GENERAL ELECTRIC REVIEW

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CONTENTS

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GENERAL ELECTRIC REVIEW

TRANSMISSION LINE PROBLEMS.

If collected, the literature dealing with transmission line problems would fill many volumes, and the subject has been treated from various points of view. As it lends itself readily to theoretical treatment, the question has been discussed mathematically to a greater extent perhaps than any other branch of electrical engineering.

In the February number of the REVIEW, Mr. M. W. Franklin shows how to derive the exact solution of the problem by means of the hyperbolic functions. The equations so obtained involve certain constants which include the geometrical properties of transmission lines, *i.e.*, their self induction and capacity, as well as the resistance and frequency, and necessitate the evaluation of the constants and of the hyperbolic functions before numerical results can be obtained from them.

The articles, by Mr. W. E. Miller, commencing in this issue, are of value because these constants, as well as the hyperbolic functions, have been computed at sufficiently close intervals to allow of ready and accurate interpolation by inspection, for all values of the constants and functions which lie within their range. Tables of these functions will be published in a supplement to the next issue of the REVIEW, which will contain the transmission line equations and examples showing how to use them. By the aid of the tables, numerical results can be immediately obtained from the equations by multiplications of two, or at most three complex quantities, and two simple divisions. No capacity, self induction or resistance need be found, because these are included in the constants.

As the wires in transmission lines are very often strung equally spaced with their axes lying in a plane, as well as at the corners of an equilateral triangle, the constants have been calculated for both methods.

The great advantage of using an exact solution of the problem is that the electrical conditions can be as readily determined at any point of the line as at the generator or receiving end, so that if a branch line is connected at any point, the electrical characteristics at its junction with the main line can be immediately obtained.

Apart from this practical aspect of the case, it is of some educational value to see how the volts, amperes and power-factor vary along lines of great length, for which approximate solutions are not reliable. The length at which most approximate methods fail can be roughly taken as 200 miles at 60 cycles, and 400 miles at 25 cycles. The complex hyperbolic functions in these articles have been calculated to take care of lines up to 435 miles in length at 60 cycles, and 850 miles at 25 cycles, even when using the smallest wire considered. Slightly longer lines can be calculated, when larger wires are employed, though the difference is immaterial.

The knowledge of the hyperbolic functions and of the complex quantity possessed by the majority of engineers, is small, and for this reason a short discussion has been given of these matters, which should prove useful to those who wish to get some insight into these quantities. Their understanding is important if the meaning of the equations and their operation are to be understood. The analogy is traced between the circular and hyperbolic functions, and there can be but little doubt that if the hyperbolic functions were taught in school or college in conjunction with plane trigonometry, very little extra work would be required for appreciating and handling them.

In following issues of the REVIEW, curves will be given illustrating how the electrical characteristics vary along a transmission line 400 miles in length at 60 cycles, with various terminal conditions at the receiving end.

A considerable amount of interest is now being taken in corona effect, and therefore this question is briefly considered, curves being drawn in which the corona loss is separated from the capacity current loss along the line at no load, the example taken being a 200 mile line using No. 1 wire and operating at 25 cycles.

Amongst other points discussed, the following may be mentioned: transmission efficiency, velocity of power propagation, shift of phase, and variation of power-factor along the line, a method being given for discovering under what conditions maximum transmission efficiency can be obtained for a given load at the receiving end. As an interesting case in the use of hyperbolics, the volts and amperes of a 1000 mile telephone line have been calculated at various points of the line, both the maximum and instantaneous values of these quantities being plotted. A short discussion on a few of the theoretical points in connection with telephone lines closes the articles.

The table of the hyperbolic complexes and the constants required for transmission lines have been calculated with the greatest possible care, and,through the greater part of the range, the accuracy is about one-quarter per cent. Greater accuracy is not attempted, not only because it is not generally required in electrical engineering, but also because the labor involved would have been enormously increased, since a slide rule could not have been used. It is hoped that few errors occur in the tables, but in work involving over twevle thousand separate calculations, it is practically impossible to entirely avoid mistakes. There is little doubt, however, that no serious discrepancies can exist.

ELECTRICITY ON THE FARM

The high and ever increasing cost of living, which, it is well recognized, is due in a very large measure to the scarcity and the consequent steady advance in the cost of farm produce, is causing the necessity for greater production to assume vital economic importance.

The need for agricultural commodities is urgent, and the reward for the producer certain, but the problems involved are many and perplexing, the chief one being that of securing efficient labor at a rational, or in fact any, price. This difficulty may be overcome to an extent not generally realized by the utilization of machinery for reducing the manual labor necessary. In pursuance of this course, many modern farms have been equipped with labor-saving machinery and, where this solution has been applied to the problem, the results have far exceeded the expectations and have more than justified the investment; not only by greatly increasing the output, but by doing away with "the discouraging and never ending hard work which in the past has done more than any other thing to drive the boys from the farm."

In the great grain districts of the Northwest, agricultural operations have, of course, long been accomplished by the use of machinery; the harvesting, etc., of these enormous crops would otherwise be an utter impossibility. In Europe also, and especially in Germany, plowing and similar operations have been performed by means of electrically driven machinery. These methods have resulted in material economies, and this although the land is poorer than that in the United States and the cost of labor only about one-sixth of that in this country.

While in the Eastern states, the employment of engine or motor driven machines for the more extensive operations may not fit the present conditions, the uses for power on an average American farm are many and varied. The threshing and grinding of grain, the operation of separators, churns, and pumps (both for regular water supply and for service in case of fire), the driving of washing machines and other household devices, are only a few of the labor saving items.

For the purpose of driving farm machinery, the electric motor is the logical choice; there, if anywhere, it stands pre-eminent. The flexibility of the electric system; the fact that a number of scattered motors used for intermittent service may be supplied from a small generator of very much less than the aggregate capacity of the motors; the availability of the current for lighting purposes and the absolute safety as regards fire risks; are but a few, and not necessarily the most important reasons for the selection of electricity as the motive power. The further fact that with the introduction of electricity come many material comforts, and even luxuries, is another cogent reason for its adoption; and when in addition to the above, it is realized that the power for generating the current can, in very many cases, be obtained from local streams, the energy of which would otherwise be wasted, the superiority of electric power becomes evident.

The article by Mr. Liston, in the present issue, describes a large model farm in which electricity has been utilized extensively and has been found to be reliable, safe, and economical.

THE WESTPORT-STOCKTON COAL COMPANY'S COLLIERY WESTPORT, NEW ZEALAND

By W. A. Reece

With the opening of the Westport-Stockton Coal Company's Colliery on October 6th, 1908, an engineering work was successfully brought to completion which affords not only a striking example of a modern coal mine equipment in its highest perfection, but also offers a most interesting study of how a difficult and complicated haulage problem was overcome, involving as it did, the introduction of electric hoists, gravity inclines, and electric locomotives.

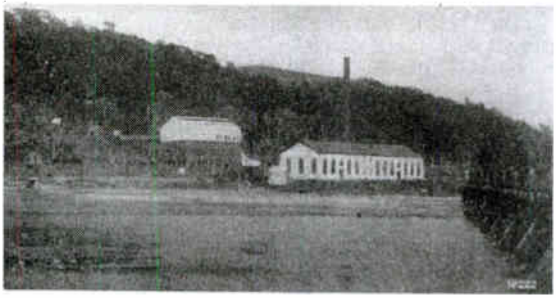
In order to give an intelligent idea of the work, it will perhaps be best to first describe the coal formation, taking up the various other considerations such as power plant equipment, haulage systems, transmission line, braking problem, etc., in order.

The Company holds a Crown lease of two thousand acres of coal bearing land forming part of the Buller coalfield. From the outcroppings and test bores the famous Westport seam of coal—a bituminous coal of high calorific power and great purity—was proved to underlie the greater part of the 2000 acre area. The seam is from eight to twenty feet in thickness and has a fine roof of hard sandstone and in most places a hard bottom of the same material. The lease is situated on the tableland of the steep coastal range, at an elevation of about 2000 feet above sea level.

The Buller coalfield may be described as unique. The coal lies at a moderate inclination on the coastal range plateau, and is underlain by sandstones which repose directly on granite. The thickness of these sandstones rarely exceeds 100 ft. and in some portions of the field the granite intrudes into the coal. The coal formation belongs to the Cretacio-Tertiary, but the coal is truly bituminous in composition and characteristics. Gold is found in the immediate vicinity of the coal measures.

Power Considerations

The coal is brought down from the Company's mines to the Government railway at Ngakawau, which is 19 miles from Westport, the port of shipment. The distance from the Company's tipple at Ngakawau to the siding in the mine, from which the coal is hauled by the Company's main haulage system, is four miles. It was decided to install electric power for the whole of the mining operations and to generate it in a central station at Ngakawau; the reasons for locating the plant at this point alongside the government railway being as follows:



Power Station with Tipple and Bins in the Rear

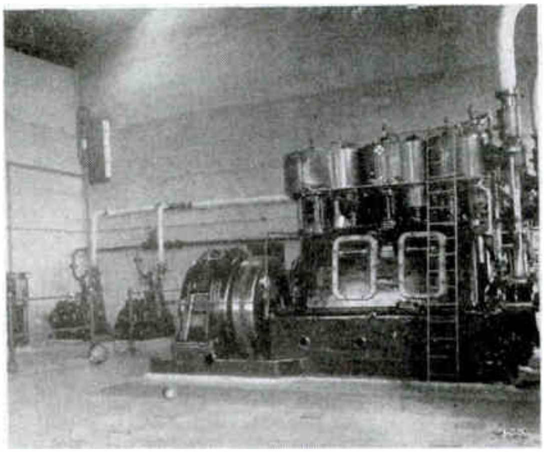
1. (1) Possibility of later augmenting the steam power by available water power.
2. (2) Saving of difficult transportation and the facilities offered by the Ngakawau site for economical handling and erection.
3. (3) Proximity to tipple, facilitating the use of screenings from the coal for power plant fuel.
4. (4) Best location for supervision.

Power House

The power-house is of ferro-concrete construction and is fireproof throughout; it is 174 ft. long by 50 ft. wide, and is divided into three compartments, engine room, condenser room, and boiler room.

There are two main generating units, each consisting of a 300 kw., 6600 volt, 60 cycle, three-phase generator direct connected to and resting on a common bedplate with a 475 b.h.p. Bellis & Morcom triple expansion engine, the set running at 400 revolutions per minute.

In addition there are two exciter sets, each made up of a 14 kw., 88 volt, 600 r.p.m. generator direct connected to and on a common bedplate with a Bellis & Morcom single expansion engine run condensing. For lighting about the plant and for operating a number of d.c. motors on the conveyors and jiggers in the main coal storage bins, a motor-generator set is installed in the power-house. This set consists of a 100 kw., 280 volt flat compound direct current generator direct connected to a 150 h.p., 6300 volt, form K, three-phase motor, the set running at 705 r.p.m.



Generator Units in Power Station

The main switchboard comprises eight panels of blue Vermont marble and three blank panels to provide for future extensions. From left to right the switchboard is made up as follows:

Feeder panel for generator of motor-generator set.
Generator panel of motor-generator set.
Starting panel for motor of motor-generator set.
Two blank panels.
Two main generator panels.
Main high tension feeder panel.
Blank panel.
Two exciter panels.

The direct current voltmeter for the motor-generator set is mounted on the extreme left panel, the synchronizing indicator and exciter voltmeter, together with voltage regulator, being mounted on the extreme right panel.

The engines exhaust into a Worthington surface condenser, which has a capacity of 30,000 lbs. of steam per hour with the circulating water at a temperature of 55 deg. F. A Worthington centrifugal pump draws circulating water from a well near the power house. The air pump, which is of the three-throw "Edwards'" type, is driven by an engine of 25 b.h.p. condensing. A Webster feed water heater which is capable of raising the temperature of 30,000 lbs. of water 30 deg. F. in one hour, is installed and uses the exhaust steam from the two boiler feed pumps and the engine driving the automatic stokers.

There are four Babcock & Willcox boilers, each with a heating surface of 1690 sq. ft. and a fire grate area of 34 sq. ft. and capable of evaporating 5000 lbs. of water per hour at

212 deg. F. The boilers are fitted with Babcock superheaters which superheat the steam 150 deg. F., and with automatic stokers of the Babcock chain grate type having four-speed feed gears and driven by a 15 b.h.p. single engine.

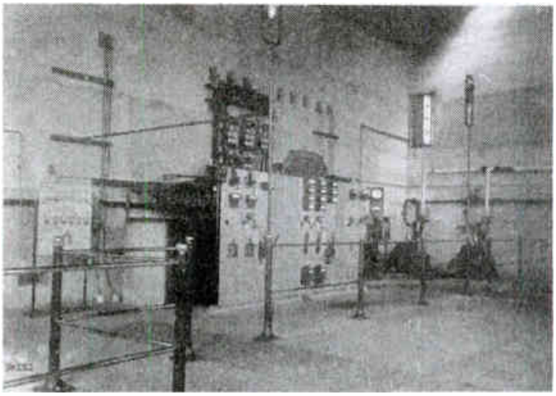
The boiler feed pumps, of which there are two, are of "Tangye's" manufacture and have each a capacity of 75,000 lbs. of water per hour against a pressure of 150 lbs. It will be noted that the condenser plant and the feed pumps are of sufficient capacity to take care of the ultimate engine and boiler capacity of the plant, which will be double that at present installed.

Hoists

Two small auxiliary panels are located near the main switchboard in the power house, one of which is employed for the control of a 40 kw., 6600/230 volt transformer. This transformer supplies current to a 52 b.h.p. motor connected to a Lidgerwood hoist located near the bins, the hoist being used for hauling the government railway coal trucks out of a dip onto an incline. From this incline the trucks are distributed by gravity to the various tracks under the bins for loading; after which they are run by gravity to the main siding and there made up for dispatch to Westport harbour. The second auxiliary panel is for the control of a 75 kw., 6600/230 volt transformer supplying current to a 112 b.h.p. motor connected to a second Lidgerwood hoist. This hoist has two drums with main and tail ropes and brake and friction clutch levers, and is used for hauling the loaded coal tubs from the foot of the lower incline through the Ngakawau tunnel to the bins, and for returning the empties; the method of haulage being main and tail rope. An auxiliary arrangement is also provided so that tubs, stores and miscellaneous material can be hauled up from the shops and stores to the tunnel mouth.

Haulage Way

Ngakawau tunnel. The Ngakawau tunnel is 28 chains long with an average gradient of 1 in 60 in favour of the load. The tunnel commences about 100 yards from the bins and runs through to the foot of No. 1 incline, a single track of 40 lb. per yard rails being laid, with sidings at each end. The method of haulage, as previously mentioned, is by main and tail rope, and the tubs can be run in sets of 25 at the rate of four round trips, or 100 tubs per hour.

