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GENERAL ELECTRIC REVIEW

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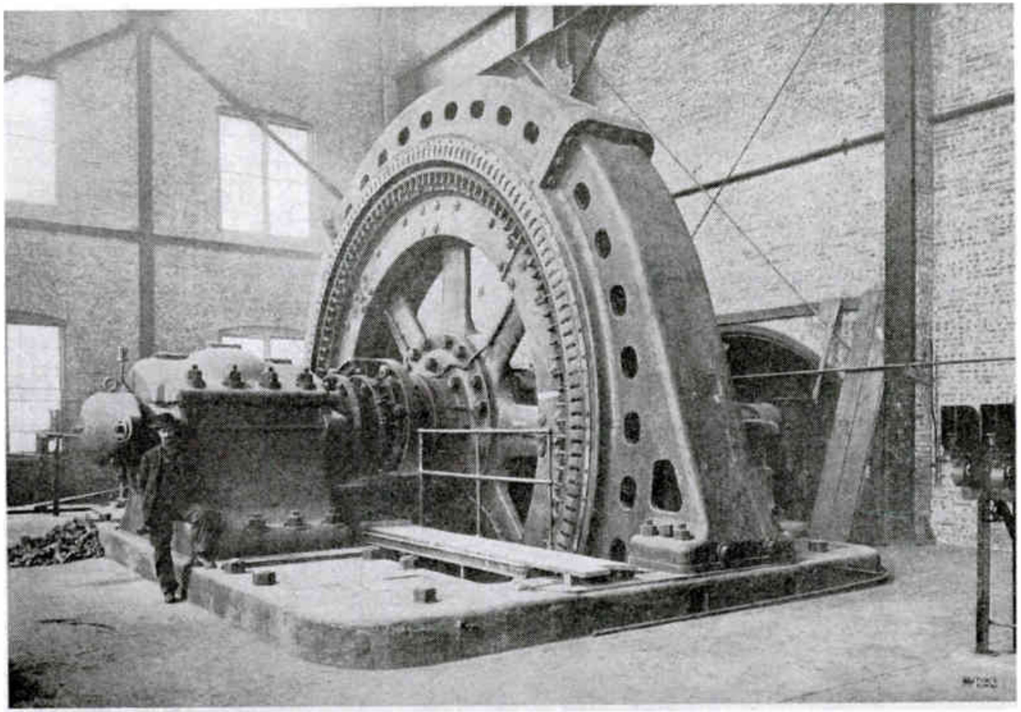
CONTENTS



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

"A Motor Operated Rail Mill"—Page 85

GENERAL ELECTRIC REVIEW

STEAM ENGINEERING DEVELOPMENT

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

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 The steam turbine has been successfully developed, and has already superseded its one-time rival, the reciprocating engine, in many branches of the art.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

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

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

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

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

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

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

A MOTOR OPERATED RAIL MILL

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

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

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

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

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

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

ATMOSPHERIC ELECTRICITY*

By Prof. Elihu Thomson

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

By G. R. Parker

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

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

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

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

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

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

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

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* A Paper read before the joint Meeting of the American Society of Mechanical Engineers and the St. Louis Engineers Club, December 11, 1909.

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

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

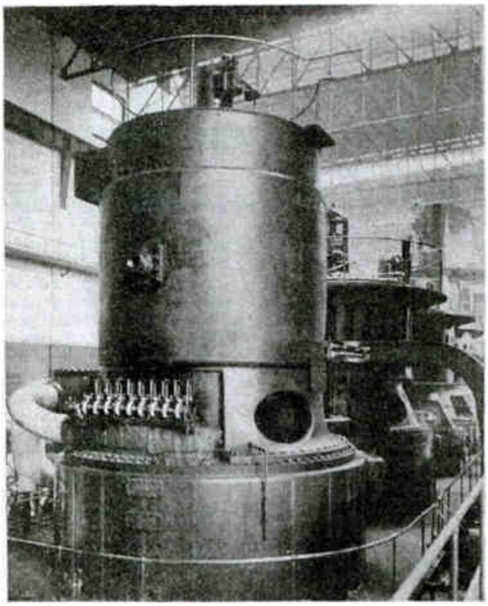
One of the principal and most justly founded claims for the steam turbine is its relatively high economy at other loads than rated load. Even in the best designed reciprocating engines the best economy is obtained at one point, and at loads greater or less than this, cut off occurs either too early or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

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

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

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

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



12,000 Kw. Curtis Turbine. This machine replaced a 5000 Kw. Curtis Turbine of older design, the original foundation and base being retained. Three of the old machines are shown in the background

during the coming summer. The economies obtained in these plants are reflected in the rates which the Commonwealth Edison Company is able to make its consumers.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

THE EFFECT OF ROTARY CONDENSERS ON POWER-FACTOR

By John Liston

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

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

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

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

As transformers require magnetizing current, they may seriously affect the power factor when unloaded or partially loaded, but when operating at full load their effect is practically negligible.

