however, remaining constant at 150 r.p.m.

The walls which separate the wheel pits from the generating room are 4 ft. thick and made of reinforced concrete; the turbine shafts entering the power house through cast-iron watertight bulkheads, ring concreted in the wall. Each turbine is controlled by a standard "Lombard" oil pressure governor, belt connected to the generator shaft and geared to the wicket shaft, as shown in Fig. 3. The governor is ordinarily automatic in operation, but hand control is provided for in the event of injury to the governing mechanism.

A tubular glass water gauge located in the power house and set vertically between the governors at all times indicates the operating head.

The power house is constructed of reinforced concrete and steel, the approximate inside dimensions being 80 ft. long, 30 ft. wide, and 40 ft. high, the general arrangement of the interior being as shown in Figs. 2 and 3.

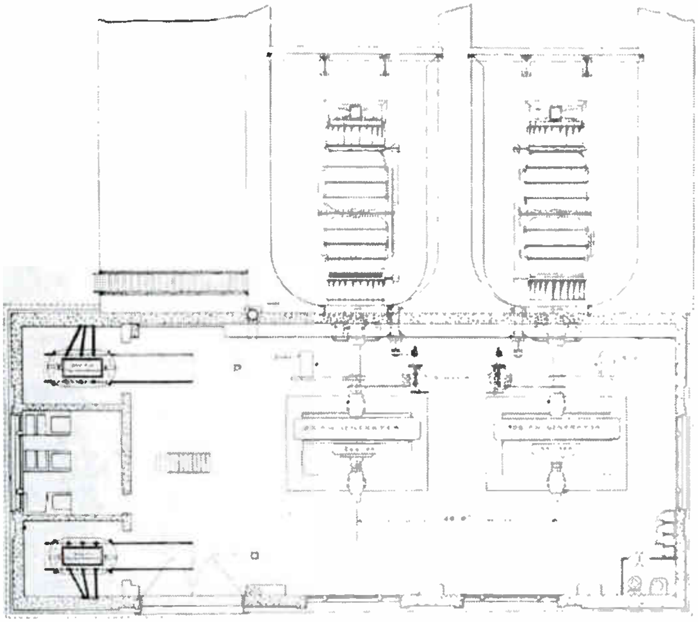
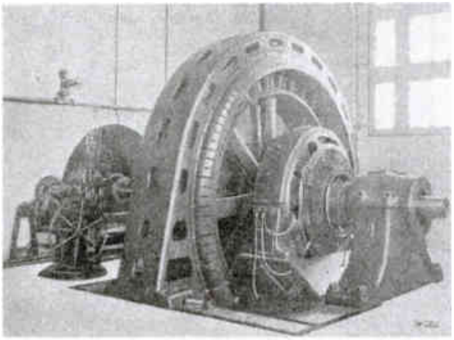


Fig. 3. Plan of power house and flumes showing the location of turbines, generators and governors

Although the capacity of this station is only 3600 kw., the construction throughout is of the most substantial nature and every device of approved value for maintaining high efficiency and uninterrupted service has been installed. The two transformers are located at the north end in separate fireproof compartments with steel curtain doors, and the switchboard is erected on a gallery between these compartments. Above this gallery is a floor extending across the building on which are located the generator and line motor operated oil switches, instrument transformers, aluminum lightning arrester equipment, and the high tension wiring. All the low tension equipment is located in a brick walled compartment beneath the switchboard gallery.

A 15-ton overhead traveling crane is included in the station equipment, and there is also a portable motor-driven air compressor set for cleaning the machinery; the direct current for the motor being supplied by the exciters.

After leaving the turbine draft tubes the water passes through 4 tail race openings, the arched walls of which support the floor of the generator room. Beyond these, and extending down stream from the power house, are two heavy concrete walls (see Fig. 1), one about 100 ft. long with a maximum height of 24 ft., which forms a support to the north bank of the river at this point and protects the road to the power house from the effects of erosion. A lower wall about 120 ft. long, and curving toward the center of the stream, serves to divert the flow from the ice chute and sluice gates away from the tail race.



One of the two 1800 Kw. Type ATB 3-phase 40 cycle 4400 volt generators with self-contained exciter

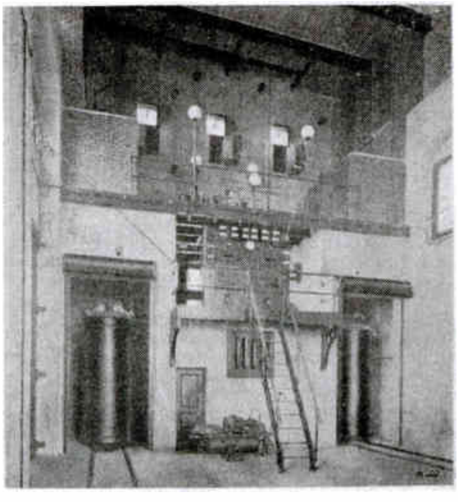
The total amount of excavation for the construction of the dam was about 6500 cu. yds. of earth and rock, and the concrete used in the main dam totals about 12,000 cu. yds., more than 1600 cu. yds. being used in the gate section alone. Work was begun in June, 1908, and current was first sent over the line in June, 1909.

The accompanying illustrations show the compact arrangement of machinery and controlling apparatus which can now be realized in even the smallest modern hydro-electric plant, and the efficiencies which may be obtained in the operation of properly selected generators and transformers are indicated by the following description of the apparatus installed at Johnsonville.

The generator equipment consists of two 1800 kw., three-phase, 40 cycle, 4400 volt generators delivering 237 amperes at 150 r.p.m., direct coupled to the turbine shafts. The machines are of the horizontal shaft, two-bearing, revolving field type, designed for water-wheel drive and are provided with an exciter mounted on the generator shaft between the armature and the collector rings. The field windings are tested for 1500 volts and the armature windings for 9000 volts. The temperature guarantee for full load run of two hours, at 100 per cent. power factor, is 40 deg. C. rise, and at 25 per cent. overload, 55 deg. C., these guarantees being based on a room temperature of 25 deg. C. The machines will operate at 2000 kw., 90 per cent. power factor for two hours with a temperature rise not exceeding 55 deg. C. The generators have the following efficiencies: full load, 95 per cent.; ¾ load, 94 per cent.; ½ load, 92 per cent. These efficiencies are based on 100 per cent. power factor, and the regulation under these conditions is within 8 per cent.

The total weight of combined generator and exciter is 119,200 pounds, and the fly-wheel effect 726,000 (WR^2). The armature windings are all "Y" connected, with the neutral brought to the terminal block, and the generators are operated in parallel with those in the Schaghticoke station.

In these machines the mechanical design is such that they may be run momentarily at

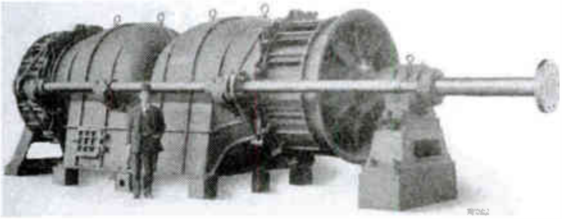


Interior view showing north end of power house and the general arrangement of transformer cells, switchboard, and high tension gallery

300 r.p.m. (or double speed) without danger of any displacement of parts, or other injury. The generators are controlled by means of field rheostats arranged for magnetic operation from the switchboard, from which point the turbine governors can also be controlled.

The exciter equipment comprises two 8 pole, 60 kw. exciters operating at 150 r.p.m. and delivering a full load current of 480 amperes at 125 volts. The exciter is compound wound and tested to deliver the same voltage at full load as at no-load, the series field being provided with a short circuiting switch for cutting it out of circuit. The exciters are also guaranteed to withstand temporary operation at double speed. Each exciter has sufficient capacity to excite both alternators and operate the auxiliary machinery.