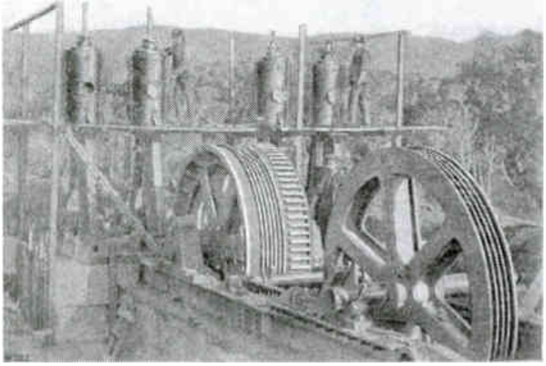


Switchboard in Power Station

Gravity Inclines

The lower incline is 33 chains in length and has an average gradient of 1 in 4 and a maximum gradient of 1 in 3. At the top of this incline is located a flat where the mine tubs are changed from the upper incline rope to that of the lower incline. The upper incline is 40 chains in length with an average gradient of 1 in 6.7 and a maximum gradient of 1 in 5. These inclines have been most carefully graded; there are no dishes, and changes of gradient have been effected by long vertical curves. Towards the bottom of the upper incline there is a sandstone tunnel seven chains in length, but on the lower incline there are no tunnels. Heavy cuttings and fillings have had to be constructed on both inclines; filling having been resorted to wherever practicable in preference to bridging, with a view to keeping down cost of maintenance.

A double track of 40 lb. rails is laid on each of these inclines and the cars are operated by gravity, the endless rope system of haulage being used. The tubs are spaced on both the full and empty sides at intervals of 1½ chains, the greater weight on the loaded side causing the motion. The speed of the rope is regulated by powerful four-cylinder hydraulic brakes of the vertical type, which were built by Messrs. Simpson Brothers, of Sidney, Australia. The braking is effected by churning the water from end to end of the cylinders through by-pass valves, a small quantity of water being admitted and a small quantity expelled at each stroke to keep the water cool. These brakes act admirably, imparting a steady motion to the ropes and giving good speed regulation.



Hydraulic Brakes for Gravity Incline

Vertical grooved pulleys 10 ft. in diameter are employed in place of surging drums to eliminate side friction between the coils of rope. The braking pulley has five grooves turned to fit the ropes, and the idler pulley four grooves. The incline ropes are of Shaw's manufacture and are made of the best patent plough steel wire, the lower incline rope being 1½ in. in circumference and the upper incline rope 4 in.

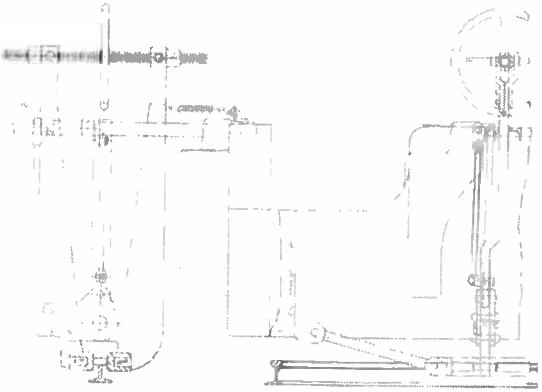
The mine tubs are built of mild steel with wooden buffers and 12 in. diameter cast steel fast wheels of Hadfield's make set for 3 ft. gauge. The tubs weight 12 cwt. empty and have a carrying capacity of 30 cwt., and when spaced every 1½ chains and travelling two miles per hour, have a capacity about 160 tons per hour. With the tubs spaced every chain and travelling at the same speed, their capacity is increased to 240 tons per hour. The rope runs under the tubs and is attached to each by means of chain clips. The tub drawbar is provided with a hook, and the clip chain, which is made with a large link at each end, is wound three times round the rope, one end being then passed through the other and hung onto the tub hook. The lower incline clips are made of ⅞ in. diameter Staffordshire short link chain and the upper incline clips of similar chain ¾ in. diameter. These clips hold well on the steep gradients, and so far not the slightest trouble with them nor with the hydraulic brakes has been experienced. It is surprising with what facility boys can handle these clips. Before employing the chain clip, a patent screw clip was tried, in which the rope was held in a sort of vise; but it was found that with this clip the personal factor came too much into play, and one clip insufficiently screwed up might be responsible for a serious wreck. An accident of this kind actually happened on one occasion when a loaded tub got away on the lower incline on the 1 in 3 grade and cleared the rope of all tubs below it, piling up and wrecking about 14 tubs.

Electric Haulage System

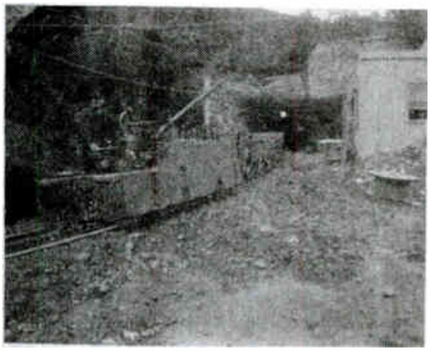
At the head of the upper incline, which is termed the brakehead, the trucks run onto a level plat where the main electric locomotives begin their run. These locomotives deliver the loaded tubs from the mine to the head of the upper incline and pull back the empties. At present the Company has three of these main locomotives (an additional one being on order) and two gathering locomotives. The main locomotives weigh 20 tons each and are equipped with Sprague General Electric Type M control to permit them to be worked as separate units or coupled in tandem as required. Each locomotive has a drawbar pull of 7500 lbs. and a speed of 8.2 miles per hour. The length of the tramway from the brakehead to the mouth of "A" tunnel is 2½ miles, and from the latter point the track runs for half a mile in the mine through a coal tunnel 8 ft. high and 7 ft. wide to the layby, where the loads are at present picked up.

Braking Problem

The vertical rise in this 2¼ miles of track is 710 feet, giving a gradient of 1 in 20.5. There are several curves on the track and the minimum radius is two chains. Up to the present time the locomotives have been used singly, no difficulty having been experienced in hauling the empty tubs up to the mine. The train is made up of twenty empties weighing 12 cwt. (112 lbs. per cwt.) each, and a braking car weighing two tons; making a total train load on the up grade of 14 tons. Braking the loads down has proved a much more difficult problem. In the first place the center rail for the Fell brake was laid only on the steeper gradients and the tubs were all fitted with wheel brakes independently operated. These brakes were set before the train started from the mine and it was impossible to manipulate them for the first half mile of the run as there was insufficient room in the tunnels for a man to get from tub to tub; and even outside it was not practicable to work the brakes in this way owing to the small clearance between line and trolley poles which made it dangerous for the brakeman to pass over the tubs.



Fell Center Rail Brake



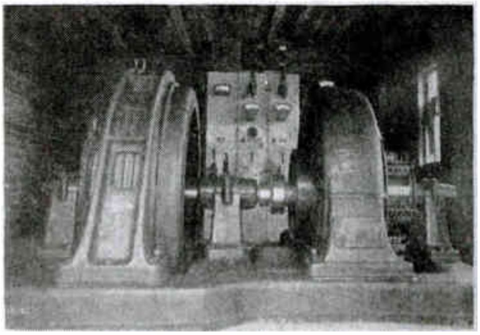
Train of Cars Leaving Tunnel

The result was that the brakes were often set so tight as to skid the wheels, or else so light that there was very little braking effected. It was early discovered that the locomotive wheel brakes in conjunction with the tub brakes could not be relied upon for braking the train, even on the flattest grades, and it was necessary to put in the center rail from end to end of the track. It was also found that accidents occurred at points where the center rail had to be picked up by the so-called Fell center rail grip brake, owing to the fact that the brake occasionally struck the end of the rail. After installing the center rail throughout the entire hauling distance, it was found that one Fell brake, although powerful enough to control the speed of the train with the assistance of the tub brakes and wheel brakes could not be depended upon to stand the heating and strain of continuous running.

The loaded tubs weigh 42 cwt. each and the weight of the train load is therefore 42 tons plus the 20 tons weight of the locomotive, or 62 tons. On the Rimutaka incline of the New Zealand Government railway, the train load allowed per Fell brake on a 1 in 14 grade is 20 tons. On one occasion, after the equipment had been in operation a few weeks, the Fell brake gear carried away on a downward trip, fortunately at such a point that the damage caused was not great and the driver escaped injury. Should such an accident occur near the top of any of the steep grades on the road under consideration, which, by the way, is the most likely place for an accident of the kind to occur, it would probably wreck the locomotive and train and kill the driver. It was therefore decided to add a braking car fitted with a second Fell brake, to be used in conjunction with the locomotive Fell brake and sufficiently powerful to brake the whole train load in case of emergency; the most improved braking car being fitted with two Fell brakes. This method has proved satisfactory and the tub brakes have been discarded on account of the difficulty of effectively manipulating them and the heavy cost of upkeep. On the up-trip to the mine with the empty tubs, the braking car is placed at the rear end of the train and is run with the Fell brake down ready for action should a coupling break. On the downward trip, however, better results are obtained by running the car at the front end of the train next to the locomotive, as in this position the brakeman is more in touch with the driver and can apply the brakes as required.


Gravity Incline

In making the down trip with the braking car at the rear end of the train, it was found that on approaching a brow the car brakes were sometimes applied too soon, thus throwing a severe strain on the couplings, or else not soon enough, throwing the whole weight on the locomotive. It is believed that it would not be advisable to run the locomotives in tandem, owing to the excessive amount of current that would be required in ascending steep grades on the up-trip and to the severe strain the buffers would be subjected to on the down-trip unless two braking cars were employed, one next to the locomotive as at present, and one at the rear end of the train.


Motor-Generator in Substation

The wear and tear on brake shoes is very heavy, the wheel brake shoes lasting for only eight hours and making about eight trips. It was found necessary to design the Fell brake shoes with removable wearing strips, mild steel proving most economical for the purpose and giving the best results. Cast iron was found to wear away very quickly and consequently required to be heavier and was considerably more costly. A set of mild steel wearing strips lasts about eight hours, as stated above.

The smaller gathering locomotives weigh 6½ tons each and have a drawbar pull of 2500 pounds and a speed of 7.4 miles per hour. These locomotives are used for the subsidiary haulage from the working places in the mine to the siding from which the main haulage starts. They are equipped with a reel which is mechanically worked from the locomotive axle and which is supplied with 900 feet of flexible twin cable, thus permitting the locomotive a considerable range of operation beyond the point of overhead construction.

Track

The track from the brakehead into the mine is 36 in. gauge and of extremely solid construction. The rails are 40 feet long and weigh 56 lbs. per yard; they are laid on 8 in. by 5 in. ties and are bonded at each joint with two number 00 bonds and cross bonded at every third rail. The distance from the brakehead, where the main locomotives deliver the loaded trains to be conveyed by gravity down the endless rope inclines and thence through the Ngakawau tunnel to the bins at No. 1 substation, is 35 chains, with a minimum curve of 132 ft. radius and the grades varying from 1 in 32 to 1 in 12, or an average of 1 in 25, all in favour of the load.

From No. 1 substation to No. 2 substation at the mouth of A tunnel is 145 chains, the grades all being in favor of the load and varying from 1 in 12 to level, the average being 1 in 21. The minimum radius of curves is 132 ft. From No. 2 substation to No. 3 substation, through A and B tunnels, is 79 chains, the A tunnel being 15 chains long and the B tunnel 64 chains long. The distance to the layby, where the coal is at present lifted, is 40 chains, the track being straight and the minimum grade 1 in 12.

Overhead Construction

The trolley wire is 7 ft. 8 in. above the level of the head of the rails, and is of No. 0000 throughout. In parallel with the trolley for the whole run is a bare stranded cable of 600,000 c.m., the latter being tied to the former at an average of every 150 feet.

Sub-Stations

Three sub-stations, which are identical with regard to electrical equipment, feed the overhead trolley network. In each substation is a motor-generator consisting of a 200 kw., 280 volt flat compound direct current generator direct connected to and on a common bedplate with a 300 b.h.p., 6300 volt, form K three-phase motor, the set having three bearings. The switchboard consists of three panels of blue Vermont marble, and from left to right are as follows:

Starting panel for motor with automatic oil switch.

Direct current generator panel.

Direct current feeder panel with voltmeter on swinging bracket.

Transmission Line

The three substations operate in parallel and are supplied with three-phase current at 6600 volts, the transmission wires being No. 0 hard drawn bare copper throughout and the total length of the transmission line six miles. A lightning arrester ground wire consisting of five No. 16 stranded galvanized wires is strung along the high tension line and stapled to the top of each pole. The distance between poles averages 150 feet and the lightning arrester wire is effectively grounded at approximately every fourth pole.

There are nine transpositions in the transmission line.

Telephones

Telephone lines connect the three substations, power house, offices, mine, etc., and are run on the transmission line poles from the power house to the brakehead; thence following the overhead construction to the end of the tramway. Each locomotive carries a portable telephone by means of which communication can at once be established with any of the points on the telephone network.

Mine Working

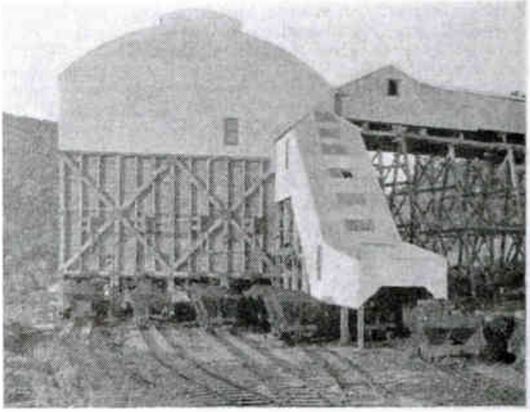
The mine is worked on the bord and pillar system, with six yard bords and 16 yard pillars. The coal is from 8 to 20 feet in thickness and lies in positions varying from horizontal to a slope of 1 in 8, the grades being all in favour of the haulage. The main drainage of the mine is also free, the haulage tunnel cutting the coal at its lowest point.

The present output is 500 tons and upwards per day of eight hours, half of this quantity being mined by hand and half by machinery. The machine mining is proving the more economical, however, and additional machines will shortly be installed. The Company is at present working two "Sullivan" bord and pillar chain machines with six foot cutting bars, each machine being driven by a 30 h.p. motor. These machines are the first of their class to be used in New Zealand and are giving excellent results.

The machines are cutting from three to four 6 yard bords per shift, each bord producing on an average about 30 tons of coal. The undercut is made in the coal itself at the bottom of the seam.

Ventilation

The mine is singularly free from explosive gases and the workings are so arranged that the ventilation is a simple proposition. The main workings are at present in the "B" tunnel, which is ¾ of a mile in length and runs out to daylight at each end. An electrically driven Waddel fan is situated at the top of a shaft in the center of the tunnel and draws air through the workings from both ends of the tunnel. At 290 r.p.m., the fan has a capacity of 80,000 cubic feet per minute at 1 ½ in. water gauge and requires 30 b.h.p. to operate. It is belt driven from a 40 h.p., 500 volt, three-phase motor, the three single-phase transformers for which are situated in No. 3 substation. The object in using 500 volt, three-phase motors for driving the fans in preference to operating them from the 250 volt direct current trolley is that this service will be continuous irrespective of any possible interruptions to the trolley overhead network. In addition to this fan there are six "Sturtevant" blowers direct connected to 3 h.p., 250 volt, direct current motors; these units being located at various points in the workings and used for ventilating the headings through 12 in. pipes which are run into the working places in place of brattice. These blowers are found very convenient and can easily be moved from place to place as required.



Tipple and Storage Bins, Showing Hydraulically Operated Doors

Quality of Coal

The coal is a good bituminous variety with a high calorific value and low percentage of ash, swelling on heating and giving a fairly hard coke. On the opposite page an analysis of coal taken from "B," "C," and "D" tunnels is given, which was made by the government analyst:

From an inspection of these figures it will immediately be noted that the ash percentage is unusually low. It should, however, be taken into consideration that the coastal range from which this coal is obtained has other coals which are also very low in ash, though test figures have hardly been comparable with the analysis given here.