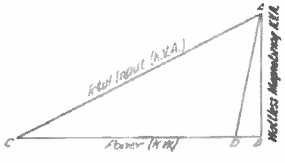


Fig. 1

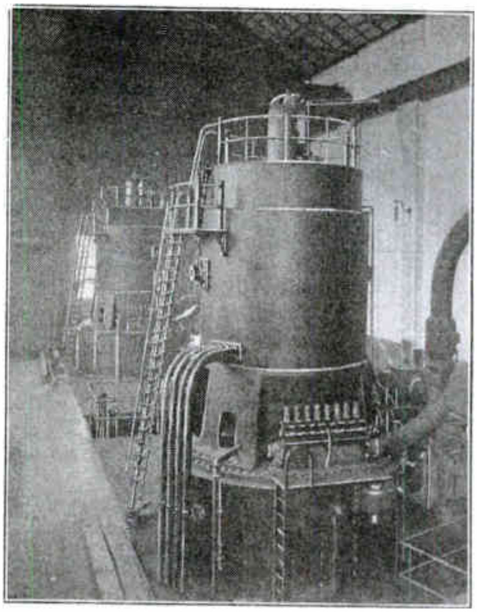


Fig. 2. Two 9000 Kw. General Electric Curtis Steam Turbine Generators in Generating Station, Cleveland Electric Illuminating Company

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

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

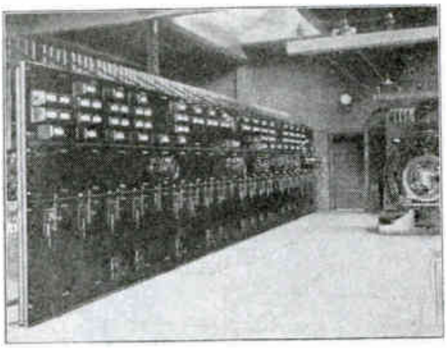


Fig. 3. 750 Kv-a. Rotary Condenser installed in a substation of the Cleveland Electric Illuminating Company

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

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

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

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

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

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

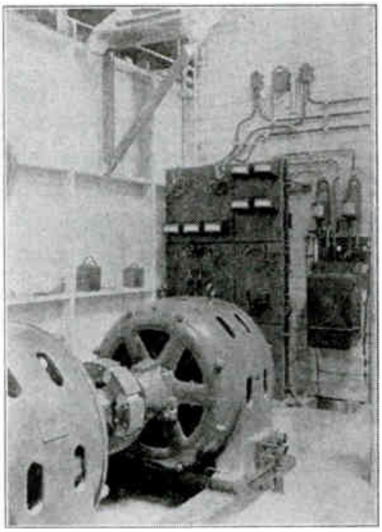


Fig. 4. 100 Kv-a., 2300/430 volt General Electric Synchronous-Motor Generator Set in the Plant of the National Electric Lamp Association, Cleveland, Ohio

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

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

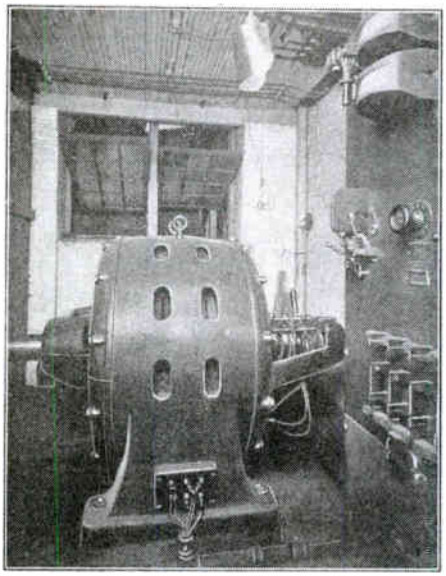


Fig. 5. 200 Kv-a. General Electric Rotary Condenser installed in factory of the National Acme Manufacturing Company, Cleveland, Ohio

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

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

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

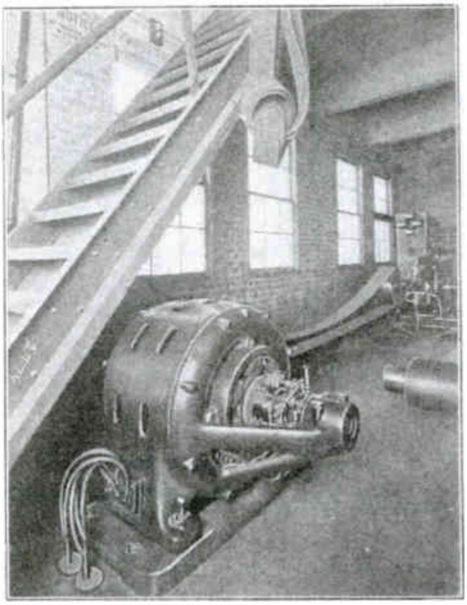


Fig. 6. 100 Kv-a. General Electric Synchronous Motor, Belt Connected to a D.C. Generator—The Ohio Ceramic Engineering Company, Cleveland, Ohio

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

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

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

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

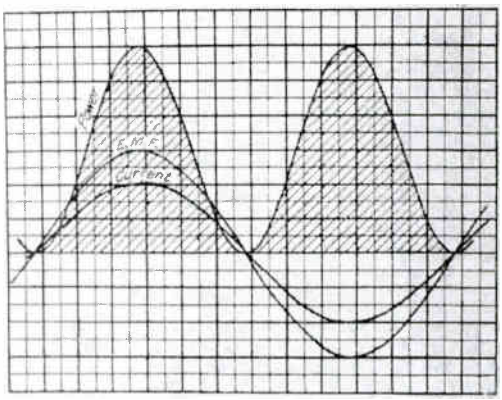


Fig. 7. Power, E.M.F. and Current Curves for 100% Power-Factor Current in phase with E.M.F.

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

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

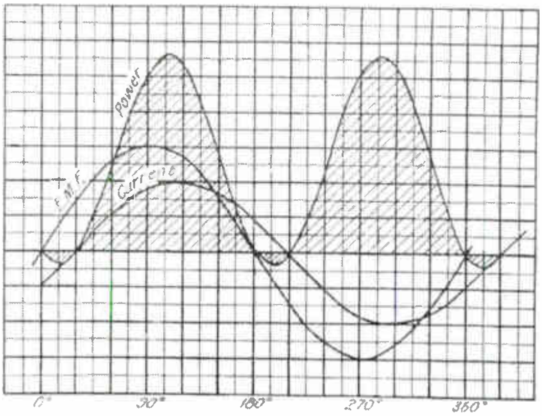


Fig. 8. Power, E.M.F. and Current Curves for 86.5% Power-Factor
Current lags 30° behind E.M.F.