Two 40 cycle, 1800 kw., 32000/4400 volt transformers are used, requiring 1300 gallons of oil and a water circulation of 14 gallons per minute. The water for cooling is piped to the transformers from the wheel pits, and the cooling coils are tested to withstand a pressure of 250 lbs. per sq. inch. The temperature rise for a full load run of 24 hours does not exceed 35 deg. C., while a 25 per cent. overload maintained for the same length of time will not produce a greater rise than 55 deg. C.



A complete turbine unit showing wicket gate arrangement for controlling inflow of the water

The regulation on non-inductive loads is 1.5 per cent. and with 80 per cent. power factor it is 3.6 per cent. The total weight of each transformer, including oil, is 38,000 pounds. Each unit is able to withstand an instantaneous short circuit at its high potential terminals when connected to the 3600 kw. of generator capacity (or the total normal capacity of the power house) without displacement of or damage to any of its parts.

Fig. 4. The Johnsonville-Schaghticoke Transmission Line

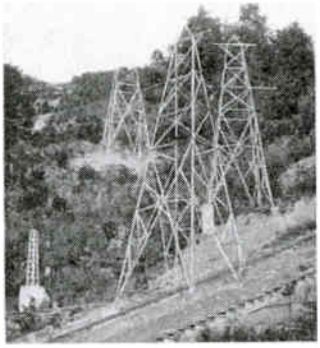
Practically the entire output of the Johnsonville station is transmitted at 32,000 volts, three-phase, 40 cycles, to the Schaghticoke power house over a single circuit line of light structural galvanized steel towers 5.8 miles long. It is there tied in with the circuits running to Schenectady.

A short 4000 volt line extends across the river to Johnsonville on the south bank, where it acts as a local feeder for a mill consuming about 150 h.p., and will also in the near future supply a lighting circuit for Johnsonville and Valley Falls.

In the event of shut-down at Johnsonville, for any cause, current can be fed back from Schaghticoke to supply local requirements and for the operation of the station auxiliaries.

The conductors leave the power house through perforated plate glass windows in the high tension gallery, the electrolytic lightning arrester cells being located in the building, and the horn gaps and discharging mechanism on the roof.

All of the towers, 54 in number, are of the same structural form as the ones illustrated herewith, and the average spacing is between 500 and 600 feet. They will withstand a side strain of 3000 pounds at the cross arm 47 ft. from the ground, are 16 ft. square at the base, and weigh about 1500 pounds. The conductors are No. 2 B.&S. solid copper wire spaced 5 ft. 6 in. apart, and the lightning guard wire is No. 2 B.W.G. galvanized iron, running along the peaks of the towers 2 ft. 9 in. above the cross arms. On account of the lightness of the conductors no attempt was made to string the line at high tension. The conductors were, therefore, run at 600 pounds average tension, corresponding to about 18 ft. sag for standard spacing.

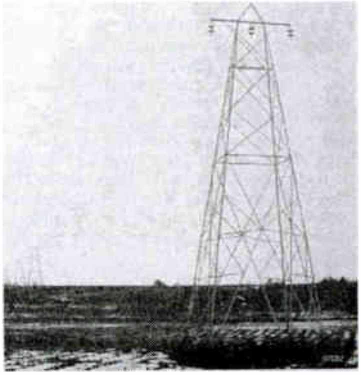


The end of the line showing transmission towers turning angle on the hillside back of the Schaghticoke power house

Heavy towers of the same general dimensions are used to negotiate angles in the line, and General Electric multiple disc suspension and strain insulators have been used throughout.

The entire development was designed and constructed by Messrs. Viele, Blackwell & Buck of New York, the hydraulic machinery was supplied by S. Morgan Smith Company of York, Pa., and all the electrical apparatus by the General Electric Company.

In conclusion, it might be well to note the benefits actually derived from the operation of this auxiliary power plant, located at what is practically an impounding dam primarily intended to supply additional storage water for a larger existing station. We find that at the present load factor of 50 per cent. the total output of both stations during an average year is equal to 67,600,000 kw. hr., and of this total 13,120,000 kw. hr. is delivered by the Johnsonville power house.



Standard transmission tower used between Johnsonville and Schaghticoke

STORE LIGHTING

By F. L. Healy

Among the many rapid strides which have been made in illuminating engineering, perhaps no one particular branch of the art has received more careful attention than the artificial lighting of stores.

The chief reason for this was the necessity of overcoming the color distortion which was characteristic of certain forms of artificial illuminants.

Until recently the ordinary enclosed arc lamp has best served the purpose very well, but it remained for the intensified arc lamp to provide that white light and soft and even illumination to which the eye is so accustomed.

A striking illustration of the value of intensified arc lamps for store lighting is furnished by the new store of C. G. Gunther Sons Co., of Fifth Ave., New York City, dealers in high grade furs. When changing their headquarters from the old down-town store to the new building, the utmost care was taken to obtain the best available equipment for a rapidly extending business Past experience had taught them that sales were seldom, if ever, as good when artificial light was used, as when daylight was employed for lighting, due to the fact that the goods did not show up as well under the former as under the latter.

Determined to remedy this if possible, a series of exhaustive tests was conducted on all the latest forms of illuminants and so-called white lights, with the result that the intensified arc lamp, although the last one tried, was immediately chosen, as its true daylight qualities and superiority over any other illuminant were at once appreciated. That these lamps fully come up to expectations, is realized on entering this new store on Fifth Avenue, where they are installed throughout.

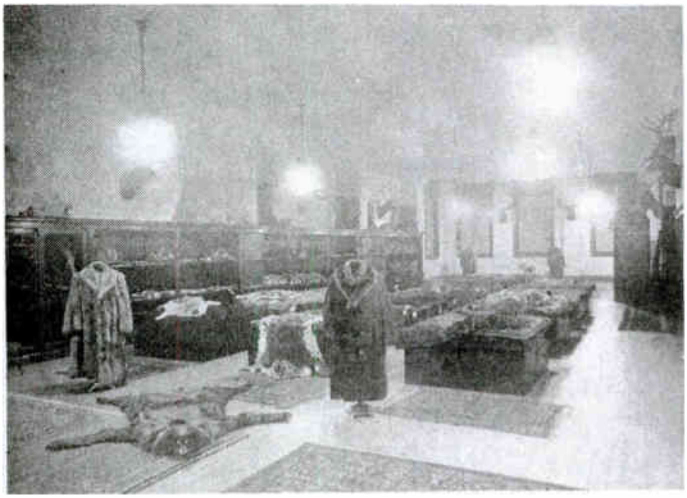


Fig. 1. Main Floor of C. G. Gunther Sons Co., New York City Lighted by General Electric Intensified Arc Lamps

The main floor has a very high ceiling which gives the large display room a commodious appearance. The finish is a rich dark brown walnut and it is doubtful if a better background could be obtained for the display of costly furs and hats. On the upper floor are other reception and fitting rooms, in which an elaborate line of complete garments and furs is displayed.

Figs. 2 and 3. R. H. Stearns, Boston, Mass., Lighted by General Electric Intensified Arc Lamps

After a general survey of the store, attention is naturally turned to the lighting scheme, which accords so well with the highest type of store furnishing, and it is then that the intensified arc lamp is really appreciated at its true worth, as the illumination is particularly effective. Men in the fur business state that people will not trust to artificial light in selecting furs, as under a light of imperfect color, the finest grades of sable and other costly skins lose their lustre and have the flat unattractive appearance of skins many times cheaper. This is the point—the ordinary artificial illuminant does not give the fur dealer a fair chance to show his goods to advantage, and what is equally important, the buyer is not able to distinguish the high grade furs from the low, or even to match skins of apparently the same color. The Gunther people say that the light from the intensified arc lamp is the nearest approach to daylight that they have ever seen.

The light itself is exceptionally well diffused; there is not a bit of glare in the store—just a soft even light throughout. This excellent diffusion relieves one from the ordinary annoyance experienced when the source of light comes within the range of vision. Another point worthy of mention is the steadiness of the light. There is no apparent wandering of the arc, no flickering. One wonders if the lamps are in reality arc lamps.

Although efficiency was somewhat of a secondary consideration, the Gunther firm is ready to admit that it is getting a great deal more light at a lower cost than it was in the old store. The lamps themselves are particularly attractive in appearance, being equipped with an ornamental casing of a very attractive design.