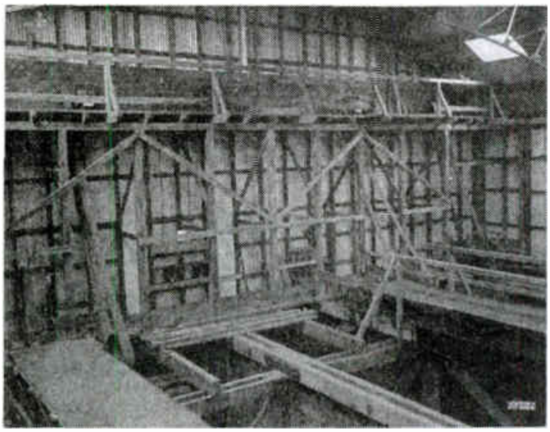
Tipple and Storage Bin

The main bin into which the coal is delivered at Ngakawau has a capacity of 5000 tons and is divided into three compartments, two of 2000 tons each for the storage of unscreened coal and one of 1000 tons for the storage of slack. The loaded tubs run into the bins by gravity and are thrown into any one of the three tipples desired, whence their contents are discharged onto the distributing jiggers or into bins as the case may be. The slack from the screens is elevated and conveyed by a scraper conveyer to the slack bin. Through tipples are employed, the loaded tubs displacing the empties which automatically gravitate to the empty siding to be made up into a train for the trip back to the mine. The main bin is composed entirely of ironbark built on pile foundations and has five loading roads under it, from which the coal is loaded into the eight ton capacity government cars and conveyed to Westport. The loading doors work in a horizontal plane and are opened and closed by hydraulic rams which operate at a pressure of 120 lbs. per square inch. Pressure is obtained from an accumulator operating from a 500 foot head of water derived from a small stream near the top of the lower incline, the object of the accumulator being to maintain a constant pressure when the doors are operated. The scraper conveyer for elevating the slack from the screens, and the picking band for loading the screened coal, are both operated by one 15 h.p. direct current motor. The two unscreened conveyer belts are each operated by a 10 h.p. motor and the distributing and screening jiggers by 5 h.p. motors. The bins are lighted by two arc lamps and in addition by a number of incandescent lamps where required.

Mark	"B" per cent.	"C" per cent.	"D" per cent.
Fixed carbon .	61.75	61.85	66.80
Volatile hydrocarbons	36.80	36.45	31.85
Water	1.25	0.95	1.05
Ash	0.20	0.75	0.30
	100.00	100.00	100.00
Coke (from closed retort)	61.8	61.90	67.10
Calories per gram	8182	8183	8139
British thermal units per lb. . . .	14718	14698	14650
Evaporative power per lb. . .	15.24	15.3	15.22
Practical evaporative power per lb. (calculated on 60 per cent. efficiency) .	9.19	9.18	9.13

Labour Conditions

The supply of all classes of labour necessary for working the mine is fairly plentiful at the present time. Wages are regulated by the Arbitration Court, and New Zealand has practically been without a strike since the introduction of the "Arbitration and Conciliation Act," although recently there has been some signs of dissatisfaction on the part of the workers.



Distributing Belts

Cost of Production

A royalty of twelve cents per ton to be paid to the State, and the compulsory payment to the "Government Compensation for Accident Fund" of one cent per ton, are factors which must be considered in addition to the actual cost of production.

Markets

Up to the present there has been a full and ever increasing market within the Dominion for the West Coast coal, this section being the only part of the Dominion in which good bituminous coal has been found. For the past ten years, the local consumption has increased at the rate of 100,000 tons per annum. Ten years ago the consumption was, roughly speaking, one million tons, while at the present time it is two millions, rather more than half of which is supplied from the West Coast coal fields. The balance, with the exception of about 200,000 tons imported from New South Wales, is supplied from the Lignite & Brown coal seams which are found in various parts of the colony. Up to the present time, owing to the full home market, the foreign coal trade has not been exploited, but with the extension of coal mining on the West Coast, it may become necessary to look for an uversea trade. The foreign markets commanded through Westport are:

Entering the Tipple

West Coast of South America. This, perhaps, is the most important customer in the Pacific, and a glance at the chart shows that Westport is 1200 miles nearer than Australia. Australia exports about 300,000 tons per annum to South America, and in addition, shipments are frequently made from English ports and latterly from Durban.

Manila, Java, Sumatra, or in other words the East Indies, are perhaps the next in importance. There is a strong demand for good steam and gas coal there. The Indian coal does not by any means satisfy the requirements and from three to four hundred thousand tons are sent annually from Australia.

Mexico, California and the Hawaiian Islands are also, geographically speaking, close to New Zealand, and the West Coast bituminous coal must command an extensive market there.

Harbour

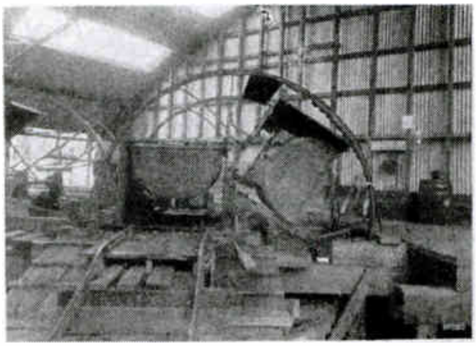
The Westport harbour is the most prosperous bar harbour in the Dominion, about half a million sterling having already been expended in improving the harbour and deepening the water on the bar.

The port may be safely worked by vessels drawing about 18 feet of water.

The expenditure of a new loan of £200,000 is expected to increase the depth of water on the bar and in the fairway to such an extent that ocean going tramp steamers of from 5 to 6 thousand tons will be able to fully load. This will encourage and render possible a much larger foreign trade than can be coped with at the present time.

Electrical Equipment

The entire electrical equipment for this enterprise was furnished by the Australian General Electric Company, and manufactured partly by the General Electric Company, Schenectady, U. S. A., and partly by the British Thomson Houston Company, Rugby, England.



The Tipple

The writer is indebted to the Company's engineer for assistance in securing the photographs and data for this article.

COMMERCIAL ELECTRICAL TESTING

PART VI

By E. F. Collins

Technical Superintendent, General Electric Company

ROTARY CONVERTERS

Preliminary Tests

The cold resistance of the armature of a rotary converter is measured between the collector rings, as follows:

For a three-phase machine, between rings 1–2, 1–3, 2–3

For a two-phase machine, between rings 1–3, 2–4

For a six-phase machine, between rings 1–4, 2–5, 3–6

The resistance of the various phases should be the same and it is immaterial whether the rings are numbered from the inside or from the outside for this measurement.

Running light on a rotary is taken with the machine running from the direct current end. With the brushes set on the neutral point, the direct current voltage is held constant and the shunt field varied until the rated speed of the machine is obtained. The input to both field and armature is then read. Since there is very little armature reaction in a rotary converter, the brushes are set on the neutral point before the machine is started. It often happens, however, that better commutation can be secured by shifting the brushes away from the neutral point very slightly. In case of unsatisfactory commutation, the brushes should be shifted in each direction, since some machines require a forward and some a backward shift from the mechanical neutral.

The determination of the ratio of the alternating current to the direct current voltage is one of the important tests on a rotary, and care should be taken to secure accurate results. The converter may be driven from either the alternating or the direct current end and, in order to check the accuracy of the instruments, two alternating current voltmeters, two potential transformers, and two direct current voltmeters should always be used. During the test the direct current voltage is held constant and the alternating current voltage read between rings 1 and 3 on a two-phase, and 1 and 4 on a six-phase machine.

The ratio is taken at no load and at full load, and should be as follows when the machine is running from the alternating current end:

RATIO A.C. TO D.C. VOLTAGE

	No Load	Full Load
Single phase	71.5	73
Two phase (measured on diameter)	71.5	73
Three phase	61	62.5
Six phase (measured on diameter)	71.5	73
Six phase (measured on adjacent rings)	35.8	36.5
Six phase (measured on alternate rings)	61	62.5

The amount of pole face arc will change the ratio.

An easy and approximately correct method of telling whether a rotary is running with the proper shunt field excitation, is to note the ratio of the alternating current to the direct current, which should be as follows:

Three-phase alternating current and direct current practically the same.

Two-phase alternating current equal to three-quarters of the direct current.

Six-phase alternating current equal to one-half the direct current.

Equalizer Taps

As soon as a rotary is assembled and before any running tests have been started, the spacing of the equalizer taps and the taps to the collector rings must be carefully checked. Occasionally a wrong connection is made and, if it is not corrected before the running tests are started, one or more equalizer leads may become badly overheated or be burned off.

Constant Ratio

The standard shunt wound rotary converter has a very nearly constant ratio of alternating to direct current voltage, so that any fluctuation in the voltage of the alternating current supply will show directly on the direct current voltage delivered. Such machines are unsatisfactory when much variation in load occurs. When the direct current volts have to be varied on a standard machine, the impressed alternating current volts must be altered. This is generally done by using transformers provided with dial switches, by means of which the transformer ratio is changed.

If a series field winding is added to the standard machine, a practically constant voltage can be obtained with sudden changes in load by introducing reactance into the circuit, or in some cases by using the inductance and resistance inherent in the feeder circuit. This is possible, for the reason that an alternating current passing over an inductive circuit will decrease in potential if lagging, and increase in potential if leading.

A rotary converter running as a synchronous motor requires a certain definite field excitation to effect the minimum input current to the armature. Varying the excitation either way changes the input current, so that by using sufficient reactance in the alternating current circuit from which the converter receives its power, the alternating current voltage at the converter terminals may be increased or decreased by increasing or decreasing the field current. By adjusting the shunt excitation of the compound wound machine to give a no load lagging current of about 25 per cent. full load current, and the series field to give a slightly leading current at full load, the impressed voltage at no load will be automatically lowered and that at full load increased. Hence a practically constant direct current voltage will be delivered at all loads.

Variable Ratio Machines

The split pole rotary differs from the ordinary rotary in that the poles consist of two separate and independent parts, each provided with its own field coil. The auxiliary pole may be placed on either the leading or the trailing side of the main field, depending upon the conditions under which the machine is to operate. If it is to operate as a straight rotary, the auxiliary pole is to be placed on the trailing side; while if the machine is to float on the line to take fluctuations of load through a storage battery, and hence run inverted part of the time, the auxiliary pole should be on the leading side. The reason for this is as follows: The auxiliary pole influences commutation when on the leading side, as well as regulates the direct current voltage, and will be of correct polarity for commutation if the machine inverts at a direct current voltage corresponding to no excitation of the auxiliary poles.

In wiring a split pole rotary for test, the transformers used must be exactly alike. The best results are obtained by using transformers with two secondaries excited by one primary. Care should be taken to see that the cables from the transformers to the rings do not differ in length or cross section, and that all switches in these circuits have their contact surfaces well cleaned with sandpaper. These precautions are necessary to prevent any unbalancing of the current in the alternating current circuits outside of the armature.

The testing instructions should specify the manner in which the transformers are to be connected, both primary and secondary; the alternating current volts to be held across corresponding rings; and the range through which the direct current volts are to be varied by means of the auxiliary field. The following no load readings should be taken:

Current per phase. (Must be balanced.)

No load phase characteristic.

Ratio of voltage.

Volts between adjacent collector rings with main field only.

A set of readings of alternating current amperes while varying the direct current volts by means of the auxiliary field through the total voltage range, the main field being held at minimum input value, the alternating current volts constant, and the brushes shifted to give the best commutation over the whole range.

A set of readings while varying the direct current volts through the total range by means of the auxiliary field, the main field being adjusted to give minimum input for each change in direct current voltage.

A full load ratio and the current per phase for minimum input, using main field only.

Phase Characteristics

Three full load phase characteristics should be taken as follows:

1st. Holding the alternating current volts constant and using the main field only.

2nd. At the lowest limit of the direct current volts: holding the alternating current and direct current volts constant and adjusting the direct current line current to that value which gives the rated output for the mid voltage with zero auxiliary field.

3rd. At the highest limit of the direct current volts: holding the alternating current and direct current volts constant and adjusting the direct current line current to that value necessary to give the rated output for the mid voltage with zero auxiliary field.

Core Loss

Three core loss tests are required to cover the various conditions of operation. These are made as follows:

1st. Core loss while varying the direct current volts by means of the main field only, with auxiliary field not excited.

2nd. Core loss while holding the excitation of the main field constant at that value which gives mid direct current voltage, and varying the auxiliary field to change the direct current voltage.

3rd. Core loss while holding the alternating current volts constant and varying the main field each time the auxiliary field is changed to change the direct current volts throughout the range. This gives unity power factor.

All other tests are made as on standard rotaries.

Inverted Rotaries

The speed of a rotary when running from the alternating current side is determined by the line frequency. The same machine running as an inverted rotary and delivering alternating current operates as a direct current motor. Its speed depends upon the field excitation and load, and it will deliver a variable frequency, particularly if compound wound. When run inverted, a compound wound machine should have its series field almost, if not entirely, short circuited when part of its load is inductive, since a lagging current will weaken the field and increase the speed, sometimes causing a runaway. For this reason care must always be taken when running a rotary inverted to see that sufficient shunt field excitation has been obtained to prevent excessive speed, particularly when another machine is operating as a rotary from the inverted machine.

Motor-Converter

A motor-converter consists of a standard rotary converter and an induction motor. The induction motor has a wound rotor with taps brought out to a set of common rings, which take the place of the collector rings for both motor and converter. The voltage of the induction motor rotor is the alternating current voltage of the converter. The advantage of the motor converter is that high tension currents (up to 13000 volts) may be applied to the stator of the induction motor, the rotor delivering low voltage to the converter. Hence the intervening bank of transformers, always necessary with a rotary, is not required. No reduction of power factor is caused by the induction motor, since unity power factor may be maintained with the motor-converter by the proper adjustment of the field of the rotary.

Starting Tests from the Alternating Current End

The rotary should be wired to an alternating current generator of sufficient capacity to start it without overloading. If transformers are needed in order to get the correct voltage, they should be placed between the dynamometer board and the generator.

A rotary, when starting from the alternating current end, is similar in action to a transformer. The armature corresponds to the primary, and the field, which has a large number of terms, to the secondary. Hence the induced volts on the field may be very high, often 3000 or 4000 volts. In all cases, therefore, the field connection must be broken in two or more places to keep this voltage within safe limits. A potential transformer and voltmeter should be connected across one or two spools in series for reading the induced volts field, and a record made as to the number of poles included in the reading.

Starting tests should be made from several different positions of the armature with respect to the field. A scale, corresponding in length to the distance between collector ring taps, should be laid off on the armature and divided into five equal parts. A point of reference is then marked on the field, opposite to which the marked positions of the armature are placed for the successive starts.

Having brought point No. 1 opposite the reference point, the alternating current switches should be closed and the field on the alternator increased until about one-half normal full load current is sent through the rotary, reading volts and amperes in the various phases. As it is impracticable to read all phases at once during the start, the ammeter should be cut into that phase which shows the highest current and the voltmeter across the phase which indicates the highest voltage, in order to get the maximum readings at the instant of starting. The field of the generator should be increased until the armature begins to revolve, when volts and amperes input and induced volts on the field should be read. The voltage across the collector rings should then be held constant until the rotary reaches synchronism, the time required to reach this point from the start being noted.