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

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

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

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

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

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

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

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

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

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

TRANSMISSION LINE CALCULATIONS

PART V

By Milton W. Franklin

CAPACITY, REACTANCE, CHARGING CURRENT

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

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

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

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

$$Q = CE. \qquad (2)$$

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

$$i = \frac{dQ}{dt} = \frac{CdE}{dt} \qquad (3)$$

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

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

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

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

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

$\left(\frac{1}{T}\int_0^T i^2\,dt\right)^{\frac{1}{2}}$, whence its value may be obtained from (4) as follows:

$$\left(\frac{1}{T}\int_0^T i^2\,dt\right)^{\frac{1}{2}} = \left(\frac{C^2E_m^2}{T}\int_0^T \cos^2(\omega t)\,\omega^2\,dt\right)^{\frac{1}{2}} \qquad (5)$$

$$= C\,E_m\left(\frac{\omega}{T}\int_0^T \cos^2(\omega t)\,d(\omega t)\right)^{\frac{1}{2}}$$

$$= C\,E_m\left(2\pi f^2\left[\frac{\omega t}{2} + \frac{1}{4}\sin(2\omega t)\right]_0^T\right)^{\frac{1}{2}}$$

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

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

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

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

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

But

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

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

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

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

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

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

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

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

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

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

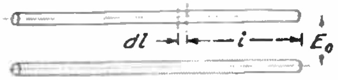


Fig. 12

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

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

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

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

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

Let I_0 be the current at receiving end of line.

Let ω be $2\,\pi f$.

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

The e.m.f. drop is

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

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

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

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

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

where

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

$Z\epsilon^{i\phi}$ and $Z_1\epsilon^{-i\phi_1}$ are complexes of the standard form $r\epsilon^{\pm i\phi}$ and in the present problem may be treated as ordinary algebraic constants.

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

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

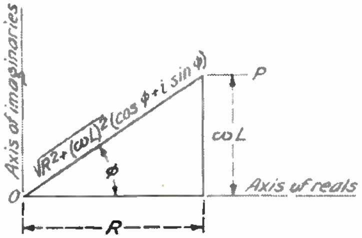


Fig. 13

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

Putting $ZZ_1\epsilon^{i\phi}\epsilon^{-i\phi_1} = \lambda^2$

and $Z\epsilon^{i\phi}/Z_1\epsilon^{-i\phi_1} = \lambda_1^2$.

From (8)

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

and substituting from (9)

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

Similarly from (9) and (8),

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

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

Taking (10)

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

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

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

integrating

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

as the constant C is purely arbitrary.

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

Integrating again

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

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

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

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

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

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

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

Adding (b) and (c),

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

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

from this development (12) may be written

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

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

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

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

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

and (14) may be written

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

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

$$I = a_1 \cosh \lambda l + \beta_1 \sinh \lambda l \qquad (16)$$

Of the four constants of integration, a, β, a_1, β_1, two may be expressed in terms of the others.

From (15)

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

From (8) and (16)

$$\frac{dE}{dl} = \lambda\lambda_1 I = \lambda\lambda_1 (a_1 \cosh \lambda l + \beta_1 \sinh \lambda l) \qquad (18)$$

equating (17) and (18)

$$\begin{aligned} &a \sinh \lambda l + \beta \cosh \lambda l \\ &\quad = \lambda_1 a_1 \cosh \lambda l + \lambda_1 \beta_1 \sinh \lambda l \end{aligned} \qquad (10)$$

Equating coefficients

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

$$\beta = a_1 \lambda_1 \qquad (20)$$

and (15) becomes

$$E = a \cosh \lambda l + a_1 \lambda_1 \sinh \lambda l \qquad (21)$$

Similarly (16) becomes

$$I = a_1 \cosh \lambda l + \frac{a}{\lambda_1} \sinh \lambda l \qquad (22)$$

It remains to determine the values of the constants a and a_1. This may be accomplished as follows:

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

$$E_0 = a \cosh o + a_1 \lambda_1 \sinh o$$

whence $a = E_0$

Again

$$I_0 = a_1 \cosh o + \frac{a}{\lambda_1} \sinh o$$

whence $a_1 = I_0$ and (21) – (22) become respectively

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

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

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

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

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

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

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

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

(To be Continued.)

COMMERCIAL ELECTRICAL TESTING

PART IV

BY E. F. COLLINS

SUPERINTENDENT OF TESTING

Regulation Test—Speed—Voltage

Shunt regulation should be taken on shunt generators. A reading should first be taken at no-load normal voltage; then, without changing the rheostat, ¼ full load should be thrown on and a reading taken of amperes armature, volts armature, amperes field and volts field. Holding ¼ full load, the voltage should be brought up to normal and the same readings taken. The load should then be increased to ½ full load, the rheostat remaining in the same position as before, and similar readings taken. This test is repeated for ¾ and full load. With full load on the machine the voltage should be brought up to normal. Without altering the position of the field rheostat, the load is then taken off the machine and the rise in voltage observed. A curve should be plotted with amperes armature as abscissæ and volts as ordinates.