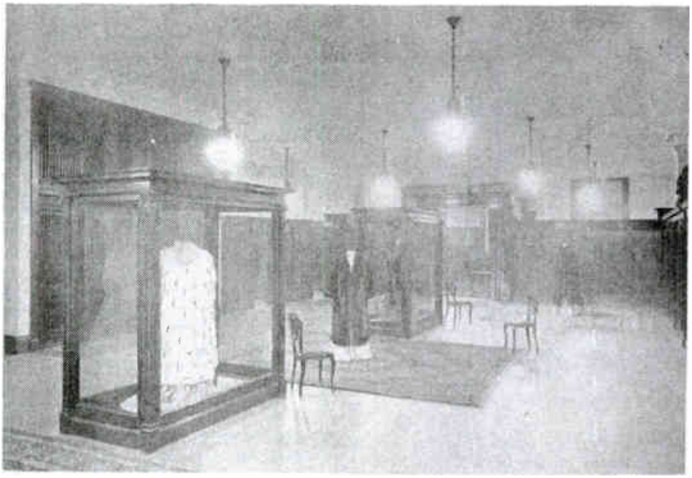


Fig. 4. Second Floor, C. G. Gunther Sons Co., New York City

A somewhat similar installation, in the new store of R. H. Stearns of Boston, Mass., is shown in Figs. 2 and 3. Here also the intensified arc lamp was finally installed after a competitive test and, as will be noted from the photographs, the results are indeed very satisfactory. Note how all the finesse of expensive embroideries and imported laces is brought out in all its beauty. The illustrations do not reproduce the color effect, but it is easy to see from the detail shown, that as an example of ideal store lighting, these lamps are without an equal.

STARTING COMPENSATORS*

By E. F. Gehrkens

Transformer Engineering Department
General Electric Company

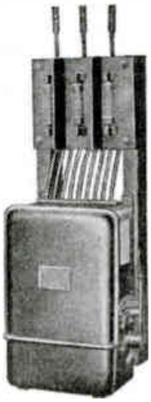


Fig. 1. Single Tap Compensator, Type CR, Form F.

Some form of starting device, the function of which is to limit the current taken from the line by the motor in starting, is used for alternating as well as for direct current motors, and for both the induction and synchronous types; but, as the starting compensator is used principally in connection with the squirrel cage type of induction motor, the present discussion will refer only to the various methods now in use for starting this kind of machine. An induction motor designed to meet the best condition of normal operation, should have as low an impedance as practicable, but a motor of this description necessarily takes a very large current in starting, this current being inversely proportional to the impedance; the starting torque is consequently high, and, being in the majority of cases much higher than necessary, some sort of a device is usually provided to limit the current to a reasonable amount which is still sufficient to produce the torque necessary for starting. The starting devices at present used for this purpose may be classified as follows, *viz.*:

Starting Compensators,
Starting Reactances and
Starting Resistances.

An induction motor requires a certain amount of current to start, and, to obtain this current, since the applied voltage is the only factor susceptible of adjustment, it is immaterial, as far as the starting of the motor is concerned, whether this result is secured by means of a resistance, a reactance, or a compensator; or whether the voltage necessary to produce this current is applied at once or gradually.

The compensator, however, is used almost exclusively, the reason for this being that for a given condition of starting, the current taken from the line with a compensator is always less than with either a resistance, or a reactance. These latter devices have the disadvantage of taking the same amount of current from the line at 100 per cent. voltage as they deliver to the motor at a lower voltage, the reduction in the voltage being dependent upon the resistance of the device, whether ohmic or reactive. They therefore simply serve to reduce the current taken from the line by limiting it to the amount actually required by the motor to start.

A starting compensator, however, consists of an inductive winding with taps, together with a switch for connecting the motor thereto. By the operation of this device a reduced potential is impressed upon the motor to bring it up to speed. With the switch in the starting position, the arrangement is equivalent in effect to

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Reprinted from *General Electric Review*, March 1907.

* Since the above article was written, starting compensators have been redesigned so as to incorporate a number of improvements, and Fig. 1 does not therefore show an up-to date device. A detailed description of the improved compensator will, however, be given at some future date. The starting curves of the motor are not exactly correct for a motor of our present design, in that the new motors require a smaller starting current than the one tested. This change in the design of the motor, however, in no way affects the conclusions drawn from the tests; viz., that, regardless of the design of the motor, there is no practical value in starting a motor by means of a multistep compensator except in a few special cases.

a step down transformer, and the product of potential times current on the line circuit is approximately equal to potential times current on the motor circuit. To illustrate: Assume that 50 per cent. of the normal voltage is sufficient to start the motor. With this potential, the motor takes one-half of the current that it would take if thrown on the line direct, *i.e.*, one-fourth of the volt amperes. Assuming the current taken from the line by the motor if thrown on the line direct as 100, the use of a starting resistance or a reactance would reduce it by one-half or to 50, and the use of a compensator would reduce it by three-fourths, or to 25.

The actual relation between the starting currents for a 100 h.p., 25 cycle, 440 volt motor, is illustrated graphically by Figs. No. 2 and No. 3, the former showing the current taken with the motor starting up with 100 per cent. load, and the latter with about 25 per cent. load. Both curves serve to show the decrease in the line current by the use of the compensator, but especially when starting the motor with no load or light load.

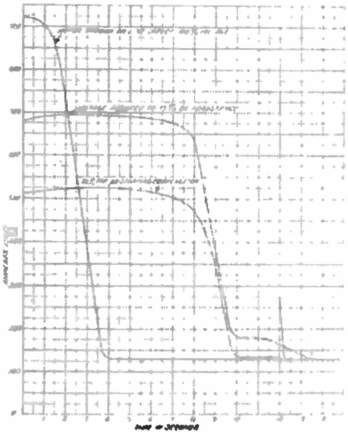


Fig. 2. Starting of 1-6-100-500-440 Volt Form K Motor with 100 per cent. Load

(Rise at end of compensator curve is due to throwing switch from tap to full load voltage.)

To fulfil the purpose for which the compensator is designed, the switch must be left in a starting position long enough to allow the motor to attain practically full speed. This usually requires from five to twenty seconds, and, at the end of that time, the switch should be thrown quickly into the running position. If the switch is thrown before the motor has attained speed, the current broken on the starting side, and the instantaneous current taken from the line on the running side, are much larger than when the full time allowance is given. The latter is also the case if the switch is not thrown quickly, as the motor must necessarily drop in speed during the time the switch passes from the starting to the running position. This, therefore, not only defeats the purpose for which compensators are designed, but the excessive current is also detrimental to the switch.

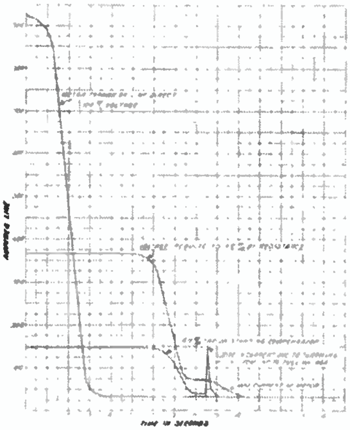


Fig. 3. Starting of 1-6-100-500-440 Volt Form K Motor with 25 per cent. Load

Starting compensators are arranged in one of two ways, first, so that one reduced voltage may be applied to the motor terminals, and second, so that several successive voltages may be so applied. The former, or single tap compensator, is the simpler in construction, and is suitable for the majority of installations. The latter, or multi-tap compensator, has advantages only when the static friction of the load varies from day to day, or for the starting of a *synchronous* motor operating under conditions that require very low starting torque and when it is desired to take advantage of this condition in avoiding undue line disturbances. Under these conditions a comparatively low voltage is required for starting and bringing the synchronous motor up to synchronous speed; then, by adjusting the field current to each increase in voltage, the current taken from the line in passing from the starting tap to the full line voltage is reduced to a minimum. As inferred, this method cannot be used to advantage where comparatively large starting torque is required, nor does it apply to the induction motor, in which machine field current adjustment is not possible.