There are several methods of determining whether the rotary is in synchronism; one, by the fact that the induced volts field will fall to zero; another, that the voltmeter across the armature will read a definite voltage, which will vary from a negative to a positive reading if the rotary is below synchronism. Readings of volts and amperes should be taken on all phases after the rotary has reached synchronism. The machine should then be shut down, the armature brought to position No. 2, and the test repeated. In this manner all five points should be tested. After these tests have been made, the time required to bring the rotary to synchronism should be taken by throwing one-half voltage across the collector rings.

Starting Tests from Direct Current End

When starting from the direct current end, the rotary must be wired to a direct current generator of ample capacity. The rotary should be separately excited with a field current corresponding in value to that for no load at minimum input (unless full field is specified), and the voltage across the armature brought up gradually by increasing the field on the driving generator, until the armature begins to revolve. The voltage should then be steadily increased at that rate which will bring the rotary to normal speed in approximately one minute. This rate can be found by trial, and when once found, the test should be repeated once or twice to make certain that the results are correct.

Phase Characteristics

No Load. If the phase characteristic tests follow a heat run in which an IRT regulator has been used, it must be disconnected. The most satisfactory combination is to run two converters for this test, the one under test running as a rotary and driven by the other running inverted with a direct current loss supply. The speed and the direct current voltage are held constant by varying, respectively, the field of the inverted machine and the voltage of the loss supply. It must be remembered that a lagging current will increase the speed of the inverted rotary, and therefore the inverted machine should be watched constantly so long as the current lags.

With the field excitation of the rotary reduced to the lowest limit permitted by the inverted machine, the alternating current amperes and volts line and the direct current amperes and volts field should be read. As stated above, the speed and the direct current volts are held constant throughout the test. The field current of the rotary is increased by small increments and readings taken as above. The alternating current amperes input will decrease rapidly until the minimum input point is reached, when they will increase again. The field excitation should then be increased until the input current has a value of at least half the full load current of the machine.

Full Load. The full load characteristic is taken in exactly the same way as for no load. The direct current volts are held constant at normal rating and the amperes output constant at full load value. The field excitation is varied through nearly as possible the same range as for no load characteristic. The readings taken are, for the alternating current side, volts and amperes; and for the direct current side, volts armature (held constant), amperes output (held constant), volts field, and amperes field. The speed is held constant.

Compounding Test with Reactance

When a rotary is required to automatically deliver a constant direct current voltage under a load subject to sudden changes, a compound wound machine is used with a definite reactance inserted between the rotary and the line. Such reactances must be tested with the machines for which they are designed. A constant voltage is possible, since an alternating current passing through a reactance will increase the potential if leading, and decrease it if lagging. By adjusting the shunt field so that about 20 per cent. lagging current flows at no load, the strength of the series field can be adjusted to give a slightly leading current at full load and thus maintain a constant direct current voltage. A compound converter operating with reactance in circuit must be compounded like a direct current generator. Unless otherwise specified, the voltage of the alternator driving the rotary should be held constant and the shunt field adjusted to give the correct no load voltage; when, without touching the field rheostats, full load should be applied and the direct current volts read. If the machine over-compounds, the series field is too strong and gives too large a leading current, in which case a shunt must be adjusted across the terminals of the series winding to shunt a portion of the current. In this compounding test all readings are taken and all adjustments made without touching the field rheostat after the no load adjustment is effected, as in the case of a direct current generator.

Pulsation Bridges

Since the torque of a rotary only needs to be great enough to overcome the mechanical losses, the machine is very sensitive to changes in line conditions; *i.e.*, excessive line drop or speed changes of the driving unit. In many cases the line drop alone will start a rotary pulsating, and once started the pulsating generally increases rapidly until the rotary falls out of step or flashes over. To prevent pulsation, copper or brass bridges, which act as short circuited secondaries and prevent sudden changes of the input armature current, are placed between the poles. Rotaries of new design are tested for pulsation by inserting a definite resistance in each phase between the machine itself and the driving alternator. The drop through this resistance corresponds to the line drop which will probably occur in practice. Usually 15 per cent. drop is assumed and the resistance per phase necessary to produce this is determined from the formula $\frac{(\text{A.C. voltage})^2}{\text{Kw.} \times 1000} \times$ per cent. drop = resistance. If two rotaries are tested together each machine should have 15 per cent. drop between it and the driving alternator, or 30 per cent. between the two rotaries, as shown in Fig. 29.

With the two machines running in synchronism, self-excited, and with the fields adjusted to give minimum input, observe the direct current voltmeters on the two machines. Any slight pulsation will be shown by these instruments at once. The direct current volts should be held constant on one machine throughout the test. Now, with the field current on one machine held at minimum input value, the field current on the other machine should be reduced to about one-half minimum input value. If no pulsation is noted, a full set of readings should be taken on both machines, reducing the field current of the other machine to one-half minimum input value and watching for pulsation on both machines, which now take a heavy lagging current. A full set of readings under these conditions should be taken. The field of the first machine is again adjusted to the minimum input value, readings are taken, and pulsations watched for. With this field held at minimum input, the field of the other machine should be changed from its value of one-half minimum input to twice the minimum input value, readings and observations being made as before. The other field should then be brought up to twice normal value, readings taken, and the effect of the heavy leading current in each machine noted. Leaving one field over-excited, the other field should be weakened to give minimum input, and a full set of readings taken. If no pulsation develops with the high line drop under these extreme conditions, the machines are satisfactory.

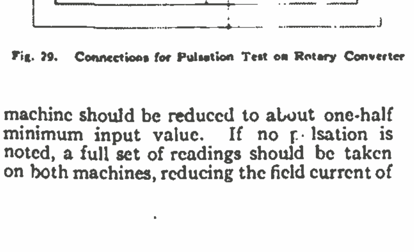


Fig. 29. Connections for Pulsation Test on Rotary Converter

Input-Output Efficiency Test

Input-output tests on small machines (300 kw. or less) are made with the machine running as a rotary, dead loaded on a water-rheostat. Larger machines are tested in pairs, one machine pumping back on the other with an electrical loss supply. The machines are wired in a manner exactly similar to that used in a pump back heat run (circulating power heat test), special attention being given to the wiring to see that no unbalancing occurs on either the alternating current or the direct current circuits. With the machine running as a rotary, wattmeters are connected in the alternating current end, between the rotary and the transformers, and preparatoins made for reading direct current armature and field amperes and volts. If current transformers are used with the wattmeters, duplicate transformers must be used in the other phases of the machine to prevent unbalancing caused by the resistance and inductance of the transformers. With the machine running in synchronism at rated speed and zero load, and all meters connected, the alternating current volts impressed on the rotary should be held constant and careful readings taken of all instruments. The currents and volts in each phase should be read as a check on the wiring and balancing of all phases. All instruments should also be carefully checked for stray fields and any instruments affected by these must be protected by iron shields, or their location changed. With full load, the test for stray field should be repeated, since any instrument affected will give misleading and erroneous results. With the no load minimum input field current held constant, the alternating current input, as shown by the wattmeters, should be carefully read as a check on the no load losses.

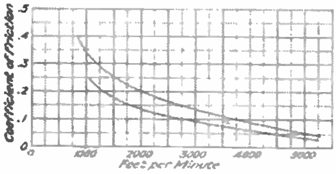


Fig. 30. Coefficient of Friction of A.C. Brushes

As efficiency is usually guaranteed at ¼, ½, ¾, 1 and 1½ full load, careful readings must be taken at these loads. Each time the load is changed, the rotary field excitation must be changed to the minimum input value for that load, which is shown when the sum of the wattmeter readings is exactly equal to the kv-a. input. To obtain this condition for each load, several trials and considerable time is usually required, so that an efficiency test made in this way is more expensive than one made by the separate loss method. The likelihood of error is also greater. This method, therefore, is not satisfactory for rotary efficiencies at other than full load.

The method employed to calculate the efficiency of a standard rotary converter is similar to that used for direct current generators, except for the additional C^2R and friction losses of the alternating current brushes. Because of the neutralizing action of the motor and generator currents it should be noted that only a certain percentage of the current as given by the instruments must be used for calculating the C^2R loss in the armature. This percentage varies for different machines as follows:

Single-phase	147%
Two-phase	39%
Three-phase	59%
Six-phase	27%

The calculation of the alternating current brush contact resistance requires a measurement of the alternating current flowing in the armature, which varies in different types of machines. The following are the constants by which the direct current should be multiplied to obtain the alternating current.

For Single-phase	1.00
Two-phase	.72
Three-phase.	.943
Six-phase	.472

As with the direct current brush resistance, a curve of the alternating current contact resistance must be referred to and no direct measurement of resistance attempted. In every case the contact resistance per ring should be calculated, the total loss being obtained by multiplying by the number of rings.

Brush contact area per ring = width of brush in inches × arc of contact in inches × the number of brushes.

The brush density per ring =

$$\frac{\text{Alternating current}}{\text{Brush contact area per ring}}$$

The resistance obtained from the curve corresponding to this value, divided by the

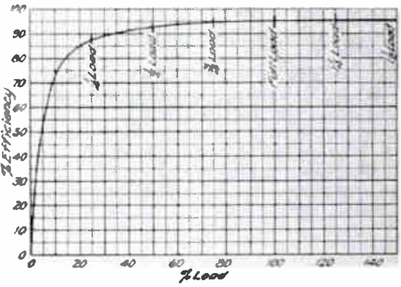


Fig. 31-a

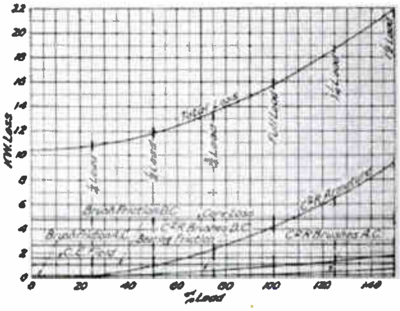


Fig. 31. Efficiency and Losses on a 750 Kw., 600 Volt, 750 R.P.M., 25 Cycle, 3-Phase Rotary Converter

TABLE XII

EFF. AND LOSSES OF A 300 KW., 600 V., 4-POLE, 25 CYCLE 3-PHASE ROTARY CONVERTER

% Load	0	25	50	75	100	125	150
Volts Line	600	600	600	600	600	600	600
Amps. Line	0	125	250	373	500	625	750
Amps. Shunt Field	2.65	2.65	2.65	2.65	2.65	2.65	2.65
Amps. Arm. D.C.	2.65	127.6	252.6	377.6	502.6	627.6	752.6
Amps. Arm. A.C.	—	122.5	242.5	362	482	602	722
Core Loss	4760	4760	4760	4760	4760	4760	4760
Brush Friction D.C.	1134	1134	1134	1134	1134	1134	1134
Bearing Friction	2654	2654	2564	2654	2654	2654	2654
C²R Armature (.585 × D.C. C²R)	0	207	1046	2340	4140	6450	9300
C²R Brushes D.C.	0	105	340	641	960	1280	1720
C²R Shunt Field	900	900	900	900	900	900	900
C²R Rheostat	690	690	690	690	690	690	690
C²R A.C. Brushes	—	17	73	161	286	446	575
C²R A.C. Brush Fric.	211	211	211	211	211	211	211
Total Losses	10349	10738	11808	13491	.15735	18525	21944
Kw. Output	—	75	150	225	300	375	450
Kw. Input	10.3	85.7	161.8	238.5	315.7	393.5	471.9
% Efficiency	0	87.4	92.7	94.3	95.0	95.3	95.4
Brush Density A.C.	—	10.45	19.9	29.8	39.6	49.5	59.3
Brush Density D.C.	—	8.5	16.9	25.2	33.6	44.5	48.2
Brush Contact Resis. A.C.	—	.00123	.00123	.00123	.00123	.00123	.00110
Brush Contact Resis. D.C.	—	.0062	.00534	.00451	.0038	.00326	.00304

Resistance of Armature D.C. End 25° C. .0243 Ohms, Warm .0280 Ohms at 65° C.

Resistance of Shunt Field 25° C. 111.3 Ohms, Warm 128. Ohms at 65° C.

Dimensions of Brushes { 1¼×1¼ arc (A.C.) / ¾×1¼ (D.C.) } No. of Studs 4 D.C./12 A.C. No. per Stud 8 D.C./1 A.C.

Brush Contact Area, One Side { 15 A"D.C. / 12.2 (A.C.) } Sq. In. Brush Pressure 2 Lbs. per Brush.

Coeff. of Friction = .2 D.C. Coeff. of Friction = .12 A.C.

brush area per ring, is the contact resistance per ring.

The alternating current brush friction should be calculated in the same manner as that for direct current measurements, the coefficient of friction being taken from a curve. (See Fig. 30.)

Table XII and Fig. 31 show the form used in calculating and plotting rotary converter efficiencies.

Normal Load Heat Runs

When loading a rotary converter on a water rheostat, see that all cables from the transformers to dynamometer boards and to the alternating current rings of the machine are of the same length and capacity, and that all contacts are cleaned and brightened before connection. Equal resistance per phase will thus be obtained and unbalancing in the alternating current circuits external to the armature prevented. In wiring the direct current circuit, the series field and its shunt are disconnected.

When wiring rotaries, as in the case of all other high current direct current machines, both sides of the circuit should be laid close together. No iron, such as a bearing pedestal or a section of the frame, must lie within the loop of the circuit, since it will become magnetized and materially affect the operation of the machine and instruments. Divide the shunt field into at least four sections by a "break up switch," which must always be open while starting from the alternating current end; since, due to transformer action and the relative number of turns of the field and armature, a high voltage is induced in the field at starting.

Always wire the positive ring of the rotary through a breaker to the blade of the water box, and the negative ring to the box itself. Connect enough boxes in multiple to limit the current per box to about 400 amperes maximum. Make provision for reading alternating current amperes and volts armature, direct current amperes and volts armature, amperes and volts field, and the speed of the alternator.

To start the machine, close the alternating current line switches and the field switch of the driving alternator, increasing the excitation of the alternator and keeping close watch on the current in the alternating current lines. If this current reaches 150 per cent.

normal before the rotary starts, check over the wiring. If the machine starts rotating in the wrong direction, reverse two of the leads on the primary side of the transformers. After starting, as soon as the alternating current drops to the minimum value (showing that the machine is in synchronism), and the alternating current volts become normal, close the field "break up switch." If, after closing the shunt field switch, the brushes begin to spark, the residual magnetism left in the poles by the induced voltage at starting is of the wrong polarity.

Two methods can be used to correct this; First, reverse the field with respect to the armature; or second, reverse the residual polarity by opening the alternator field circuit, and then closing this circuit and bringing the rotary back to synchronism, repeating the operation if necessary until the field builds up in the right direction. This second method is the more satisfactory since no change of wiring is required.

Before proceeding further, read the current in each phase to make sure that there is no unbalancing. These currents should not vary over 1 per cent. from the average; any greater variation due to wiring must be remedied at once. After balance is established, the no load and full load phase characteristics are taken.

These operations complete the preliminary tests and the full load heat run may now be made, care being taken to set the brushes for the best commutation. For the load run, hold full load direct current amperes and volts constant with minimum input field current. The load should be kept on at least one hour after all temperatures are constant. At the end of the run, temperatures must be taken on all parts of the machine and the resistance measured on the armature (alternating current end) and field. If the rotary is a six-phase machine, the armature resistance is measured between rings 1–4, 2–5, 3–6, counting outwards from the armature.