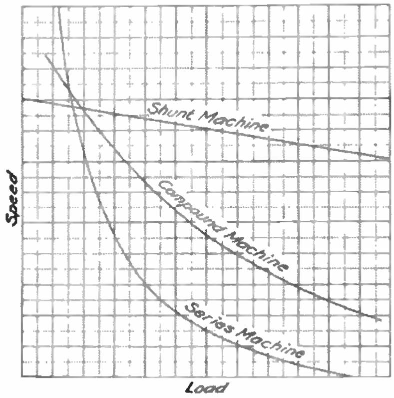


Fig. 17. Speed Curves D.C. Motors

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

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

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

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

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

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

Input-Output Tests

It is sometimes required to measure the efficiency of a machine or set by the input-output method. The measurement of the power input to the motor and output from the generator is then required. The efficiency

$$\text{of the set} = \frac{\text{Total output of generator}}{\text{Total input to motor}}$$

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

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

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

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

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

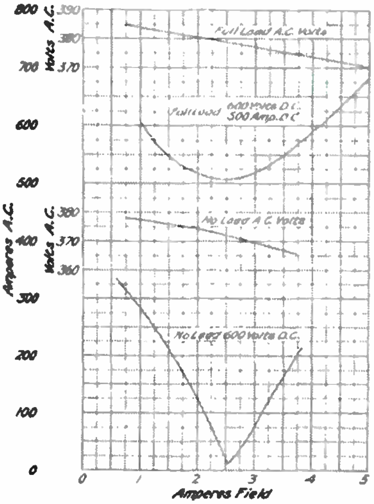


Fig 18. No Load and Full Load Phase Characteristic on a 300 Kw., 600 Volt, 750 R.P.M., 25 Cycle, 3-Phase Rotary Converter

TABLE VI

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

NO LOAD					FULL LOAD 500 AMPS, D.C.				
Volts D.C.	Volts A.C.	Amps. A.C.	Amps. Field	Volts Field	Volts D.C.	Volts A.C.	Amps. A.C.	Amps. Field	Volts Field
600	378	315	.75	91	600	384	601	1.03	125
600	377	255	1.25	150	600	383.5	570	1.23	150
600	376	210	1.50	180	600	381	543	1.50	180
600	375	156	1.75	210	600	380	530	2.00	240
600	374	120	2.00	240	600	379	512	2.25	270
600	373	85	2.20	265	600	378	507	2.50	300
600	373	65	2.30	275	600	378	505	2.63	330
600	372	41	2.40	290	600	378	510	2.73	330
600	371	23	2.50	300	600	370	525	3.00	360
600	370	14	2.55	305	600	375	547	3.30	420
600	370	17	2.60	315	600	374	585	4.00	485
600	369	21	2.65	320	600	373	627	4.50	540
600	369	35	2.75	332	600	370	685	5.00	600
600	369	73	3.00	360					
600	368	116	3.25	395					
600	367	170	3.50	420					
600	366	205	3.75	430					

Phase Characteristic

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

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

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

Synchronous and Static Impedance

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

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

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

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

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

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

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

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

Wave Form Potential Curve Between Brushes

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

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

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

D.C. GENERATORS

Preliminary Tests

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

On all multiple wound armatures of self-contained machines not equipped with equalizing rings, a potential curve must be taken. All the brushes except those on two adjacent studs are raised from the commutator, the voltage is raised to normal and the field current noted. This field current and the speed must be held constant for all other points on the curve. The brushes on stud No. 3 should now be lowered, those on No. 1 raised and the voltage read between studs No. 2 and No. 3. This procedure should be continued until voltage readings have been taken between every pair of studs. The test should be made with the field current rising. The maximum voltage variation permissible is 4 per cent. of the average value. This test, although similar in nature, should not be confused with the bar to bar potential curve taken to determine the wave form of a direct current machine.

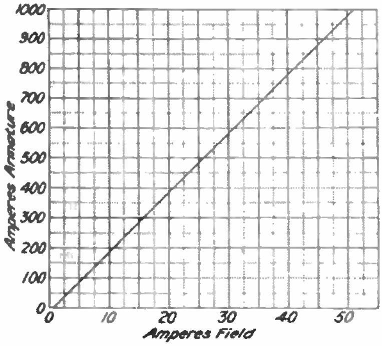


Fig. 19. Synchronous Impedance Curve on a 500 Kw., 600 Volt, 360 R.P.M., 60 Cycle, 3-Phase, A.C. Generator

TABLE VII

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

Amps Arm	Volts Field	Amps Field	Speed R.P.M.
224	15.0	11.9	360
260	17.8	13.7	360
300	20.6	15.8	360
352	23.8	18.3	360
398	26.9	20.7	360
474	31.5	24.5	360
480 480 480	32.2	24.8	360
518	34.8	26.7	360
557	37.5	28.2	360
701	47.0	36.1	360
796	52.8	40.6	360
896	59.5	45.7	360
1000	66.5	51.1	360

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

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

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

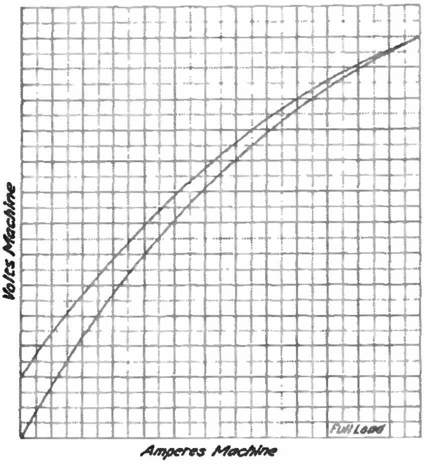


Fig. 20. Series Characteristic

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

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

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

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

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

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

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

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

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

Standard Efficiency Test

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

Consider a compound commutating pole generator.

Let V_L = Volts line.

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

C_3 = Amperes, shunt field

C_4 = Amperes, armature = $C_L + C_3$

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

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

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

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

R_2 = Brush contact resistance

R_3 = Hot resistance of shunt field

R_4 = Hot resistance of armature

R_8 = Hot resistance of series field

R_9 = Hot resistance of series field german silver shunt

R_{10} = Hot resistance of commutating pole field

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

Then total CR drop = $C_4R_4 + C_4R_2 + C_3R_3 + C_8R_8 + C_{10}R_{10} + C_{11}R_{11}$

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

W_2 = Watts brush friction from core loss test.