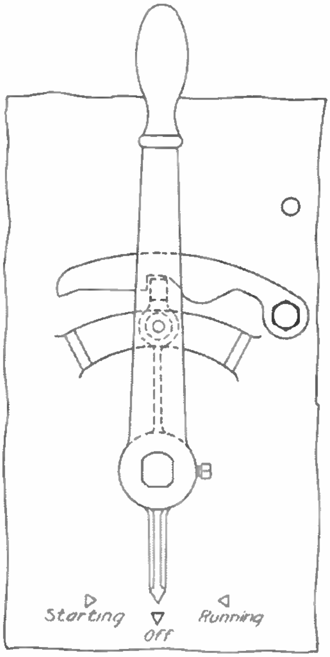


Fig. 4. Single Tap Compensator Switch with Latch

The multi-tap compensator switch is usually arranged so that the movement of the handle is continuous, starting with the "off" position, and passing through the successive steps to the full voltage position. This arrangement allows an operator to throw the switch through the starting and into the running position in so short an interval that the motor will not have had time to start before full voltage is applied. Also, because of the large number of contacts to be made at each point of the switch, a considerable amount of force is required to operate it, and, on account of the smaller angular distance between the various positions, the operator is likely either to throw the switch too far, or to operate it so slowly as to cause serious burning of the contacts.

In the single tap compensator, these difficulties can be entirely overcome by arranging the switch so that the "off" position is in the center, the starting position at one extreme end and the running position at the other extreme of the throw of the handle.

By arranging the switch in this way, the operator has a positive stop at both the starting and running points, and he will be more likely to throw the switch full into the proper position, and leave it in the starting position a greater length of time than if the entire operation could be completed with one sweep of the handle. With a compensator arranged in this manner, proper operation is assured by the addition of a latch as shown in Fig. 4. This not only prevents the operator from throwing the switch into the running position before it has passed through the starting point, but also compels him to throw it over quickly, which reduces the burning of the switch contact and also lessens the momentary increase in the current taken by the motor when thrown from the tap to the line direct.

As previously stated, the design of the squirrel cage type of motor is such that no adjustment of any kind whatever can be made for the purpose of producing the best starting conditions, with the exception of that of the voltage applied to the motor terminals; and because of the inflexibility of the system, it is immaterial how this voltage is applied, the only requirement being that the voltage be sufficient to give the current necessary to overcome the static friction of the load. As no adjustment in the motor itself is possible, the application of any voltage below this is of no advantage in any way, except that it heats the armature winding, and by thus increasing the resistance, a slightly greater torque may be obtained. Furthermore, the characteristic of a well designed induction motor is such that the voltage necessary for starting is also sufficient to bring the machine to practically full speed without further increase, so that the application of an intermediate voltage between that necessary to start the motor and full line potential is of no advantage.

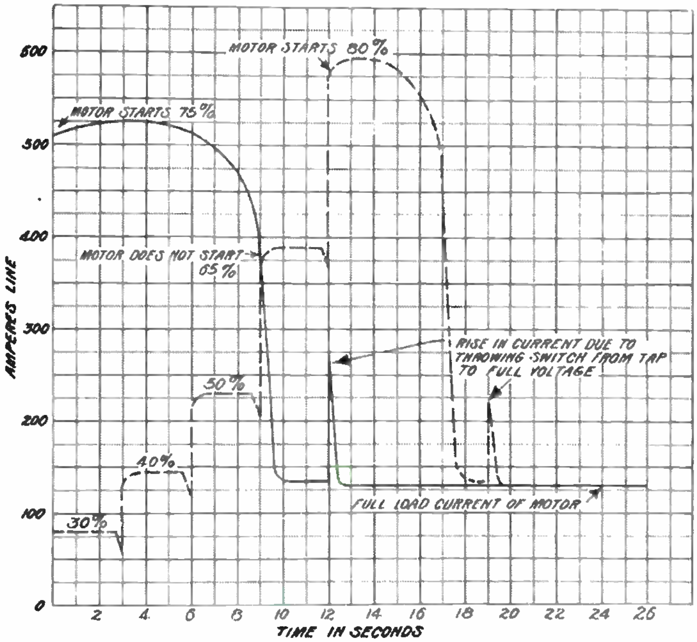


Fig. 5. Starting of 1-6-100-500-440 Volt Form K Motor with 100 per cent. Load, Using Multi-Tap Compensator, and Single Tap Compensator. Multi-Tap Compensator, 30, 40, 50, 65 and 80 per cent. Taps; Test Indicated by Broken Line. . Single Tap Compensator, 75 per cent. Tap; Test Indicated by Solid Line

This conclusion, that there is no practical advantage in the application of a gradually increasing voltage to a squirrel cage type of induction motor, is shown by the curves and is the result of a series of starting tests which were taken with different load conditions on a 15 h.p., 60 cycle, 220 volt, three-phase motor, and on a 100 h.p., 25 cycle, 440 volt, three-phase motor, using multiple tap and single tap starting compensators of the proper size for each machine.

In this investigation, the compensators were connected in series with each other and between the line and the motor, while a graphic recorder was connected in series with one leg of the line. Six starting tests were taken for each condition of load, and with the best arrangement of compensator taps, one being tested while the other was cut out of circuit by throwing its switch into the running position.

The tests were taken with each compensator alternately, and the results on the 100 h.p. motor starting under full load conditions are shown in Figure 5. A large number of tests under different load conditions were taken, but these shown are representative, and being taken with a comparatively large load on the motor, would be better suited to show the advantage of the multiplicity of starting taps, if any existed. A study of the curves will show, however, that the amount of current taken from the line to start the motor under a given condition of load is the same regardless of whether this voltage is applied gradually or instantaneously.

Attention is also called to the large currents which the switch of a multi-tap compensator is required to break. In the present instance, for a single start, the switch was required to rupture currents which were respectively 60, 110, 175 and 300 per cent. of the full load running current of the motor, whereas, with a single tap compensator, the maximum current to be broken was but a trifle over full load current.

In the majority of installations of induction motors, however, the load to be started, and consequently the voltage necessary to start, is approximately constant from day to day, and a single tap compensator, or rather one having a number of taps, any one of which can be selected for use, is therefore perfectly satisfactory after the proper tap for the particular installation has once been fixed upon.

The advantage of the single tap compensator can therefore be readily appreciated, as it is simpler in design and operation, and the desired results more likely to be obtained even when operated by inferior class of labor. The cost of maintenance is also reduced as not only are the number of ruptures of current decreased to a minimum, but the burning of the contacts and their renewal are also lessened, this reduction being in proportion to the decrease in the number of contacts, and therefore the number of ruptures of current, and also on account of the breaking of a much smaller current.

A NEW TYPE OF METER FOR MEASURING THE FLOW OF STEAM AND OTHER FLUIDS

By A. R. Dodge

The ever increasing demand for more economical generation and consumption of steam makes it imperative that the up-to-date engineer shall avail himself of every possible means for determining the behavior of apparatus that is employed for these purposes.

For many years the electrical engineer has had instruments at his command by the use of which he could determine exactly the performance of the various electrical machines. On the other hand, despite the fact that the utilization of steam and the science of steam engineering antedates the practical, commercial application of electricity by half a century or more, the steam engineer has been provided with no such instruments, and has had to content himself with the simple knowledge that he was generating enough steam to do a certain amount of work; just how much steam it was that he was actually generating he could not tell. It must be conceded that it is as important to measure the steam delivered to the prime mover as it is to determine the output of the electric generator. This point is fundamentally important, but up to the present time there seems to have been no large amount of work spent on the development of instruments which possess the desired properties of being easy to install and of accurately measuring the rate of flow of steam.

The former efforts in this direction are covered by two general types.