If an overload run is required, take a few points on the overload phase characteristic to determine the field current required for minimum input; then hold this current and the direct current volts and amperes constant, as on the normal load run.

After the heat runs, the tests should be finished by taking a phase rotation, hot drop on spools, direct current running light at normal voltage, and direct current starting tests.

(To be continued)

ELECTRICITY ON THE FARM

By John Liston

For the economical application of power to the various farm operations that are now to a very large extent carried on by mechanical means, electricity offers so many advantages for this particular service as compared with other sources of power that it stands pre-eminent. Its unqualified success on those farms where it has been adopted indicates that it has become a factor of such importance that it must now be seriously considered as affecting both the cost and quality of the products of the modern farm. If we compare electricity with other forms of applied power we find that its chief advantages are reliability, safety, cleanliness and flexibility in application.

Owing to the necessarily scattered location of the buildings on the average farm, the cost of power when applied by means of separate engines (except in isolated cases which can properly be considered as special) is practically prohibitive. At the same time, the use of such engines would add appreciably to the fire risk, which is a consideration of more vital importance in farming than in any other industry owing to the absolute dependence, as a rule, upon relatively limited local fire fighting facilities. When electricity is used for power and lighting the fire risk is reduced to a minimum.

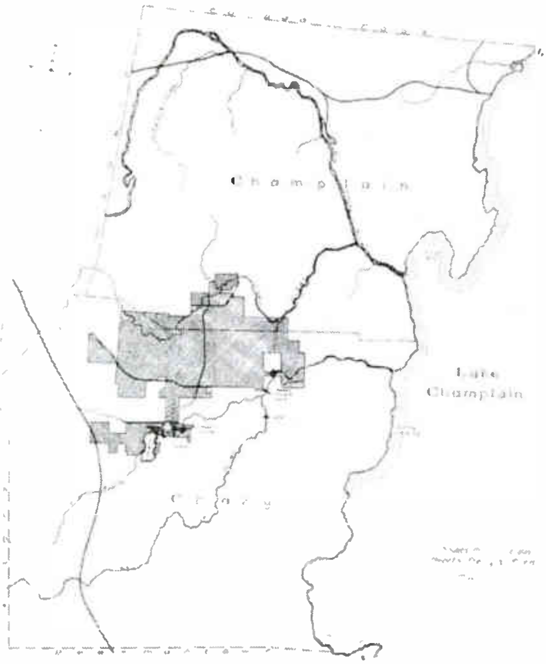
In the application of electric power the relative location of the buildings is immaterial, as motors can be installed in each building or group of buildings and the current transmitted by means of wires from a central generating plant, which may be erected either on the farm or at a distance from it.

When planning the electrification of a farm, it should be remembered that as the service required of motors for farm work is in nearly every case intermittent, the periods for operating the various units can be so arranged that at no time will all of the motors or even a large proportion of them be in operation simultaneously.

This condition will in most cases allow the installation to be so designed that a small generator can supply ample current for a relatively large number of motors, having an aggregate capacity greatly in excess of that of the generating plant. As a consequence the cost of generating current for a given capacity in motors for farm work is usually much lower than that involved in other industries.

The use of electric motors does not involve the necessity of employing skilled men to operate them, for, owing to the simplicity of the controlling devices, the average farm hand can start and stop them and control their speed without danger of injury to himself or the apparatus.

Local conditions must always affect the selection of a prime mover for the electric generators, and compact generating sets for utilizing steam, gas, gasoline or water power can now be readily procured. Where streams of sufficient head and volume exist in the vicinity of the farm, they may easily be converted into economical producers of electrical energy by the construction of dams and the installation of automatically governed water turbines. Many streams have in recent years been utilized in this way with entire success, both as to cost and service rendered, even on comparatively small farms.



Map Showing Location of Heart's Delight Farm and Streams from which it Derives its Hydraulic Power

As an interesting demonstration of the value of electricity on the farm, the following description will appeal to every practical farm manager.

At Chazy, N. Y., near the western shore of Lake Champlain and at a point about 15 miles north of the city of Plattsburg, there is located a modern stock and dairy farm which, in its operation, exemplifies the manifold advantages to be derived from the use of electricity for lighting and for the various power requirements of the farm.

This farm, which is owned by Mr. W. H. Miner and is called "Heart's Delight", is centrally located across the border line of Champlain and Chazy townships, in Clinton County, as shown in Fig. 1, and covers an area of 5160 acres. The nucleus of the present farm consisted of the old Miner homestead of 150 acres, which is now entirely surrounded by the land subsequently acquired.

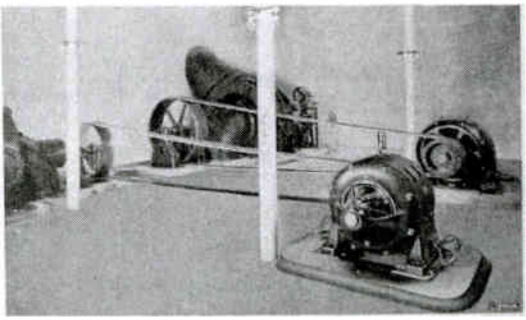
Of the total farm area, about 1200 acres are under cultivation, another 1200 acres are used for pasturage, and the remainder is woodland. The output consists of live stock and dairy products; all crops grown on the farm being fed to the stock and only finished products shipped out.

The live stock includes registered Percheron and Belgian horses and pure bred short horn Durham and Guernsey cattle, special attention being given to the raising of "Dorset" sheep for breeders and hot-house lambs, and hogs for breeders and the production of sausage, hams and bacon. There is a considerable number of poultry and squabs, and a well equipped fish hatchery is devoted to the propagation of trout. The quality of the materials shipped is indicated by the fact that practically the entire output of the farm goes directly to the Waldorf-Astoria and to other high-grade hotels and clubs in New York, Washington and Chicago.

View of Tracy Brook Power House and Beginning of Direct Current Transmission Line

About three years ago it was decided to provide the farm with electricity for light and power, and the results have been so uniformly satisfactory that the equipment has been increased from time to time, some novel applications having resulted owing to the energy and initiative of those charged with the management of the farm.

Sufficient water power was found on the farm itself to provide a cheap and reliable source of electric energy. Two streams pass through the southern portion of the farm, as shown in Fig. 1; the smaller one being known as Tracy Brook and the larger one as the Chazy river. It was found that these streams were both fed by numerous active springs which, together with the drainage area afforded by the Adirondack foot hills, insured a dependable flow of water that could readily be conserved by the construction of dams.



Interior View of Chazy River Power Station, Showing General Electric Alternating Current Generator Belts Connected to Water Turbines

Across Tracy Brook three small concrete dams were built, thereby forming three ponds and giving a total reservoir area of about 170 acres. A concrete penstock 44 in. inside diameter and 670 feet long carries the water from the reservoir to a power house compactly constructed of concrete, and so located as to obtain an effective head of 19 feet.

The power house equipment consists of two reaction water turbines, automatically governed and direct connected respectively to one 30 kw. and one 12½ kw., 220 volt direct current generator. The current is transmitted over a pole line 1½ miles long to a central station located in the main group of farm buildings.

About a mile below the power house Tracy Brook joins the Chazy river, and the tail race water from the Tracy brook station adds to the volume of water in the Chazy river reservoir, which is formed by a dam across the river a short distance below the point of confluence of the two streams.

The Chazy river is about 30 miles long and empties into Lake Champlain; it has a considerably greater volume than Tracy Brook, and it was found that by building dams ample storage water and an effective head of 30 ft. could be obtained.

It was therefore decided to construct two concrete dams and a second and larger power house to supplement the Tracy Brook station, to provide current for the rapidly extending electric power applications at the farm.

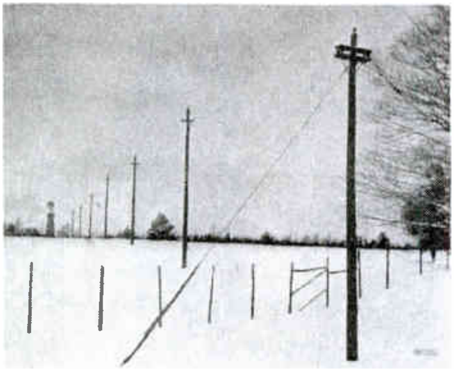
After passing through screens at the intake gate-house (which forms part of the lower dam), the water is carried to the Little Chazy power house through a concrete penstock 48 by 60 inches inside diameter and 630 ft. length. At the power house, it enters a concrete flume provided with controlling gates and is led directly to the water turbine wheels by short steel pipes.

There are two turbine belts connected respectively to one 50 kw. and one 100 kw., 2300 volt, 60 cycle, three-phase General Electric alternating current generators. The current is transmitted at the generator voltage over a single circuit pole line 2¾ miles long, to the power station at the farm.

In the hydro-electric development the work has been carefully and thoroughly done, so that the danger of interrupted service has been reduced to a minimum. The concrete penstocks are reinforced with steel bars, both horizontally and vertically, and are covered with earth embankments. The tail water from the Chazy river power house is carried by a canal to some distance below the station before being returned to the river, in order to secure the full benefit of the available head. The turbine governors are arranged for both hand and automatic control, and in addition, the governors at this station are also provided with emergency motor-operated mechanisms, controlled from the switchboard. Telephone wires are carried on the transmission pole lines, establishing communication between the power houses and the central station on the farm.

The transmission line poles are of cedar with fir cross-arms, and are fitted with pin insulators; they are from 35 to 40 feet high and are spaced at an average of about 120 feet. The conductors are bare copper wire, No. 00 B.&S. being used for the Tracy Brook line and No. 2 B.&S. for the Chazy river line.

An auxiliary of the hydraulic equipment consists of two hydraulic rams receiving head from the Tracy Brook reservoir and pumping water to a 60,000 gallon tank located 100 ft. above the ground on a steel tower erected at the farm for fire protection.



View of the Alternating Current Transmission Pole Line

As stated above, both the direct current Tracy Brook power house and the alternating current Chazy river power house feed into a power station at the farm, where the equipment includes a six-panel switchboard and two motor-generator sets of General Electric manufacture, and a storage battery.

Nearly all the motors used on the farm at present are direct current machines, operating on 110 and 220 volt circuits, and in order to supply the 110 volt motors and the lighting circuits, and to charge the storage battery, the current which is received from the Tracy Brook power house at 220 volts direct current is stepped down by means of a three-unit, 1100 r.p.m., direct current motor generator set, consisting of:

One 25 kw., 220 volt, direct current motor, compound wound

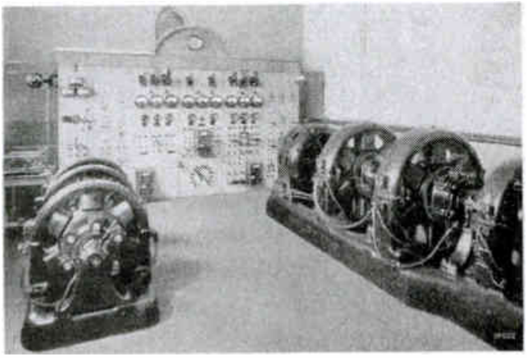
One 25 kw., 110 volt, direct current generator, compound wound

One 12 kw., 110-150 volt, direct current generator, shunt wound

The alternating current from the Chazy river power house is received at 2300 volts, three-phase, 60 cycles, and stepped down to 220 volts through three 40 kw. type H transformers. It is then converted to direct current by means of a four-unit, 900 r.p.m., motor generator set, consisting of:

One 100 h.p. synchronous motor

One 75 kw., 220 volt direct current generator, compound wound



Interior of Power Station at the Farm, Showing Switchboard and Motor Generator Sets

One 75 kw., 110 volt direct current generator, compound wound

One 12 kw., 110-150 volt generator, shunt wound

These two sets are interconnected by means of switches in order to insure continuity of service in the event of a shut down of either of the hydro-electric stations. If the incoming direct current supply is interrupted, the alternating current—direct current motor generator set can replace it. Vice versa, if the incoming alternating current supply fails, the 220 volt direct current unit of the alternating current—direct current set is operated as a motor, and the synchronous motor is then utilized as an alternating current generator.

On both of the motor generator sets the 12 kw. units are used for charging the storage battery, which consists of 52 main and 13 end cells, and has a capacity of 600 ampere hours. The battery is used as a balancer, and for lighting and power after 9:30 p.m., at which time the hydro-electric plants are shut down.

An interesting feature of the farm power station is an electrically operated instrument which is connected with a weather station located on one of the fire tank towers and automatically records on a cylindrical chart a continuous record of the speed and direction of the wind, the amount of moisture in the air, and the precipitation.

MOTOR DISTRIBUTION

No.	H P.	R P M	Department	Service
1	10	850	Dairy Barn	Hay Hoist
1	2	1100	Dairy Barn	Root Cutter
1	1½	1350	Dairy Barn	Vacuum Pump
1	1½	2000	Dairy Barn	Cream Separator
1	3	1440	Butter Making	Butter Churn
2	20	650	Refrigerating	Ammonia Pumps
2	3	500/1000	Refrigerating	Brine Circulating Pumps
1	7½	1500	Refrigerating	Centrifugal Water Pump
1	25	600	Grist Mill	Milling Machinery
1	4	650	Sausage	Meat Grinder, Mixer and Bone Cutter
1	2	1100	Sheep Barn	Root Cutter
1	1½	1350	Sheep Barn	Root Cutter
1	2	750	Fish Hatchery	Fish Food Grinder
1	7½	500	Woodworking	30 in. Band Saw
1	7½	825	Woodworking	Wood Surfacer
1	5	1650	Woodworking	Circular Saw and Boring Machine
1	5	1650	Woodworking	Wood Planer
1	3	500/1500	Machine Shop	Engine Lathe
1	2	1100	Machine Shop	30 in. Drill
1	5	900	Water Supply	Triplex Water Pump
1	3	685	Laundry	Washing Machine
1	2	1100	Laundry	Centrifugal Dryer
1	½	535	Laundry	Mangle

Plan of the Main Group of Farm Buildings. Black Dots Indicate Location of Motors

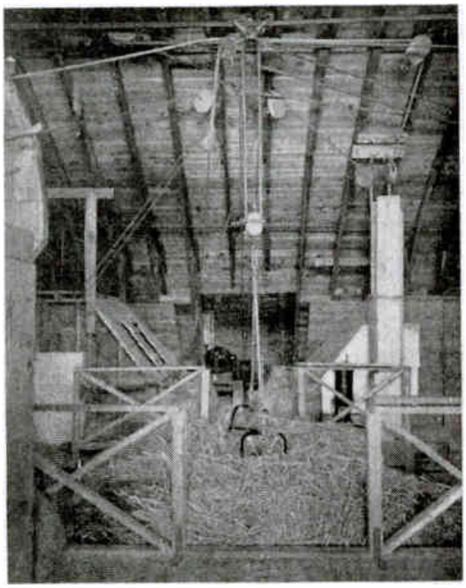
The steam boiler capacity at the farm station is 120 h.p. Steam is used in the various farm buildings for heating, for cooking food for the animals, and for the operation of air and circulation pumps. There is also a vertical engine direct connected to a 22½ kw., 110–150 volt direct current generator, this set being ordinarily held as a reserve.

It will be seen from the foregoing that, in planning the farm equipment, every effort has been made to insure the continued maintenance of the electric service. That the precautions are fully justified by the benefits derived from the electric service in the saving of time and labor, and the possibility of carrying on all indoor work under safe, well lighted and sanitary conditions, will be fully appreciated from the following description of the varied motor applications.