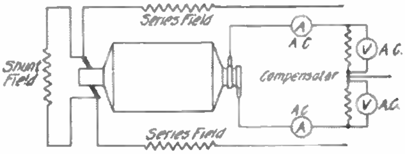


Fig. 21. Three-Wire Generator

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

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

F. = Circumference of commutator in feet

N = R.p.m.

B = Number of brushes

L = Lbs. pressure per brush

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

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

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

TABLE VIII

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

% Load	0	25	50	75	100	125	150
Volts Line	523	537.5	550	562.5	575	575	
Amps. Line	0	43.5	87.0	130.5	174	217.5	
Amps. Shunt Field	3.10	3.18	3.25	3.32	3.40	3.4	
Amps. Armature	3.1	46.7	90.3	133.8	177.4	220.9	
Amps. Series Field	0	29.2	58.4	87.6	116.8	146	
Amps. Series G.S.S.	0	14.3	28.6	42.9	57.2	71.5	
CR Drop	.417	.628	12.15	18.0	23.9	29.7	
E+CR	525.4	543.8	562.2	580.5	598.0	604.7	
Core Loss	1042	1124	1205	1295	1395	1425	
Brush Friction	314	314	314	314	314	314	
Bearing Friction	—	—	—	—	—	—	—
C²R Armature	—	213	797	1750	3080	4770	
C²R Brushes	—	36	135	222	331	430	
C²R Shunt Field	1630	1710	1790	1870	1930	1050	
C²R Rheostat							
C²R Series Field	0	33	131	296	523	820	
C²R G.S.S.	0	16	64	144	257	403	
Total Losses	2986	3.446	4436	5891	7850	10112	
Kw. Output	0	23.4	47.8	73.4	100	125	
Kw. Input	2.99	26.85	52.24	79.29	107.85	135.1	
% Efficiency	—	87.2	91.5	92.6	92.7	92.6	
Brush Density	—	8.3	16.05	23.8	31.6	39.3	
Brush Contact Res.	—	.01665	.0144	.01244	.01055	.0091	

Resistance of Armature 25° C. .0893 Ohms, Warm .098 at 51° C.
Resistance of Shunt Field 25° C. 97.4 Ohms, Warm 105.3 Ohms at 47° C.
Resistance of Series Field 25° C. .0358 Ohms, Warm .0386 Ohms at 46° C.
Resistance of Series G.S.S .070 Ohms.
Dimensions of Brushes 1¾"×¾". No. of Studs 6. No. per Stud 4. Coeff. of Friction = .2.
Brush Contact Area, One Side 5.625 Sq. In. Brush Pressure 1¼ Lbs. per Brush.

TABLE IX

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

Volts Line	500	500	500	500	500
Amperes Line	20	58	87	116	145
Amperes Field	2.43	2.43	2.43	2.43	2.43
Amperes Arm.	26.5	55.5	84.5	113.5	142.5
CR	3	6	9	12	15
E—CR	497	494	491	488	485
Speed					
Core Loss	2500	2475	2450	2400	2350
Brush Friction	460	460	460	460	460
Bearing Friction	530	530	530	530	530
C²R Armature	63	275	638	1150	1820
C²R Brush	8	36	83	153	240
CE Field	1215	1215	1215	1215	1215
Total Losses	4775	4000	5380	5908	6615
Kw. Input	14.5	29	43.5	58	72.5
Kw. Output	9.7	24	38.1	52.1	65.9
H.P. Output	12.8	32.1	51	70	88.5
% Efficiency	67.0	82.8	87.6	89.8	90.8
Brush Density	5.15	10.3	15.5	20.6	25.8
Brush Contact Resis.	.0178	.016	.0146	.0132	.0119

Resistance of Armature 25° C. .0816 Ohms, Warm .0895 Ohms at 50° C.
Resistance of Field 25° C. 169 Ohms, Warm 191.5 Ohms at 60° C.
Dimensions of Brushes 1½"×½". No. of Studs 6. No. per Stud 3. 1½ lbs. per Brush.
Brush Contact Area, One Side 5.62 Sq. In.

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

W_2 = Bearing friction from core loss test
W_b = Watts output = $C_L \times V_L$

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

Brush current density per square inch =

$$\frac{C_4}{\frac{1}{2}\text{ total brush area}}$$

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

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

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

If W_2 = bearing friction from core loss test, then total loss in watts = $\Sigma W = W_1 + W_2 + W_3 + C_4{}^2R_4 + C^2{}_4Rs_5 + C_6{}^2R_6 + (C_9V_L - C_9{}^2R_9) + C^2{}_8R_8 - C_9{}^2R_9 + C_{10}{}^2R_{10} + C_{11}{}^2R_{11}$

The quantity $C_9V_L - C_9{}^2R_9 = C^2R$ loss in the shunt field rheostats.