About ten years ago a device for measuring steam flow was brought out in which a diaphragm containing an orifice was inserted between flanges in the steam pipe, and the difference of pressure between the two sides of the orifice was measured, from which pressure difference the amount of steam passing through the orifice was known from previous calibration. No attempt was made to correct for moisture or superheat, and there is a loss of steam pressure through the orifice at ordinary loads of about three pounds, which loss increases in pressure at overloads, limiting the output and efficiency of the steam distribution system. To install this device necessitates shutting off the steam for several hours; removing a section of piping and inserting a new section, together with new gaskets and diaphragm in the same available space as was occupied by the removed section.

The second type is known as the float type meter and consists of a vertical spindle which carries a disk, actuated by the steam, an arrangement somewhat similar to the safety valve of a steam boiler with the spring removed. The more the flow of steam, the more the spindle will lift due to the pressure difference on the top and bottom. The spindle is connected through the stuffing box to an external pointer, by means of which the opening of the valve, and hence the amount of steam passing through, is known from previous calibration. Either the disk or the surrounding chamber may be cylindrical, provided the other part is conical.

The stuffing box is a serious objection, as the friction is always an appreciable amount of the moving force available from the steam, and varies over a wide range. A leakage of steam through the stuffing box is also apt to occur. These two characteristics tend to make the readings inaccurate. Such meters owing to their relatively large size and cost are not practical for pipes above 6 in. in diameter.

In the meter to be described, these objections have been eliminated and an instrument developed which, without the use of weighing tanks, scales, or other special apparatus, will determine the amount of steam, air or other fluid flowing in a system of piping.

If the temperature and pressure of the gas is a constant, the amount of steam used in a machine or group of machines is, of course, proportionate to its velocity in feet per second. This velocity, therefore, constitutes a means of measuring this quantity if the velocity, itself, can be measured. It is a well known fact that velocity is converted into pressure by means of an inverted nozzle with practically no loss and always under the same law. The measure of this pressure, due to velocity, is the most reliable means we have of determining the velocity of steam in nozzles, which may be as high as 2500 ft. per second.

The velocity being thus determined from the pressure, the quantity of the steam is at once deducible, being proportional as stated above. A nozzle plug is screwed into the pipe at the point where the flow is to be measured and extends diametrically across it. This plug (Fig. 1) carries two sets of openings; the first or "leading" set faces against the direction of flow, while the second or "trailing" set consists of three openings near the center of the plug, one of these latter being shown in the figure. The steam impinging against the leading set of openings, sets up a pressure in them which is equal to the static pressure plus a pressure due to the velocity head; while the pressure in the trailing set is equal to the static pressure minus a pressure due to the velocity head. On account of the small diameter of this nozzle plug, no appreciable drop in steam pressure is caused by its insertion in the main, even if the velocity be very high.

Fig 1. Nozzle Plug

Since the nozzle plug extends diametrically across the main, the difference of pressure set up in the two sets of openings will be proportional to the mean velocity of the gas. This pressure difference is transmitted through separate longitudinal chambers to the outer end of the plug and from there, by proper piping, to the meter, which consists essentially of a U tube of glass or metal partially filled with mercury (or other fluid of greater specific gravity than the fluid to be measured). The difference in pressure in the leading and trailing sets of openings is communicated to the two sides of the U tube and causes a difference in level in the two legs of the fluid column.

Meters suitable for measuring the rate of flow of steam are calibrated to read directly in pounds per hour, while those for measuring the rate of flow of air are calibrated in cubic feet of free air at a temperature of 70 degrees Fahrenheit.

If it is desired to operate the meter on steady flow, such as occurs in supplying steam to steady flow turbines, heating systems, manufacturing processes, etc., no recalibration is necessary after installing, as all meters are calibrated at the factory for this condition.

If, however, the meter is to be used on periodically intermittent flow, such as occurs in supplying steam to intermittent flow turbines, reciprocating engines, pumps, etc., it must be recalibrated after it is installed, unless the arrangement of the piping permits the insertion of the nozzle plug at a point where the flow is steady. For example: where an engine is supplied with steam by a long pipe line, the nozzle plug may be inserted near the boiler where the flow is steady.

No change whatever is required in the main piping system of the station to install the meter; it·is only necessary to drill a small hole in the main for the nozzle plug.

Fig. 2. Recording Steam Meter, Showing Connections to Pipe

RECORDING FLOW METERS

The recording flow meter for measuring the rate of flow of steam is a curve drawing instrument, giving an accurate record of the rate of flow in pounds per hour, in pipes of any diameter, at any degree of temperature, pressure, or moisture.

The meter consists of two cylindrical hollow cups filled to about half their height with mercury, and joined together at the bottom by a tube. This arrangement of cups and connecting pipe forms the U tube, which is supported upon a set of knife edges about which it is free to move as a balance.

Any difference of pressure in the two sets of openings in the nozzle plug is communicated to the cups through flexible steel tubing placed inside the case, and causes the mercury to rise in the left hand cup and fall in the right hand cup until the unbalanced columns of mercury exactly balance the difference in pressure.

By the displacement of the mercury, the beam carrying the cups moves downward on the left hand side of the knife edges. This side will descend until the moment of the weights on the right of the knife edges exactly balances the moment caused by the displacement of the mercury into the left hand cup. The motion of the balancing beam is multiplied by suitable levers and actuates the recording pen which moves in proportion to the amount of mercury displaced.

The time element of the meter consists of an eight day clock, which drives the drum feeding the paper. A paper feed of one inch an hour has been adopted as standard and one roll of paper is sufficient for about a month's record. All recording meters are equipped with a re-roll device, which is operated by spring mechanism, and is of sufficient capacity to accommodate one complete roll of paper.

Compensating Devices for Pressure and Superheat Variation

The velocity of the steam being measured may remain practically constant, while the pressure and temperature vary over a considerable range; to obtain the actual rate of flow in pounds per hour, it is necessary to compensate for the latter fluctuations.

This compensation is made automatically in the case of pressure variations, by a hollow spring, similar to the pressure spring in a steam gauge, which is connected so as to be influenced by the static pressure at the point where the flow is being measured. Any variation of the static pressure causes the spring to expand or contract, and this movement actuates a small correction weight in such a manner as to affect the deflection of the pen, so that the indicated rate of flow recorded by the pen is correct.

Compensation for temperature variation is made by an independent hand adjustment of the same correction weight that corrects the reading for pressure variations. This adjustment is made by increasing or decreasing the distance of the correction weight from its point of suspension; this distance is determined from a curve furnished with the meter.

INDICATING FLOW METERS

This type of flow meter will meet general commercial requirements where an indicating instrument is desired. It will be found especially useful for testing work, locating troubles due to leaks, etc. This indicating meter gives an accurate reading of instantaneous rate of flow of steam or air or any other gas, at any condition of temperature, pressure, or moisture. If used to measure steam flow, it gives a true indication of the instantaneous rate of flow in pounds per hour per square inch of pipe cross sectional area.

As it is portable, a single meter may be utilized to obtain readings in any number of different pipe lines through a station. It is only necessary that each pipe be provided

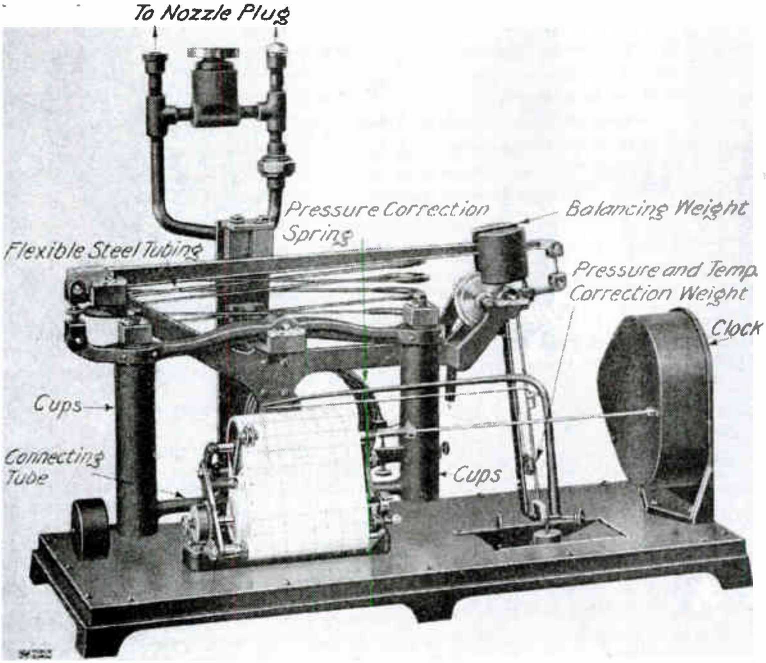


Fig. 3. Recording Steam Meter

Meters for Constant Temperature and Pressure

In many stations steam is generated at practically constant pressure and temperature; this will be found to be especially true where a battery of boilers is supplying steam to one unit. For such conditions the automatic pressure correction is not essential, and the meter is adjusted by hand to suit the existing conditions of pressure and temperature.

with the proper nozzle plug to which the meter can be connected.