The motors are distributed among the different buildings as shown in Fig. 2, and in most cases no special foundations have been required, since one of the advantages of motor drive for farm machinery is the fact that the motors usually required for this service are relatively light in weight and may be mounted either on the machine itself or on the floor, wall or ceiling.

In the main dairy barn a motor driven hay hoist is installed, to which is geared direct a 10 h.p. motor, a simple drum controller being used to regulate the hoisting speed. The load of hay is driven in onto the main floor of the barn and stopped under an opening to the loft, located in the center of the building. Two U-shaped forks are inserted in the hay by the driver and the hoist is started by a man in the loft and the entire load elevated thereto, the motor controller being so placed near the loft opening as to give the operator an uninterrupted view. The hoist pulley is then automatically tripped, and the load of hay thereby transferred to an overhead rail, along which it is pulled by the hoist to the position selected for it in the loft. The forks are next released by pulling two light tripping ropes and the hay is deposited on the loft floor, the hoist tackle returning for the next load. The entire operation is carried on by two men and a ton of hay can be lifted from the wagon and stored at either end of the 280 ft. loft in less than five minutes.

On the main floor of this barn is a root cutting machine for preparing feed for the cattle. This machine is operated by a 2 h.p. motor mounted on the ceiling and belt connected to the machine, the controller being mounted on the wall beside the machine.



Motor Operated Hay Hoist and Controller

In the dairy section is a vacuum pump operated by a 1½ h.p. motor and supplying power for milking machines. A metallic vacuum pipe leading from the pump is permanently located around the outside of a double row of cow stanchions, with an outlet for each pair of stalls controlled by a single valve. When ready for milking, the motor is started and flexible tubes from the milking machines are connected to the vacuum pipe outlets; soft rubber cups at the ends of other flexible tubes connecting with the milking machine are then placed on the nipples of the cows, where they are securely held by the uniform pressure created by the vacuum.

There are five of these machines used at Heart's Delight farm, each machine milking two cows simultaneously. The suction is applied intermittently by an automatic valve on the milking machine; and thus by alternate pressure and relaxation the effect of hand milking is obtained, with the added assurance of absolute cleanliness, since the machines are totally enclosed. The milk as it is withdrawn from the cow passes through a short glass tube in the top of the machine and is in this way made visible to the operator, who is thus enabled to stop the process at the proper time. The milk is then carried to a room located on the same floor and provided with a motor driven separator. After being tested it is passed through the separator, the cream being thence taken to the butter making section of the dairy building.

A 1½ h.p. vertical shaft motor having an initial speed of 2000 revolutions per minute runs the separator. Upon its arrival in the dairy building the cream is deposited in a covered tank and is ripened before being piped to the churn. The churn is driven by a 3 h.p. motor, which is mounted directly on the churn frame and drives it and its auxiliaries through gears which are enclosed in a sheet iron casing to insure safety and cleaniness.

The motor starting rheostat is mounted on the wall back of the churn, the solenoid of the rheostat being arranged that it can be short circuiting from the front of the churn, thus permitting the operator to stop the churn instantly, at a distance from the rheostat, by simply pressing a button.

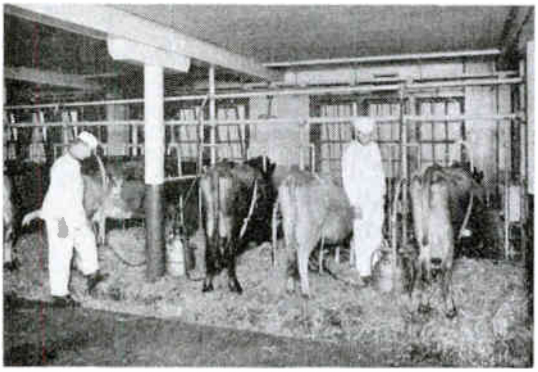
All the milking and butter making processes are carried on by, or under the direct supervision of experts; this arrangement together with the high grade cattle and scientific feeding insuring the best quality of dairy products and a correspondingly good market.

Near the dairy building is an ice making plant with a capacity of twenty tons every twenty-four hours. Motors are utilized for driving the pumps, although there is also a steam equipment for the purpose; this, however, is held only as a reserve. Two ammonia pumps are driven through chain drive by two 20 h.p. motors, and the brine circulation pumps by two 3 h.p. motors, also through chain belts.

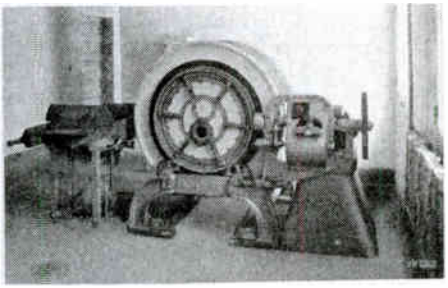
This plant uses only spring water and furnishes ice for drinking purposes, for cold storage, and for the shipment of products affected by changes in temperature.

A small centrifugal lift pump direct connected to a 7½ h.p. motor is located in the ice machine building and elevates water to a nearby tower tank. This motor runs at 1500 revolutions per minute, and as both the centrifugal type of pump and the electric motor operate best at relatively high speeds, this unit is a particularly good example of a compact, high efficiency pumping set. If necessary, it can be equipped with device, which will automatically maintain a predetermined water level in the tank.

A substantial grist mill is included among the farm buildings and the machinery in this is driven through counter shafting by means of a 25 h.p. motor, housed in a separate building to eliminate the fire risk due to the presence of inflammable grain dust in the mill. Many modern grist mills, however, use motors which are installed in the mill buildings, and the polyphase induction motor is peculiarly adapted for this service owing to the absence of a commutator; thus eliminating the potential danger from sparking brushes.



Milking with Vacuum Operated Milking Machines



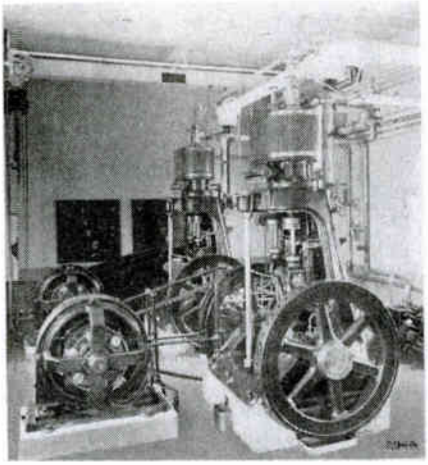
Butter Churn Operated by Direct Geared Motor

The grist mill motor is not set on permanent foundations, but is mounted on a truck and can therefore be readily transported to other buildings for temporary or emergency service. It is taken out in the field in this way and used to drive a threshing machine, the necessary conductors being laid along the ground to supply the current.

The use of portable motors for field work on farms is becoming of increasing importance wherever electric current is available. A notable example of its possibilities was recently given in Germany, where two motors were used to pull plows across a field by means of steel cables actuated by motor driven drums. Two portable motor driven outfits were located on opposite sides of the field and moved forward as the plowing progressed. Of course, this method of plowing would only be practicable under certain conditions; but it illustrates the all-round adapability of the electric motor for farm work.

An item of growing importance at Heart's Delight farm is the production of sausage, the meat chopping and mixing machines, for which are driven by a single 4 h.p. motor utilizing an overhead countershaft. The sausage casings are filled by a machine operated by hydraulic pressure and compressed air, and in this way two men can maintain continuous production up to the capacity of the sausage making equipment.

The two sheep barns are supplied with root cutting machines driven through belting by



Two 20 H. P. Motors Driving Ammonia Pumps in Ice-Making Plant

motors of 1½ and 2 h.p. capacity. The motors are mounted on shelves and therefore occupy no space which could be otherwise utilized.

One of the farm auxiliaries is a thoroughly equipped fish hatchery used for the propagation of trout. A number of concrete fish ponds, located at slightly different levels in order to maintain the necessary water motion, have been constructed, and the fish food is prepared by a grinding machine, belt connected to a 2 h.p. motor.

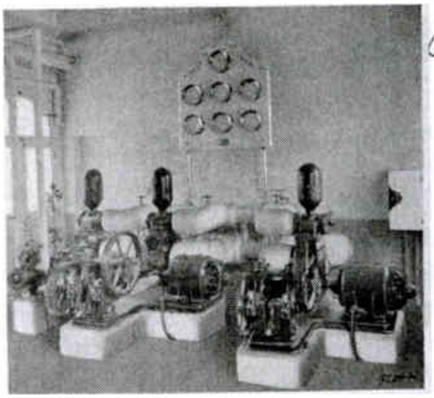
Every farm occasionally requires carpentry work, and the use of up-to-date wood-working machinery will always expedite such work and lessen the labor cost. The serviceability and economy of motor drive for wood working machinery has led to its extended adoption in sawmills and other wood-working plants, and one of the largest plants of the kind in the world—that of the Great Southern Lumber Company at Bogalusa, La.—is equipped with General Electric motors throughout.

The utility fo the electric motor in the operation of woodworking machinery on the farm, for farm building construction and repairs, and for repairing wagons, etc., is well demonstrated here, where the wood-working building contains a 30 in. band saw and a wood surfacer, each driven by a 7½ h.p. motor. The band saw is directly connected to the driving shaft of its motor, while the wood surfacer is driven from a countershaft. There is in addition a wood planer, which is driven by a 5 h.p. motor, and a circular saw and a wood boring machine, also driven by a 5 h.p. motor.

In connection with this woodworking shop, there is a machine shop having a 30 in. drill driven by a 2 h.p. motor and an engine lathe driven by a 3 h.p. motor; both motors being mounted directly on the machines and driving them through gearing.

The blacksmith shop has not as yet been electrically equipped, but a motor driven centrifugal forge blower and a motor operated trip hammer will be installed there at an early date.

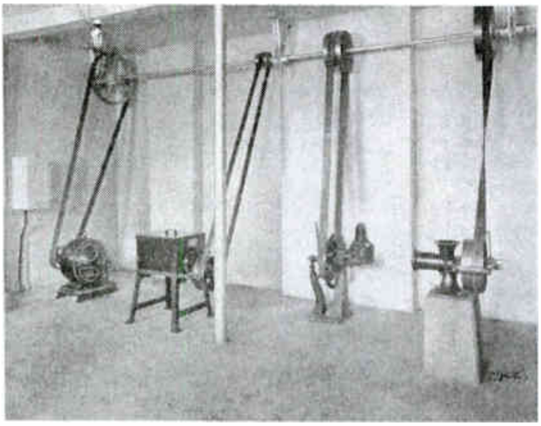
While windmills are used for pumping the water for some of the outlying buildings on the farm, there is also a 5 h.p. induction motor installed in a pump house and direct connected to a triplex reciprocating water pump. This is the only alternating current motor installed on the farm at present, but the further adoption



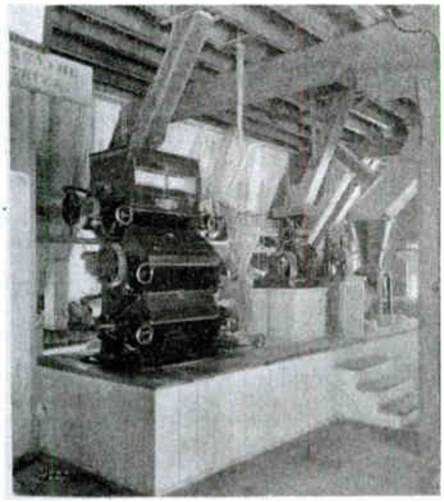
Motor Driven Brine Circulation Pumps in Ice-Making Plant of this type of motor is being considered in providing for the future extension of the electrical service, as it is the best form of motor for operations requiring a constant speed.

In addition to the present equipment, motors will hereafter be utilized on this farm for shearing sheep, clipping horses and other similar work.

Motor drive has been extended to the housework, and there are installed in the laundry of the main house on the farm, known as "Heart's Delight Cottage", a clothes washing machine driven by a 3 h.p. motor a centrifugal dryer operated by a 2 h.p. vertical shaft motor, and a mangle driven by a 2/5 h.p. motor direct connected.



View in Sausage-Making Department, Showing Meat Cutting, Mixing and Bone Grinding Machines

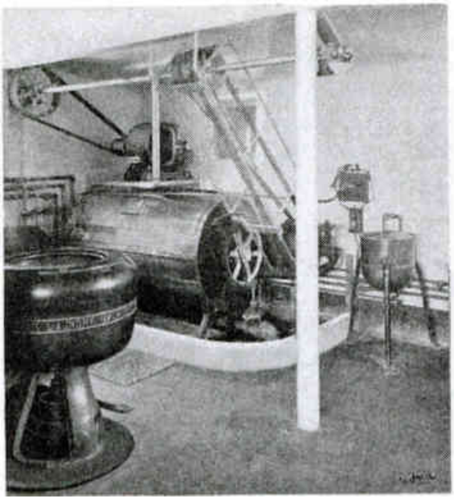


Grist Mill Machinery which is Driven by a 25 H. P. Motor Housed in a Separate Building

Among the auxiliary electrical devices at the cottage are an electric piano, heating and cooking devices, and a motor driven ice cream freezer. Fan motors are also liberally provided.

Electricity on the farm not only permits the ready application of power to machinery located in widely separated buildings, but insures the safe and most efficient lighting for both buildings and farm yards.

At Heart's Delight Farm the buildings are all lighted with incandescent lamps, and in order to insure absolute safety they are enclosed in vapor-proof enclosing globes which fit into porcelain bases, the wiring being all run through iron conduit. In the yards the high efficiency of the flaming arc lamp for the lighting of large areas has resulted in its adoption for the purpose, and four lamps of this type are used, one of them being installed on the top of the 134 ft, steel tank tower. At an early date, the lighting system will be extended to the roadways on the farm, and either luminous arc or incandescent lamps will be used.



View in Laundry, Showing Motor-Driven Washing Machine and Centrifugal Dryer

In accomplishing the electrification of this farm, every effort has been made to preserve the natural beauties of the farm lands. The concrete dams are smoothly finished and the penstocks covered by earth embankments which have been carefully sodded. The wiring to the various farm buildings is carried underground in conduits, and as a consequence there are no unsightly effects produced by the various conductors which radiate from the farm power station.

It is obvious from the foregoing that the adoption of electricity on the farm effects a marked saving in the labor cost of a great variety of operations and renders possible those economies in production which result from the elimination, either wholly or in part, of manual labor and the substitution of mechanical devices which are highly efficient and easily operated and controlled by the average farm worker.

It renders possible the adherence to a definite schedule of work and therefore enables the modern farm to emulate the successes obtained in other industries by the most economical use of that expensive commodity, modern labor.

Heart's Delight Farm has had electric service for a period of about three years during which time it has been definitely proven that the electric motor can be applied with unqualified success to the operation of all machinery used in farm buildings. It constitutes a potent argument for the general adoption of electricity on the farm.