The watts input W_a will then be

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

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

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

The total losses will then be

$$\Sigma W = \text{Running light} + C_4{}^2R_4 + C_4{}^2R_5 + C_9V_L + C_L{}^2Rs_F + C_L{}^2Rc_F.$$

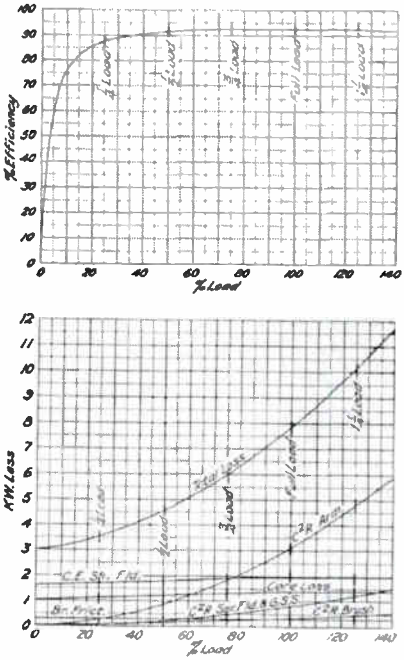


Fig. 22. Efficiency and Losses on a 100 Kw., 6 Pole, 275 R.P.M. 515/575 Volts, Compound Wound D.C. Generator

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

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

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

A FINANCIAL STATEMENT OF THE CAUVERY HYDRO-ELECTRIC DEVELOPMENT

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

Dewan L. Ananda Dao

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

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

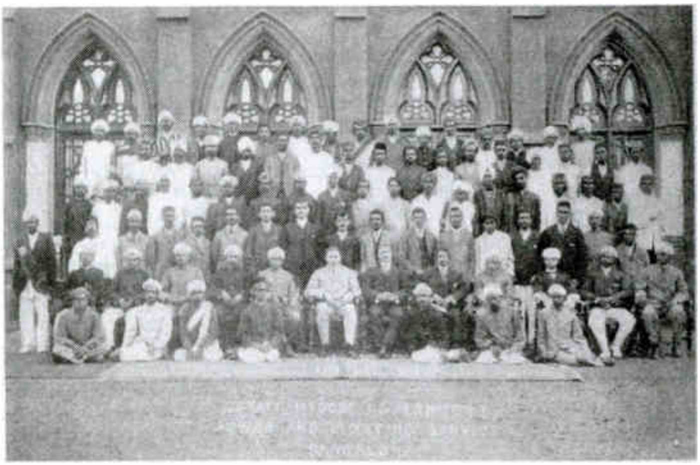
The original development generated 6000 h.p.; to this was added two extensions of 5000 and 2000 h.p. respectively, making in all 13,000 h.p. By the original arrangement, the mining companies agreed to pay for power a flat rate based on the normal full load consumption of the motors, the agreement covering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

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

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

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

The total capital expended by the Government in the development has been $2,500,000. The gross revenue received over a period of 6¾ years has been $3,743,000. The expense of operation and maintenance has been $703,000. The net revenue, against capital of $2,500,000, is therefore $3,040,000.



A MOTOR OPERATED RAIL MILL

By B. E. Semple

Chicago Office, General Electric Company

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

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

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

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

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

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

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

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

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

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

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

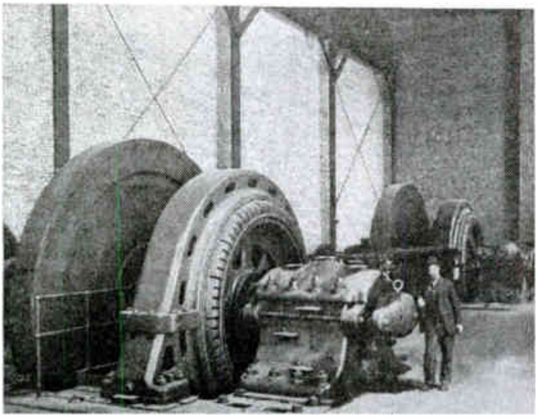


Fig. 1. 2000 H.P., Three-Phase Induction Motor Geared to Two-high Blooming Mills

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

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

Each motor is provided with a thrust bearing or mechanical fuse, mounted on the front pedestal and held in place by two breakable rods which can be seen in the illustration. The purpose of this thrust bearing is to care only for ordinary thrusts in amounts less than 150 tons. This point may be exceeded at times, however, by the breaking of a roll or a roll spindle, and in such emergencies the thrust is sufficient to break the rods holding the collar in place, thus allowing the rotating element to move longitudinally away from the rolls, thereby relieving the thrust and preventing further damage to the roll machinery or to the motor itself. The brush rigging is arranged in such a manner that it can move longitudinally with the rotating element, thus allowing the brushes to remain on the collector rings regardless of the position of the rotor.

These two motors operate the first four "passes," each motor driving two stands of 42 in. blooming rolls. They are connected to the rolls through a double reduction gear arranged to give six revolutions per minute on the first two passes and ten revolutions per minute on the next two.

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

This gearing is of special interest when the speed ratios and the power transmitted are considered. In one case the motor driving pinion has a 21 in. face, 23 teeth, and a pitch diameter of 26$\frac{9}{32}$ in; the large gear engaging this pinion has a 21 in. face, 135 teeth, and a pitch diameter of 12 feet, 10$\frac{9}{32}$ in.; and the intermediate pinion has a 27 in. face, 20 teeth and a pitch diameter of 3 feet 2¼ in. The gears on the roll shafts are each of 18 feet 5¾ in. pitch diameter, 27 in. face, and contain 116 teeth.

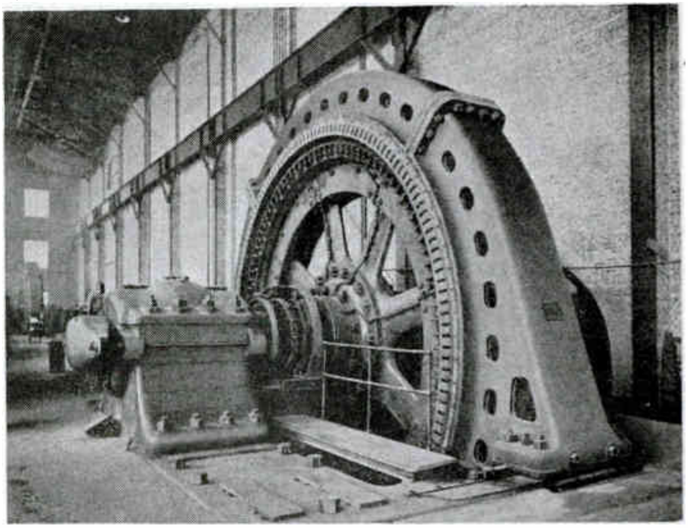


Fig. 2. 6000 H.P., Three-Phase Induction Motor. This motor drives three stands of rolls, one of which takes three passes, and the other two one pass each

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

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

This motor differs somewhat in construction from those just described, and in addition to being larger in horse-power and slower in speed, obtains its flywheel effect of 13,100,00 lbs. at one foot radius by having its flywheel mounted directly on the spokes of the rotor as shown in illustration on page 50.