The meter consists of an iron casting which is cored out to form a U tube, which, as with the other types of meters, is filled for part of its height with mercury or water, and, as in their case, a difference of pressure in the nozzle plug causes a difference of level in the two columns of the liquid. A small float suspended by a silk cord actuates a pulley over which the cord passes; the pulley, in turn, moving a small bar magnet on the end of shaft next to the dial in proportion to the change in level of working fluid in the U tube.

Fig. 4. Indicating Steam Meter and Pipe Connections

The indicating needle is mounted in a separate cylindrical casing. Another bar magnet is mounted on the inner end of the needle shaft, and is free to turn in the same plane as the magnet on the inside of the meter.

The mutual attraction of these two magnets keeps them always parallel, and by this arrangement the necessity of a packed joint for transmitting the motion of the pulley to the indicating needle is eliminated.

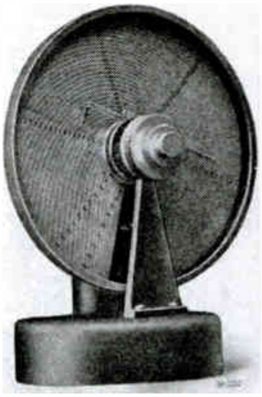


Fig. 5. Indicating Steam Meter

The pipe, receiver and nozzle plugs are of the same general design as those used with the recording meter.

The proper adjustments for pipe diameter, temperature and pressure are readily made by setting the graduated cylinders which actuate the rack carrying the pointer. When these settings are made, the rack is rotated by hand until the pointer coincides with the indicating needle. The point on the graduated scale at the intersection of the needle and pointer gives the true instantaneous rate of flow per square inch of pipe cross sectional area.

Meters of both types have been in service in the Schenectady Works of the General Electric Company for several years, and their employment provides data for continuous records of steam and air used in the principal buildings, thereby indicating where avoidable losses may be eliminated.

A number have been installed in this country and Europe, and have been giving satisfactory service under various conditions.

TRANSMISSION LINE CALCULATIONS

PART VI

BY MILTON W FRANKLIN

LINE ECONOMICS

The losses in a line are due only to resistance, but the line drop is a function of the line reactance as well as of the resistance so that the effective resistance must be considered and not only the ohmic resistance.

For a given voltage at the receiving end of the line and given power output at the generating end the most economical drop (resistance only) and power loss under certain conditions of cost of power, conductor, etc., may be mathematically computed.

Let E_R = Voltage at receiving station.
P = Kw. output at generating station.
L = Length of line in miles, length of a single conductor.
c = Cost per kw. year at generating station in dollars.
c_1 = Dollars per lb. conductor.
p = Interest rate on cost of conductors.
K_1 = Ohms per mil mile of conductor.
K_2 = Pounds per mil mile of conductor.
R = Total resistance of line (two wires) in ohms.
S = Cross-sectional area of conductor in circular mils.
x = Loss in terms of generated power.

Then line loss $= Px$ (1)
Annual cost of loss on line $= cPx$ (2)
Weight of conductors $= 2LK_2S$ (3)
Cost of conductors $= 2c_1K_2LS$ (4)
Interest per annum (conductors) $= 2pc_1K_2LS$ (5)

Line resistance $= R = K_1 \frac{2L}{S}$ (6)

Line drop (Ri components only) =

$$\frac{E_R \cos\theta x}{(1-x)} = \frac{1000\ PR(1-x)}{E_R \cos\theta}$$

Substituting value of R from 6 we get

$$\frac{E_R \cos\theta x}{1-x} = \frac{2000\ PK_1L\ (1-x)}{E_R \cos\theta\ S} \tag{7}$$

$$C.S.A. \text{ of conductor} = S = \frac{2000\ (1-x)^2PK_1L}{E_R^2 \cos^2\theta x} \tag{8}$$

The annual cost due to line loss and interest charges is then given by (2)+(5) $= cPx + 2pc_1K_2LS$ (9)

The annual cost per generated kilowatt is the total annual cost divided by the generated kilowatts, $= q$

$$q = \frac{cPx + 2pc_1K_2LS}{P} \tag{10}$$

Substituting the value of S from (8)

$$q = \frac{cPx + 2pc_1K_2L\left[\frac{2000(1-x)^2PK_1L}{E_R^2 \cos^2\theta x}\right]}{P} \tag{11}$$

Rearranging terms:

$$q = cx + \frac{4000\ pc_1K_1K_2L^2(1-x)^2}{E_R^2 \times \cos^2\theta x} \tag{12}$$

Putting $K = \frac{4000\ pc_1K_1K_2L^2}{\cos^2\theta}$ in (12)

$$q = cx + \frac{K(1-x)^2}{E_R^2\ x} \tag{13}$$

Differentiating q with respect to x gives

$$\frac{dq}{dx} = c + \frac{K}{E_R^2}\left(1 - \frac{1}{x^2}\right)$$

Putting $\frac{dq}{dx} = 0$ for the minimum value we get

$$x = \sqrt{\frac{K}{cE_R^2 + K}} \tag{14}$$

In which $K = \frac{4000\ pc_1K_1K_2L^2}{\cos^2\theta}$ (15)

and x = the most economic loss

and $S = \frac{2000\ (1-x)^2PK_1L}{E_R^2 \cos^2\theta x}$ (16)

Equations (14) (15) (16) are to be used for single-phase lines.

If the preceding equations were worked out entirely with reference to the receiving end of line, the constants having the following significance:

P_R = kilowatts delivered (receiving end).
x = loss in terms of delivered kw.
E_R = voltage at receiving end.
$\cos\theta$ = power factor of load.

Then we would have:

$$q = cx + \frac{K}{E_R^2\ x} \tag{17}$$

and $\frac{dq}{dx} = c - \frac{K}{E_R^2\ x^2} = 0$ or $\frac{K}{E_R^2\ x} = cx$ (18)

which is the standard expression for interest = loss, a minimum for cost per delivered kw. with respect to line losses.

In a three-phase (three-wire) system the area of each of the three wires is one-half the area of the wires used in the corresponding single-phase case, so the weight of the metal is three-fourths of that used for the same drop and loss.

Substituting $\frac{3}{4}K$ for K in (10) will give $\frac{3}{4}K$ instead of K in (13).

This gives $$x = \sqrt{\frac{3K}{4cE_R^2+3K}} \qquad (19)$$

The cross-sectional area of each conductor becomes

$$S = \frac{1000(1-x)^2 PK_1L}{E_R^2 \cos^2\theta \, x} \qquad (20)$$

$$\text{and } K = \frac{4000\, pc_1K_1K_2L^2}{\cos^2\theta} \text{ as before} \qquad (21)$$

Equations (19) (20) and (21) are to be used for a three-phase line when E_R receiving voltage is given and, P, power generated is given, x being in terms of the quantities at the generating end.