General View of Heart's Delight Farm

HYPERBOLIC FUNCTIONS AND THEIR APPLICATION TO TRANSMISSION LINE PROBLEMS

PART I

BY W. E. MILLER

Introduction

The discussion of transmission lines has not, as a rule, considered lines much above 200 miles in length. This being the case, approximate methods have generally been used, as these possess all needful accuracy for lines not over 200 miles long operating at 60 cycles, or not more than nearly double this distance at 25 cycles. When applied to greater distances, however, these methods are not reliable,* and the following discussion of long distance lines has therefore been prepared. These methods are equally applicable to short distances, and in general are as simple to handle as those usually employed. The results are obtained from the exact solution of the general equations which solve the problem of transmission lines with distributed capacity and self induction and leakage, of which the last can appear either due to corona effect, † or to leakage at the insulators. The various constants required for the complete computation of any transmission line likely to be used for some time to come have been calculated, as well as the mathematical tables necessary for the work. The solution employed is that used by Kennelly and involves the use of hyperbolic functions of the complex quantity. The use of the complex quantity was first introduced into this problem by Steinmetz, with a resulting simplification of the formulæ and operations required for obtaining results.

Applications of Formulæ and Conditions Necessary for Determining Problem

The determination of the power factor, voltage and current can be as readily made at any point of the line by this method as at the line terminals, a matter of considerable importance where another line is connected at some intermediate point. Further, except for changes in sign, the same formulæ apply whether the terminal conditions are given for the generator or receiving end, so that it is a matter of indifference so far as the calculations are concerned at which end the volts, current or power factor are given.

The calculations can easily be adapted to take care of cases where two of the terminal conditions are given for, say, the receiving end, and the other condition for the generator end. Actually, the method is not limited in any way and can be used, if necessary, to solve cases where three electrical conditions, such as volts, current, and power factor are given at any point or points along the line, or where two power factors and a voltage or current are given, or any combinations of these factors, provided that none of them is used more than twice and that only three are given.

Tables and Constants Calculated

One of the reasons why the hyperbolic functions are not commonly known is due to the absence of complete and readily available tables of their values. In transmission line problems, where hyperbolic functions of the complex quantity are used, the tables so far published do not give the values of the functions at sufficiently close intervals to allow of either ready or accurate interpolation. A sufficiently complete set of tables has therefore been computed which give the values of these functions at intervals which allow interpolation to be made by inspection for any value of the function which lies between those tabulated. The tables have been very carefully calculated and through the greater part of their range can be relied upon for an accuracy of one-half to one-quarter per cent. They will be published in the next issue of the REVIEW, together with a table of the constants required for calculating transmission line problems involving their geometrical properties, i.e., capacity and self induction, at frequencies of 25 and 60 cycles.

The latter constants are calculated for three-phase transmission with the three wires placed at the corners of an equilateral triangle, and for the wires equally spaced and lying in a plane, provided a sufficient number of transpositions has been made in the latter case to obtain a balanced system. The constants include lines using wires from No. 2 B.&S. to 250,000 circ. mills, and are calculated for the following spacings, 6 ft., 8 ft., 10 ft., and 12 ft. As the values of the constants do not change quickly with the spacing, the proper constant can be at once determined by inspection for any spacing lying between those determined. The capacity and self induction involved in these constants are taken between line and neutral, so that the voltage relating to them is that between line and neutral and must be multiplied by $\sqrt{3}$ to obtain the line voltage.

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* See Steinmetz "Transient Phenomena" pages 294 and 296.

† Only true if voltage is practically constant along the line.

Operations Required and Speed of Calculations Possible

By the aid of these tables and constants, the calculation of the power factor, amperes and volts at the generator end of the transmission line of any length up to nearly 500 miles long for 60 cycles, and nearly 900 miles long for 25 cycles, can be performed with a little practice in about a quarter of an hour, when volts, amperes and power factor are given at the receiving end, or vice versa. From these results, the transmission efficiency can be at once obtained for the given load, and the line regulation can be determined by a calculation for no-load conditions by means of a simple multiplication. The electrical conditions at any point of the transmission line can also be as easily and quickly computed. In fact, after looking up the proper constants to employ and the values of the hyperbolic functions, as given in the tables, the whole problem, so far as results are concerned, resolves itself into two multiplications and one addition for obtaining either volts or amperes at any point, and two divisions for obtaining the power factor, although a table of cosines is necessary for the latter.

Curves Illustrating Electrical Conditions Along the Line

To show how the electrical characteristics vary from point to point in a long transmission line, curves have been plotted for a transmission line 400 miles long, using three 0000 stranded hard drawn copper wires, with a spacing of ten feet between wires, operating at a frequency of 60 cycles. These curves and the ones mentioned below, will be published in the next issue of the REVIEW, where this side of the matter will be more fully discussed. They include curves showing the variations of volts, amperes, and power factor along the line, under various conditions at the receiving end as to power factor and load, the volts at this end being assumed constant and 60,000 volts, or 104,000 volts between wires. Curves illustrating a method for determining what power factor at the receiving end gives maximum transmission efficiency at any given load delivered. Curves illustrating the corona effect along a line 200 miles in length operating at 25 cycles, using No. 1 wire with a spacing of 8 ft. and a voltage of 110,000 volts between wires. The power wasted in capacity current and owing to corona are separately plotted for each point of the line. The corona constant used in these calculations was computed from results obtained on a 50 mile line, operating at a line voltage of 110,000 volts. This line is, electrically similar to the one taken for illustration, so that it is believed that the corona effect calculated cannot be far from the true value.

Lastly, the hyperbolic method has been applied to a telephone line consisting of two No. 6 B.&S. wires twelve inches apart and 1000 miles in length, the frequency being taken as 1000 cycles per second, and the power factor of the receiving apparatus being assumed to be .5 lagging. The voltage required for the receiving instrument has been taken as .2 volts, and the current as .5 milli-amperes. The hyperbolic functions in this case had to be specially calculated, since the tables do not cover the range necessary. Curves have been plotted giving the variation of the maximum value, as well as the instantaneous values of the current and volts at every point of the line. This problem illustrates the shift of phase of current and volts along the line and the finite velocity of electric wave propagation much more forcibly than any problem relating to commercial transmission lines, and it was chosen for this reason.

Introduction to Mathematical Portion

The majority of engineers, unfortunately, are not familiar with hyperbolic functions, and the complex quantity has not received the attention it has deserved of the electrical fraternity. The hyperbolic functions are extremely simple and are as easily understood as the circular functions, sine, cosine, etc.; while the complex quantity is one of the greatest labor and thinking saving methods of treatment devised, and carries its physical meaning through all the mathematical operations to which it may be subjected. As the understanding of the following treatment depends on these matters being appreciated, the following short discussion is given, which may help to elucidate the meanings of these quantities and the laws governing them.

Hyperbolic Functions

The hyperbolic functions, as their name implies, can be derived from the hyperbola in a manner similar to that employed in the derivation of the circular functions, sine, cosine, etc. The following discussion illustrates the close analogy existing between the two methods.*

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* See Osborne's "Integral Calculus, page 278

Consider the circle $x^2+y^2=a^2$
Let the angle $POA=\theta$ and let the sectorial area $POA=u$
Then $x=a\cos\theta$ and $y=a\sin\theta$

While $u=\frac{a^2\theta}{2}$ or $\theta=\frac{2u}{a^2}$

$$\text{Hence, } OM=x=a\cos\frac{2u}{a^2} \tag{1}$$

$$\text{and } PM=y=a\sin\frac{2u}{a^2} \tag{2}$$

That is to say, the length OM, or x, divided by the radius or distance from the center of the circle to the circular boundary, is equal to the cosine of the ratio of twice the sectorial area to the constant area of the square erected on the radius. The length $\frac{PM}{a}$ is equal to a similar function involving the sine in place of the cosine.

If the above definition is applied to the rectangular hyperbola, the values of the hyperbolic sines and cosines, or sinh and cosh, as they are usually denoted, can be as readily obtained as follows:

Let O be the center of a rectangular hyperbola, of which the arc is PA.

Then the equation of this hyperbola referred to its center is $x^2-y^2=a^2$.

The sectorial area u is equal to the shaded area of Fig. 2, and equal to the area of the triangle POM − area PAM, which is equal to

$$\frac{xy}{2}-\int_a^x y\,dx=\tfrac{1}{2}xy-\tfrac{1}{2}xy+\frac{a^2}{2}\log\frac{x+y}{a}$$

$$=\frac{a^2}{2}\log\frac{x+y}{a} \tag{3}$$

$$\text{Whence } \frac{x+y}{a}=e^{\frac{2u}{a^2}} \tag{4}$$

$$\text{and } \frac{x-y}{a}=e^{-\frac{2u}{a^2}} \tag{5}$$

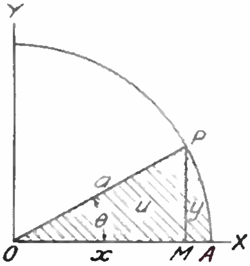


Fig. 1

Hence by definition similar to that given for the circular functions in the case of the circle.

$$\frac{x}{a}=\frac{e^{\frac{2u}{a^2}}+e^{-\frac{2u}{a^2}}}{2}=\cosh\frac{2u}{a^2} \tag{6}$$

$$\text{and } \frac{y}{a}=\frac{e^{\frac{2u}{a^2}}-e^{-\frac{2u}{a^2}}}{2}=\sinh\frac{2u}{a^2} \tag{7}$$

Hence, $OM=x=a\cosh\frac{2u}{a^2}$

and $PM=y=a\sinh\frac{2u}{a^2}$ which are exactly simila expressions as those obtained for the circular functions. If θ = angle POA then $\tan\theta=\frac{y}{x}=\tanh\frac{2u}{a^2}$

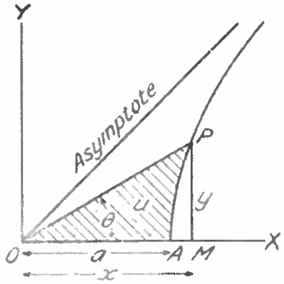


Fig. 2

The values of $\sinh x$ and $\cosh x$ can thus be obtained in terms of the exponential expressions, i.e.

$$\sinh x=\frac{e^x-e^{-x}}{2} \text{ and } \cosh x=\frac{e^x+e^{-x}}{2} \quad (8) \text{ and } (9)$$

It will be observed that for large values of x, the two expressions are equal, and that therefore $\sinh x$ is equal to $\cosh x$ when x is large, when $\tanh x=1$.

The analogous expressions $\sin x$ and $\cos x$ are as follows:

$$\cos x=\frac{e^{jx}+e^{-jx}}{2} \text{ and } \sin x=\frac{e^{jx}-e^{-jx}}{2j} \quad (10) \text{ and } (11)$$

where j is imaginary and equal to $\sqrt{-1}$, whereas the expressions for $\sinh x$ and $\cosh x$ do not involve imaginaries. The presence of imaginaries in the exponential expressions for $\sin$ and $\cos$ render them periodic in value; the absence of these imaginaries in the straight hyperbolic functions make them non-periodic. The complex hyperbolics have, however, a period $2\pi j$ as will be seen later.

By adding or subtracting (8) and (9) the following series are obtained.

$$\sinh x=x+\frac{x^3}{\lfloor 3}+\frac{x^5}{\lfloor 5}+ \tag{12}$$

$$\text{and } \cosh x=1+\frac{x^2}{\lfloor 2}+\frac{x^4}{\lfloor 4}+ \tag{13}$$

from which the value of these functions can be calculated.

The addition and subtraction formulæ of $\sin(x\pm y)$ and $\cos(x\pm y)$ are $\sin x\cos y\pm\cos x\sin y$ and $\cos x\cos y\mp\sin x\sin y$ respectively, these formulæ being readily obtained geometrically from the properties of the circle. The following formulæ can be deduced for the hyperbolic functions from the geometrical properties of the hyperbola in a similar manner.

$$\sinh(x \pm y) = \sinh x \cosh y \pm \cosh x \sinh y \quad (14)$$
$$\cosh(x \pm y) = \cosh x \cosh y \pm \sinh x \sinh y \quad (15)$$

By changing x into $-x$ in 8 and 9, it follows that $\cosh x = \cosh(-x)$ and $\sinh x = -\sinh(-x)$

also $\cosh o = 1$, $\sinh o = o$, $\cosh \infty = \infty$, $\sinh \infty = \infty$ hence, $\tanh \infty = 1$ and $\tanh o = o$

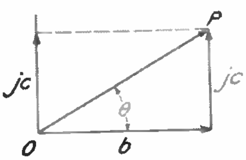


Fig. 3

By the addition and subtraction formulæ, 14 and 15, the following relations are seen to exist:

$$\sinh 2x = 2\sinh x \cosh x$$
$$\cosh 2x = \cos^2 hx + \sin h^2 x$$
$$\cos^2 h\, x - \sin^2 h\, x = 1, \text{ etc.}$$

Compare $\sin 2x = 2\sin x \cos x$
$$\mathrm{Cos}\ 2x = \cos^2 x - \sin^2 x$$
$$\mathrm{Cos}^2 x + \sin^2 x = 1$$

From 8 and 9, we have also

$$\frac{d \sinh x}{dx} = \frac{e^x + e^{-x}}{2} = \cos h\, x$$

and $$\frac{d \cosh x}{dx} = \frac{e^x - e^{-x}}{2} = \sin h\, x$$

Therefore

$$\frac{d^2 \sinh x}{dx^2} = \sinh x$$

and $$\frac{d^2 \cosh x}{dx^2} = \cosh x$$

That is to say, the hyperbolic functions repeat themselves in two differentiations, which may be regarded as the mathematical reason why they appear in the solution of the equations relating to transmission lines.

It is apparent from the above how closely the formulæ of the hyperbolic functions follow those of the circular, and how readily they are obtained. For further information on these functions and on the hyperbolic complex, see McMahon "Hyperbolic Functions."

Complex Quantity

As is well known, all directed physical quantities can be represented vectorially, the scalar part or length of the vector representing the magnitude of the quantity, and the direction of the vector representing the direction of the quantity. Such a vector can be resolved into two vectors, at right angles to one another. The simplest notation to employ in such cases, to differentiate between the horizontal and vertical component, is to prefix a symbol in front of the vertical component. This symbol, in electrical science is usually called j, and means that the vector in front of which it stands must be added vectorially to the horizontal component and not algebraically.

Thus if b represents a horizontal force, and c a vertical force acting at the same point on a body, the resultant of the force will be denoted by $b+jc$, the magnitude of the resultant being by the parallelogram of forces $\sqrt{b^2+c^2}$, making an angle with the horizontal component $\theta = \tan^{-1}\left(\frac{c}{b}\right)$. This at once shows that in order to get the magnitude of the vector, of which the two rectangular components are given in the form of $b+jc$, the square of b must be added to the square of c, and the square root extracted of their sum, and that the angle the horizontal component makes with the vector is given by the equation $\tan \theta = \frac{c}{b}$. Vectors thus resolved into component vectors at right angles to one another are very easily operated, when the meaning of j is appreciated, and the sum of the component vectors is called the complex quantity.

In order to discover the meaning which should be assigned to the symbol j the following case is taken, let P represent a force acting along a constant direction OP through a length l lying in the direction of OP (see Figs. 3 and 4). Then the work done by the force is equal to Pl. Now suppose that the force P is resolved into two components, $b+jc$, and the length similarly into two components $y+js$, then the product so far as magnitude is concerned

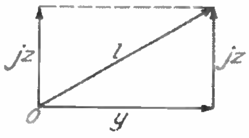


Fig. 4

$$(b+jc)(y+js)$$

must equal lp. This product equals $(by+j^2zc)+j(bs+yc)$. If j is equal to $\sqrt{-1}$, the above expression becomes $(by-zc)+j(bs+yc)$, and the magnitude of this vector is given by $\sqrt{(by-zc)^2+(bs+yc)^2} = \sqrt{b^2+c^2}\sqrt{y^2+s^2}$ which is equal to lP. Hence, the value given for j yields a correct result.