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

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

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

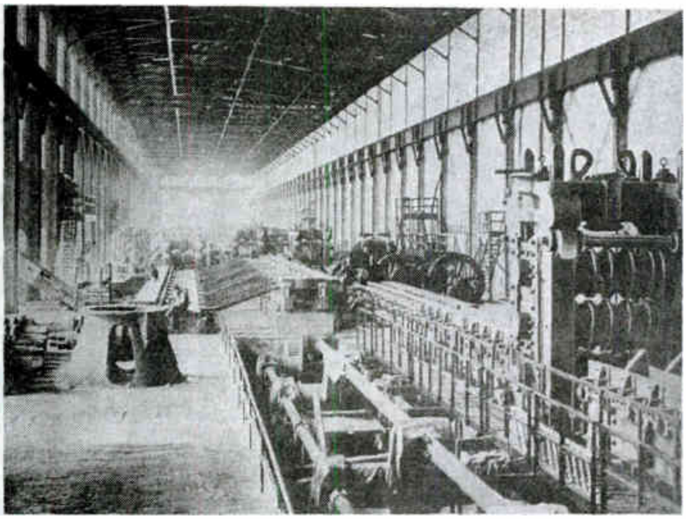


Fig. 3. Finishing End of Rail Mill

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

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

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

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

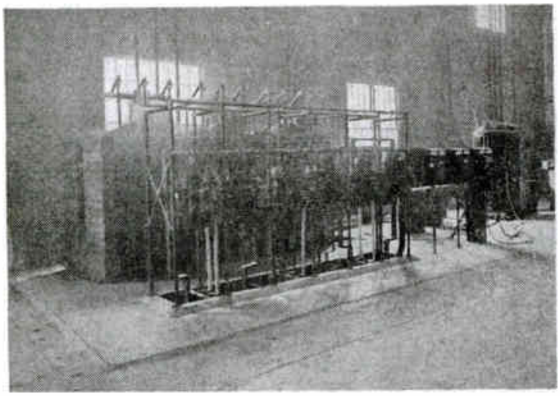


Fig. 4. Primary Control for Three 6000 H.P. Induction Motors

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The primary control equipment for each motor consists of one motor-operated three-pole line oil switch, two solenoid operated reversing switches, the necessary relays, and indicating and recording instruments. The main oil switch is interlocked with the reversing switches, making it impossible to operate the latter while the main switch is closed. The reversing switches are also interlocked as regards each other, to prevent both being closed at the same time.

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

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

The regulating device mounted on the relay panel controls the opening and closing of the contactors, and in addition to performing the function of energizing the contactor magnets during the starting operation, also opens the contactor circuits at the proper time to control the slip.