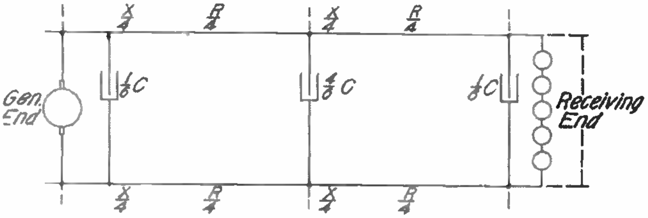


Fig. 14

The equations which apply in a three-phase system when we consider all quantities at the receiver end, are as follows:

$$x = \frac{1}{E_R}\sqrt{\frac{\frac{3}{4}K}{c}} = \frac{.866}{E_R}\sqrt{\frac{K}{c}} \qquad (22)$$

$$S = \frac{1000\, PK_1L}{E_R^2 \cos^2\theta \, x} \qquad (23)$$

$$K = \frac{4000\, pc_1K_1K_2L^2}{\cos^2\theta} \qquad (24)$$

A summary of the principal formulæ is given below:

$$K = \frac{4000\, pc_1K_1K_2L^2}{\cos^2\theta} \qquad (a)$$

Single-Phase Line: E_R receiving voltage known.
P kilowatts generated known.

$$x = \sqrt{\frac{K}{cE_R^2+K}} \qquad (b)$$

$$S = \frac{2000(1-x)^2 PK_1L}{E_R^2 \cos^2\theta \, x} \qquad (c)$$

Single-Phase Line: E_R receiving voltage known.
P_R kilowatts delivered.

$$x = \frac{1}{E_R}\sqrt{\frac{K}{c}} \qquad (d)$$

$$S = \frac{2000\, P_RK_1L}{E_R^2 \, x} \qquad (e)$$

Three-Phase Line: E_R receiving voltage known.
P kilowatts generated known.

$$x = \sqrt{\frac{3K}{4cE_R^2+3K}} \qquad (f)$$

$$S = \frac{1000(1-x)^2 PK_1L}{E_R^2 \cos^2\theta \, x} \qquad (g)$$

Three-Phase Line: E_R receiving voltage known.
P_R kilowatts delivered known.

$$x = \frac{.866}{E_R}\sqrt{\frac{K}{c}} \qquad (h)$$

$$S = \frac{1000\, P_RK_1L}{E_R^2 \cos^2\theta \, x} \qquad (i)$$

Should the formulæ on preceding page give a value of x which, when substituted in the equation for S, gives a value of S which differs considerably from a standard sized cable, then x will have to be recomputed for the selected standard sized cable.

The method is outlined below.

Suppose S = computed size of cable with value x, and we find the nearest size standard cable to be S_1 (circ. mils), it may be desirable to select this standard size cable S_1 and increase the loss of power slightly in preference to having a special cable drawn.

Let R_1 be the resistance in ohms (single wire) of the cable S_1, and let x_1 represent the new loss corresponding to this case, then

$$\frac{1000(R_1P)}{E_R^2 \cos^2\theta} = \frac{x_1}{(1-x_1)^2} \qquad (j)$$

Let;
$$\frac{1000(R_1 P)}{E_R^2 \cos^2\theta} = a \qquad (k)$$

a can be easily calculated from our known values.

$$\text{Then } x_1 = \frac{(2a+1) \pm \sqrt{4a+1}}{2a} \qquad (l)$$

This formula for x_1 (the new loss) applies to single- and three-phase lines when the power P at generating end of line, E_R receiver voltage, and $\cos\theta$, power factor of load are given.

Should the power P_R delivered to receiver, E_R voltage at receiving end, and $\cos\theta$, power factor of receiving circuit, be given, then the new value of x_1 is calculated from the following formula (formula applies to single- and three-phase lines):

$$\frac{R_1 P_R}{E_R^2 \cos^2\theta} = x_1 \qquad (m)$$

Regulation of Line

The regulation of a transmission line is defined as the percentage variation in voltage at receiver end between no load and rated *non inductive* load.

In any but the shortest lines, the capacity may not be neglected, and various schemes have been proposed for calculating the capacity effect.

The total line capacity may be regarded as concentrated and shunted across the line at the central point.

This assumption introduces an error of about 1 per cent. in a 200 mile line.

A closer approximation is obtained by regarding the total line capacity as divided into two equal parts, one of which is shunted across the line at either end. This method of approximation is sufficiently accurate for most practical cases.

A still closer approximation is obtained by dividing the capacity into six equal parts and shunting one part across each end of the line and four parts across the center. This arrangement is illustrated in Fig. 14.

The line inductance and resistance are regarded as connected in series with the line and divided as shown in the figure. X is the total line reactance in ohms, R equals line resistance in ohms, and C is the line capacity in farads.

(To be Continued)

REGULATION OF THE PERCENTAGE OF CARBON DIOXIDE IN FURNACE GASES

By E. A. Barnes

Much has been written and published in the last year or so on the subject of CO_2 in its relation to boiler room practice, the writers having given much valuable information in explanation of CO_2, but little having been said of its practical application and the pitfalls attendant on its introduction into existing boiler rooms.

In order to meet with even moderate success, the firemen who are to do the work, as well as the engineer and superintendent of the plant, must be in harmony with the arrangement. It often happens that the introduction of CO_2 economy methods in a power plant is turned over to a technically educated engineer who, through lack of practical experience, commences by calling for unnecessary refinements, especially with relation to sampling tubes in the boilers.

He is also very insistent on taking samples from different passes in the boiler, and goes about the work as though the research and history of the CO_2 percentage in the boiler itself was the thing to be arrived at; this, not being understood in the operating department, at once leads to complication and lack of co-operation.

The primary object in introducing CO_2 analysis in a boiler room is to save a percentage of the fuel by scientific firing in place of the haphazard, unscientific firing that has been in use for so long. Tables prepared up to date show that this can be done, and the best way to accomplish the result is to have the simplest apparatus possible, and that which can be thoroughly understood and operated by the boiler room force.

As firing under conditions that make for the greatest economy is much more uncomfortable for the fireman by reason of the greater amount of heat radiated from the boiler fronts, fire doors, etc., some form of extra compensation, preferably in the form of a sliding scale premium system based on a fair allowance, must be worked out.

In the opinion of the writer the best place to introduce the sampling tube is at about the center of the damper box or main flue breeching leading to the stack. This sampling tube should be of ¾ in. or 1 in. common gas pipe, from three to six feet long, open at the ends and with a 1/8 in. slot through practically its entire length.

The pipe leading from the sampling tube to the rest of the apparatus need not be over 1/8 in. standard pipe, securely and permanently fastened to the boiler walls and equipped at the lower end with a suitable stop cock so that connection by means of a rubber hose can be made to the testing apparatus.

A number of sampling devices have been designed, but the integrating bottle is the simplest, being nothing more than an inverted bottle holding five gallons of water, and provided with a suitable drain and pinch cock so arranged that the flow of water from the bottle can be regulated to continue for a certain predetermined period. The subsiding of the water forms a partial vacuum and sucks in the products of combustion from the sampling tubes in the boiler. This bottle is removed periodically and gases therein tested with the regular Orsat apparatus, the average CO_2 percentage through this period being thus arrived at.

There is another instrument called the econometer, in which the weight of flue gas as compared with that of the atmospheric air is constantly indicated on a scale.

The inverted bell sampler, as its name indicates, is a glass bell inverted in a water-sealed glass chamber. This is designed to operate by clock work and is suitably balanced. The rate at which the bell is withdrawn from the water-sealed chamber depends, of course, on the adjustment of the clock and the duration of time over which the samples are to be taken.

There is also the automatic motor-driven Orsat with recording adjustments, of which there are several designs on the market.

All the latter automatic instruments require a great deal of supervision, and unless kept in thorough working order, their indications cannot be depended on. As before stated, the simplest form of apparatus appeals most strongly to the average plant. Various conditions of induced draft, forced draft, natural draft, automatic stokers, hand firing, etc., etc., all introduce factors that tend to change the results and call for different handling in different installations. In this article, we will consider only hand fired boilers having induced draft.

In a hypothetical case, we will assume that the CO_2 averages about 11 or 12 per cent., and things go along very nicely for months, when all at once it is called to our attention that certain boilers are not holding up their percentage. Investigation is made, and it is found that the fireman has the dampers shut down and everything apparently in good condition. The boiler brick work is examined and it is discovered that there are innumerable cracks in the brick work around the clean-out doors and on top of the boiler where the domes and drums protrude. As soon as these are cemented up with suitable cement the CO_2 percentage at once goes back to the normal condition. It is the excess of air entering in through these leaks that has caused the trouble. Without the tell-tale CO_2 percentage showing, this waste would go on unchecked indefinitely.

Where a number of boilers in the same plant are being fired by men on a premium system, it is necessary to have some form of counting apparatus for each boiler or set of boilers handled by individual firemen. If this is not done, the wise firemen will keep their dampers closed and burn a very light fire and get a high percentage of CO_2 during the shift, but will consume little coal. The other fellows, who are shoveling in continuously, have their doors open and not only their CO_2 percentage goes down, but they are doing all the work and not getting as much pay as the men who are holding back. The counters are intended to indicate the amount of fuel fired per man.

Another point that is well to bear in mind is that the boiler settings as specified by the boiler makers in many cases are not properly worked out for the excessive heat that has to be withstood inside of the fire box and boiler settings under the new conditions. It has been my experience that nothing but the highest grade of fire brick should be used, and that the fire box lining brick should be laid up in courses of two stretchers and one header alternately. It is also very desirable to have every fourth header brick specially long, say 18 in., so that it not only binds the inner skin of high grade brick, but hangs over and is toothed into the low grade brick that usually constituted the intermediate filling.

If these precautions are not taken the excessive heat will warp and burn away the inner lining, causing it to bulge and crack, and there is danger of letting down the main arch. These precautions may seem unnecessary, but if results are wanted they must be carried out.

With regard to the arches, they must also be built of the highest grade brick, and should be laid out in the drafting room full size—so many straight brick and so many wedge brick—so that the masons who do the work will lay them up in this way. If this is not done, the arch will fail because the masons will use straight brick clipped into position and fill in the top crown with a lot of spalls and fire clay mortar.

I have mentioned above that different plants require different treatment, and I know of one plant in particular in which chain grates are used, where the clearance allowed around the chains and back of the chains is so great that enormous quantities of excess air enter at these points, and a low percentage of CO_2 results.

Where chain grates and automatic stokers are employed all clearances must be cut down so as to reduce to the lowest possible percentage the amount of air that does not pass through the fuel bed.

Among other important things that should be found in an up-to-date fire room are colored glasses through which the fireman can examine their fires. It is only by firing often and light, and covering over the "rat holes" and preventing the ingress of excess air that the best results can be attained. It is also very necessary that the draft be cut down as much as possible.

THE PAY-AS-YOU-ENTER CARS ARE TIP-TOP

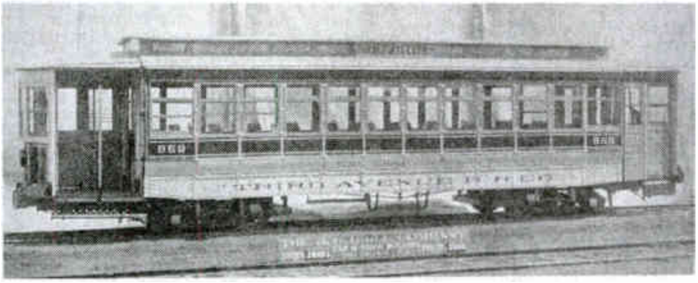
(From "*Life*")

Mr. Whitridge said he thought so much of the pay-as-you-enter cars that he had bought 375 of them since the type was tried on the first Third Avenue system.—Daily paper.

They are admirable; vastly better than the old style cars for the people who ride in them, as well as for the corporations that furnish them. They catch all the fares, which is right. They do away with constant progresses of the conductor through crowded cars, which is a great relief. They make for order, sense and better manners. They do away with the nuisance of smokers on the platforms and give the companies a better chance to exclude lighted cigars and cigarettes from the cars altogether. Publish it to the world that rides in street cars that the pay-as-you-enter cars are a great boon to mankind, and a remarkable mitigation of the sufferings of city populations.

The pay-as-you-enter cars have found favor with the street railway corporations of the larger cities and with the public, and since their introduction on the Third Avenue system, New York City, about two years ago, they have been put in operation on the more congested thoroughfares of Chicago, Baltimore and Detroit. It is also very likely that other large cities in the country will adopt these cars in the near future.

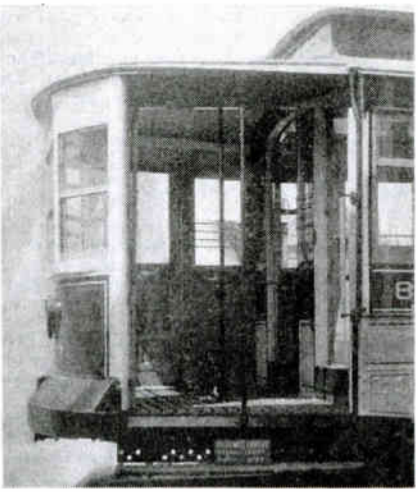
The logical arrangement of separate doors for entrance and exit, and in some cases the employment of the rear and front platforms respectively for these purposes, goes far towards eliminating the delay at stops due to interference between persons boarding and leaving cars of the ordinary enclosed type. The annoyance spared the passenger by this



Convertible Pay-as-you-enter Car for New York City
Arranged for Winter Service

single feature does much to commend the pay-as-you-enter car to his favor and thus win his fare.

Accidents are also largely prevented by the fact that the conductor is stationed at the rear platform, in a position to render assistance to women and children boarding the car, to the crippled, and to those otherwise incommoded. He can also see at a glance whether his platform is clear, and can signal his motorman without delay and without danger of injury to his passengers.



Conductor's Platform, Convertible Pay-as-you-enter Car

The illustrations show one of the 300 pay-as-you-enter cars furnished the Third Avenue Railroad by the J. G. Brill Company last summer. This car is an adaptation of the Brill patented convertible car, and is the result of an effort to embody the prepayment idea with the open car arrangement. Fifty additional cars of almost identical design are now on order for the same system. These cars will be fitted with GE-210 volt, 70 h.p. motors.

OBITUARY

Mr. H. H. Buddy, Manager of the Power and Mining and Lighting Departments of the Philadelphia District of the General Electric Company, died on the morning of January 15th after an illness of but two days, his sudden death coming as a great shock to his many friends.

In 1885, Mr. Buddy, who was then about 17 years of age, entered the employ of the Accounting Department of the Thomson-Houston Electric Light Company, of Philadelphia, and he was later promoted to the Commercial Department of that company. Upon the organization of the General Electric Company, he was made the Manager of the Power and Mining and Lighting Departments of the Philadelphia District, which position he filled with marked ability and continued to occupy until the time of his death.

Throughout his business relations he secured and maintained the respect, confidence, and friendship of many of the prominent men connected with the large corporations in that territory, and the grief at his death was widespread.

Mr. Buddy was a member of the Merion Cricket Club of Haverford, the Art Club of Philadelphia, the National Electric Light Association, and an Associate Member of the American Institute of Electrical Engineers.

The funeral services were held at the house of a friend on Mt. Vernon Street, Philadelphia, and the interment was made at Haddonfield, New Jersey, where his wife and child were interred about 15 years ago. He is survived by a father, a sister and a brother.

BOOK REVIEW

THE THEORY OF ELECTRIC CABLES AND NETWORKS

By Alexander Russel, A.M. D.S.C.

D. Van Nostrand Co. 200 Pages Price $3.00 Net

This book appeals to students and to managers of the smaller central stations who are contemplating some underground installations. It is written from the English viewpoint and refers almost entirely to English and Continental methods of cable construction and installation.

The most valuable chapter in the book is that dealing with the dielectric strength. This and the following chapter on the "Grading of Cable" make clear the undesirability of using very small conductors for high potential work.

The references at the ends of the chapters are decidedly the best things in the book, since the somewhat scanty literature on the subject of cables is scattered through numerous publications in papers by various authors covering one or more branches of the subject.