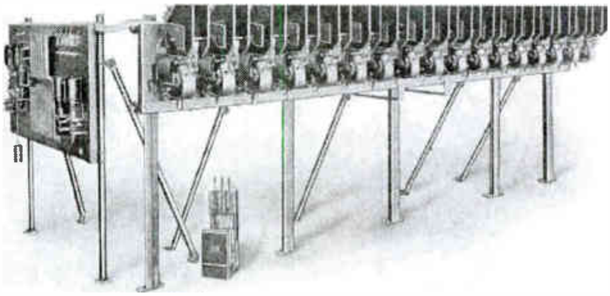


Fig. 5. Secondary Control for 6000 H.P. Induction Motor

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

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

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

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

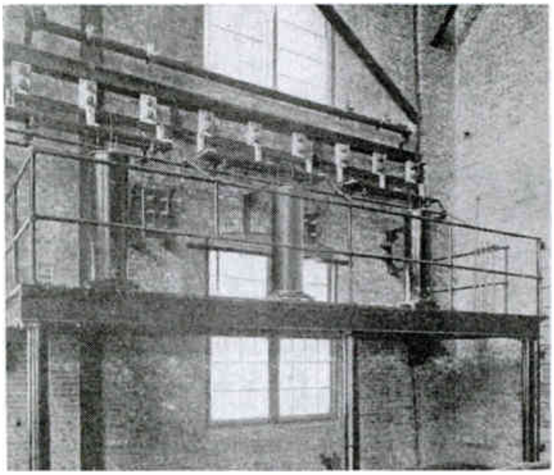


Fig. 6. Aluminum Cell Lightning Arresters

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

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

SOME POINTS OF MODERN PRACTICE IN INDUCTION MOTOR CONSTRUCTION

By E. L. Farrar

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

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

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

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

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

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

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

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

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

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

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

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

SEWING MACHINE MOTORS—DRAWN SHELL TYPE

By R. E. Barker

Small Motor Department

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

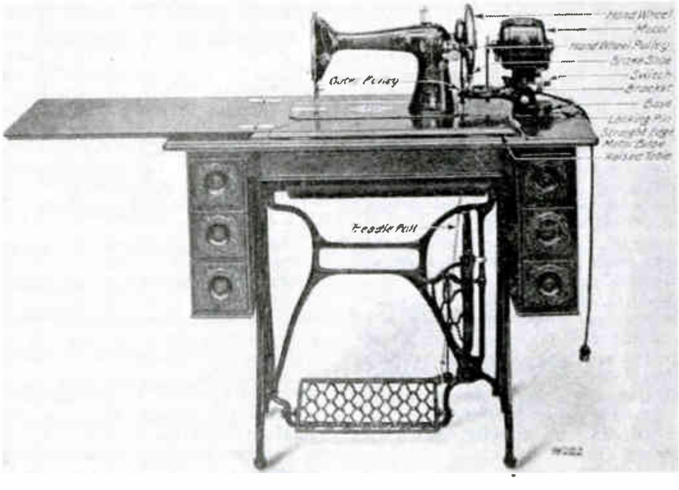


Fig. 1. Form H Motor Attached to High Arm, Drop Head Machine

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

To meet the demand for a motor for this

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

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

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

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

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

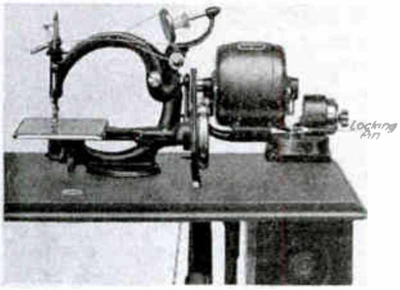


Fig. 2. Form K Motor Attached to Low Arm Machine

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

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

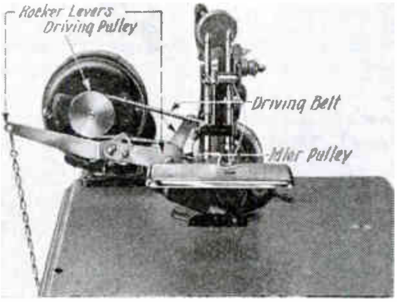


Fig. 3. End View of Form K Motor Attached to Low Arm Machine

Complete outfits are comprised of the following parts:

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

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

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

ALTERNATING CURRENT—60, 40 and 25 Cycles

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

CONTINUOUS CURRENT—Shunt Wound

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

Full and clear instructions for assembling are shipped with each outfit. When the outfit has been installed in accordance with the directions and the motor connected to the source of electric supply by means of the flexible cord and plug, the operator can start the machine by turning the snap switch and thereafter govern the speed to a nicety by gently increasing or diminishing the pressure of the foot on the treadle.

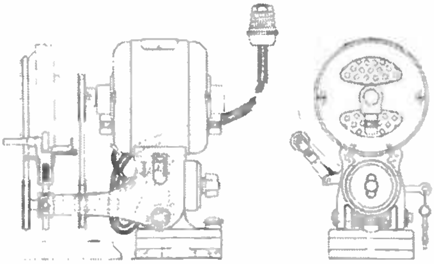


Fig. 4. Form H Motor

Pressure of the foot releases the brake and tightens the belt by means of the driving pulley, thus starting the machine or increasing the speed. Reduction of pressure on treadle loosens the belt and decreases the speed. To stop machine quickly, remove all pressure from the treadle and the brake will be automatically set against the handwheel, bringing the needle to rest immediately. This method of control is simple and satisfactory; the speed of the sewing machine may be regulated quickly to suit the varying requirements of different classes of work.

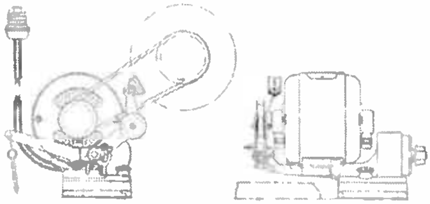


Fig. 5. Form K Motor

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

Sewing machine motor drive is one of the most attractive applications of fractional horse-power motors ever made by the General Electric Company. Large numbers of the earlier type with separate belt tightener have been sold, and now that a more improved, complete, self contained, lighter and more efficient motor is offered, it is confidently expected that the demand will greatly increase when its several good features become known to the purchasing public. The new motor is much cheaper to operate than the old, actual tests showing a saving of 50 per cent. in the current bill. The power used is about equal to that taken by one sixteen candle-power incandescent lamp. This fact should make the new outfit especially attractive.

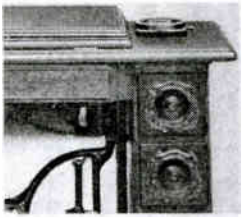


Fig. 6. Drop Head Machine Showing Motor Removed

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

OIL AND TRANSFORMER DRYING OUTFITS

By E. F. Gehrkens

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

The outfit consists of the following parts:

Hot air furnace,
Positive pressure blower,
Dust collector,
Driving motor,
Necessary piping, pulleys and belt.

The outfit is shown diagrammatically in Fig. 1.

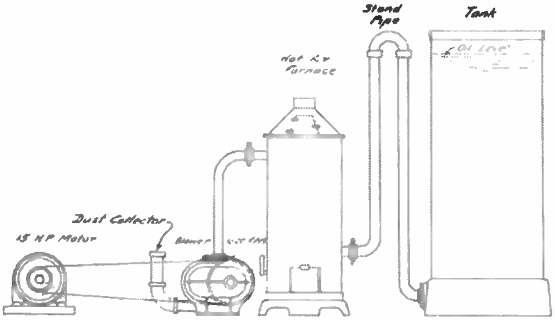


Fig. 1

Hot Air Furnace

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

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

Positive Pressure Blower

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

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

Dust Collector

The dust collector, or air filter, is of very simple construction and is attached to the inlet of the blower. It consists of a pipe 4½ in. in diameter, made from perforated sheet metal and connected to the blower with a suitable elbow. Cheese cloth should be tied around this pipe so that when the outfit is in operation the air must pass through the cloth, thereby being effectually filtered. The cloth must, of course, be changed from time to time.

Driving Motor

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

Piping, Etc.

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

Weights

The net weights are as follows:

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

OBITUARY

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

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

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

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

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

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

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