Better illustrations perhaps could be obtained from electrical engineering, because work is not a directioned quantity, but the idea is so familiar that the foregoing illustration was chosen.

Currents and volts can be resolved into two components at right angles to one another in a similar manner. And, since inductive reactance and dielectric susceptance are proportional to the rate of change of current and volts with time respectively, they can be regarded as at right angles to the resistance and conductance in the functions impedance and admittance. Thus, the impedance and admittance can be represented as $r+jx$ and $g+jK$ respectively where r is resistance, x the reactance, g the conductance, and K the susceptance. These quantities are, of course, scalars, but the method applies to any quantities which can be resolved into two directions at right angles to one another.

(To be Continued)

THE ELEMENTS OF TRANSFORMER CONSTRUCTION

Part I

By W. A. Hall

In electrical work, the term "transformer" is used to denote a certain class of apparatus which embraces a great variety of devices, each possessing a certain given inherent characteristic of marked simplicity.

Probably the simplest geometrical conception of a transformer is that suggested by three links of a chain, in which the middle one represents the magnetic and the other two the electric circuits. In constructing this device, however, the designer is immediately confronted with certain conditions which materially modify his elementary figure.

The best materials commercially available for these circuits (steel and copper, respectively), are far from the theoretically perfect in that their highest efficiency is much below 100 per cent.; or, in other words, each offers a certain resistance to the transmission of electrical forces that results in an energy loss, operating against the efficiency of the transformer. The resistance in the copper circuit varies directly with the length and inversely with the cross section of the conductor, while the loss varies directly with the resistance and as the square of the current carried by the conductor. The resistance to the passage of magnetic force through the iron circuit usually termed "reluctance," also varies directly with the length and inversely with the cross section of the core. The relation of loss to reluctance, however, is somewhat more complicated, owing to the fact that while the specific resistance of commercial copper wire is practically uniform, the specific reluctance of commercial steel varies widely. Eliminating this variable, we still find that any grade of steel of given dimensions has a different reluctance for each value of magnetic force, that is, the reluctance varies in a fixed relation with what is termed the magnetic density. Therefore, while it is not convenient, generally speaking, to express the loss in a magnetic circuit ("core loss") in terms of reluctance, it may be safely taken as somewhat greater than the first power relation, or the relation which exists between copper loss and resistance in the copper members of the transformer.

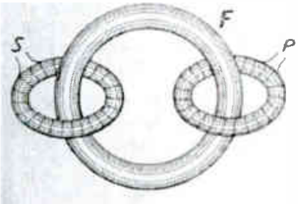


Fig. 1

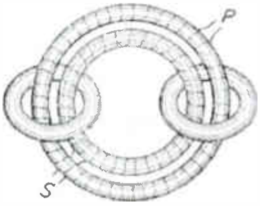


Fig. 2

From the foregoing it is evident that a minimum loss in each member results from that circuit which has minimum length and maximum cross-section. It is equally obvious that these conditions are conflicting in the primitive linkage, which fact renders this arrangement open to improvement, while other considerations make it in exact form practically prohibitive. It is further observed that space lost in one of the elements by reason of the greater length imposed upon the others, causes therein both loss of electrical efficiency and material, representing a double waste. It is essential, therefore, that the space factor; i.e., the ratio of net effective material to total space occupied, be a maximum in both iron and copper circuits.

Opposed to this are considerations of equal or greater importance. In order to increase the resistance in the path of the wasteful eddy currents within the core, this member is built up of laminations or punchings of sheet steel, varying in thickness in commercial transformers from 14 to 25 mils., to which is added on each side a coating of some insulating material that increases the thickness of the sheet by approximately another mil. This insulation, together with the loss of space incident to building up into a core, causes a loss of from 5 to 20 per cent., or in other words produces a space factor varying from 95 to 80 per cent.

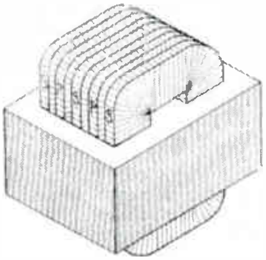


Fig. 3

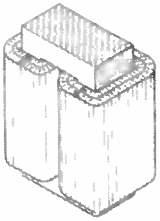


Fig. 4

In the copper circuit it is necessary to insulate each turn from all other turns thereof, and from all other parts of the transformer. Since the potential accumulates along the conductor, it follows that the amount of insulation required between adjacent turns of a coil is relatively small, that between sections of a coil being somewhat greater, while that between other parts and the coil is considerable. The entire amount of space given up to this most essential feature is even more than that occupied by the copper, and therefore the space factor of the copper circuits in the average transformer is lowered to a figure well under 50 per cent. Thus far, the discussion aims to show the value of the space encompassed by both the magnetic and current elements of the transformer.

The engineer is next confronted with the problem of conserving this space by designing in the form of regular geometrical figures, which will best accomplish the result in a manner consistent with economical manufacture. For reasons already referred to cores must be laminated, and moreover, in such a manner that they can be readily linked with the copper circuits. The prevention of waste of material during manufacture, which requires straight line punchings that interlock, at once determines the rectangle as the form of the magnetic circuit for nearly all commercial transformers; a conclusion which is strengthened by the fact that this figure is also best adapted to the formation of the coil sections which it encloses. These and other considerations have led to the development of three general types, upon one of which nearly every commercial transformer of any considerable capacity is constructed. These types are shown in Figs. 2, 3 and 4, numbered respectively in the order of their commercial origin.

The design in Fig. 3 was employed exclusively from the beginning of transformer manufacture in this country in 1883, until 1895. It consists essentially of rectangular coils, wound upon a rectangular form. The core, instead of being a single link as in our elementary conception of the transformer, has a double magnetic circuit. The portion within the coil was considered the core proper, and at a very early date came to be known as such. The remainder of the iron circuit was in a similar manner identified as the "shell." Since the coil is principally within the iron, it follows that one characteristic of this type is a relatively large amount of iron and a small amount of copper, and consequently, a small cross-section of the latter. For a given voltage then, this necessarily means few turns, which fact, for a given core loss, demands a large cross-section of the magnetic circuit. This in turn results in a long mean length of copper and short mean length of magnetic circuit.

The design shown in Fig. 4 was introduced commercially in this country about 1895. Fundamentally, it is directly the reverse of that of Fig. 3, in that the coils are, in general, disposed externally.

These two types of transformers have been named according to the arrangment of the iron with respect to the winding. Since that portion of the core which is called the shell is a prominent feature of the design shown in Fig. 1, this type has become known as the shell type. In contradistinction, the design shown in Fig. 2, in which the greater part of the iron forms the core proper, is called the core type.

The core type has relatively a lighter core of less cross-section and greater mean length, while the copper is relatively heavier and of larger cross-section and is composed of a greater number of turns of less mean length. Since the introduction of the core type approximately 15 years ago, the designing engineer, manufacturer, salesman and operator have engaged in an endless and verbose struggle to demonstrate the superiority of that particular type in which each was interested. If, in the face of this controversy, the author may venture an opinion, it is to say that each type has its comparative advantages and disadvantages, depending upon the particular use for which it is intended. In fact, some manufacturers make both types for the same or different service, and in this manner have done much to eliminate artificial differences and make the two more nearly alike.

The shell type, having a large ratio of cross-section of core to coil, is at once superior to the core-type with its opposite characteristics, when the service demands high duty from core and moderate requirements from coils. The core-type, with its large ratio of coil cross-section to length, likewise possesses an advantage in those instances where conditions are exacting with regard to windings. Hence we find the shell type particularly adapted to transformers of moderate voltage, requiring few turns and little insulation, large currents (easily provided for by heavy conductor in its few turns), low frequency and consequently heavy flux; while the core-type, with its ample winding space, lends itself more readily to the higher potentials which require many turns and much space for insulation, smaller currents and lighter wires for the many turns, and higher frequencies with low magnetic densities. Hence it follows that the former is essentially a high capacity and the latter a low capacity transformer, which fact accounts for the practice of the manufacturer who builds a core-type for his small transformers and those of exceptionally high voltage, and his large power transformers upon "shell-type" lines.

Now as we compare without prejudice the two types before us, we will in general conclude that, because of the shorter mean length of the core of the shell-type and the coils of the core-type, these elements possess advantages over corresponding elements of the opposite type; suggesting immediately the possibility of a marked gain could any means be devised whereby these points of advantage might be combined. To assist in the solution of this problem, let us briefly return to our first conception of the transformer; *viz*:. the three links. In Fig. 1 we have a single magnetic circuit and double copper circuit, hence a core-type transformer. In Fig. 2 we have a double magnetic circuit linking a single copper circuit, or a form of the shell-type transformer. Now, if the several links represent coils or cores of substantial magnitude of cross-section, the mean length of the external member may be materially lessened by distributing them about the periphery of the enclosed member.

This development will result respectively in Figs. 5 and 6, which may be considered to fairly well represent the ideal transformer of highest efficiency, where each element is in the form of a circle, and hence has a minimum length for unit area enclosed. There are many obstacles between this design and its commercial use, such as lack of good mechanical characteristics, difficulty of insulation, inability to properly dissipate heat generated within the inner member, and excessive cost of manufacture.

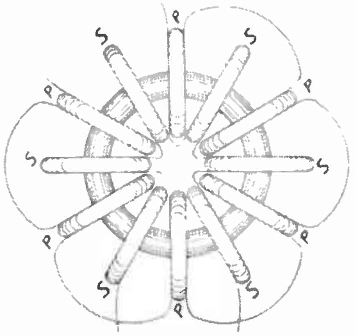


Fig. 5

The problem then narrows down to that of combining the advantageous points of the two types and extending the development as far as possible toward the design of the theoretically best. To that end there was placed upon the market in 1905 the design shown in Fig. 7, which, by subsequent adoption as the standard type for small transformers of the two largest manufacturers in this country, represents probably the majority of all transformers at present made therein.

That we may derive a proper conception of this transformer, let us first consider Fig. 3 as modified by placing all of its windings on one leg (Fig. 8.). Obviously, for equal efficiency, this step has been attended by an addition in cost of material, because of the larger mean length of the copper circuit.

Now divide the iron circuit into two equal parts and rotate one through 180 degrees when we have Fig. 3, in which it should be noted that the width of laminations outside the coil has been reduced by one-half while the full cross-section has been maintained and the mean length materially reduced, thus gaining simultaneously in cost of material and iron energy loss. Consequently, to restore the original efficiency, the whole transformer may be reduced, making a double saving in cost.

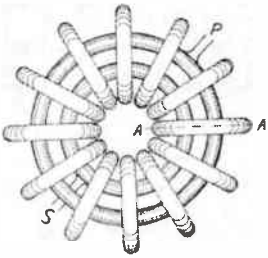


Fig. 6

Consider now a second division whereby the iron in each of the two branches is split and one-half rotated 90 degrees, thus developing Fig. 7, in which the width of iron is now one-half of that in Fig. 3, or one-fourth of that in Fig. 8, and the mean length of the magnetic circuit so far shortened that there results a very great saving in the cost of material for a given efficiency, or conversely, a greatly improved transformer for the same cost. Obviously, this process of division might be extended indefinitely until we arrived at an approximation to the ideal transformer. However, a little thought will disclose the fact that there is a problem involved in thus dividing the center leg without loss of space factors, maintaining at the same time a practical manufacturing proposition. In consideration of these facts, together with a number of others, such as coil radiating surface, oil channels, leads, cost of labor, etc., it appears that this type as shown approaches as nearly as practicable to the ideal transformer.

It is at once apparent that this new type, which is called the distributed core type, combines certain characteristics of the other two. As we have seen, the efficiency of the shell type demands small coil space and low mean length of magnetic circuit. Hence the opening in the core, or the window as it is frequently termed, is relatively short and broad; that is, it approaches a square. Consequently, it has been found profitable to make the coils narrow and deep, or of the so-called "pan-cake" type. On the other hand, for obvious reasons, the coils of the core type have become long and thin, or of the cylindrical type. Thus these features of construction have become to be regarded as characteristic of the respective types.

It is the marked increase in the mean length of the magnetic circuit of Fig. 7 that enables the designer to lengthen the core of Fig. 3 so as to employ the cylindrical coils of short mean length—an advantage which is increased by the special construction of the core and which has become to be characteristic of this new type. Recognizing the fact that but approximately a third of the mean length of the magnetic circuit is within the winding, this portion has been deliberately shrunk in cross-section and the loss increased therein, while the cross-section of that portion of the magnetic circuit outside of the coils, having twice the length, is correspondingly enlarged to compensate therefor. There thus results the design which combines with the advantages of the core-type coil construction those of the shell-type core, though much improved.

Let us now consider the practical application of these types. The commercial transformer is susceptible of division into four principal classes, each comprising a greater or less number of components, as follows:

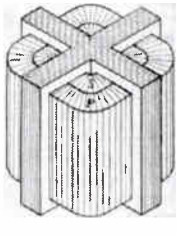


Fig. 7

I. Multiple or Constant Potential: Receiving an impressed electromotive force of fixed value and delivering upon the secondary lines regardless of load, a voltage bearing a fixed ratio to that of the primary.

II. Series Transformer: Connected in series with the line, as the name implies, and hence receiving a current of a value depending upon the load therein; possessing the function of delivering to the secondary a current the value of which bears a fixed ratio to that impressed upon the primary.

III. Constant Current: In effect, a combination of I and II, designed to receive a constant voltage and to deliver a fixed and constant current to the secondary.

IV. Variable Ratio: Receiving a constant voltage and delivering a voltage varied at will, or receiving a varying primary voltage and converting it into a fixed predetermined secondary voltage.

By far the greatest in importance is group I, in that it comprises the standard lines of lighting transformers, testing transformers, all transmission and power transformers, as well as a host of miscellaneous modifications for an almost infinite variety of purposes. Of these, undoubtedly the most familiar is the so-called lighting transformer, generally hung upon the cross-arms of a pole in the street and receiving a voltage of from 1100 to 2400, 40 to 60 cycles, and delivering from 110 to 240 volts on secondary lines carried into the buildings. More than half the value of the entire transformer output in this country consists of this type. Because of the fact that the primary voltage is dangerous to life, and the secondary circuit comes into almost actual contact with multitudes of people, it is obviously of paramount importance that the secondary should be thoroughly and carefully insulated, while the large number of these transformers employed demands that attention be given to the important question of efficiency; both, together with other characteristics, giving the design, manufacture and sale of this device great prominence.

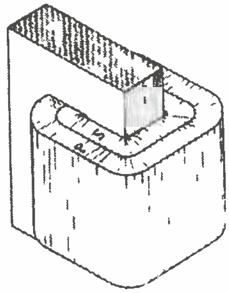


Fig. 8

Fig. 9

Reference has been made to the fact that all three types described have been employed for this service and that the distributed core type has practically superseded the other two, although the latter is still manufactured by some companies. The most convenient form of punchings devised for this core are "L" shaped, and are readily cut from the sheet steel by shearing dies in such a manner as to result in a comparatively small waste, at the same time permitting the dies to be operated at very high speed. As this shape of punching is particularly well adapted to the construction of the transformer, it is fairly economical.

The punchings are built up by pairs into four sections which, when locked together, form a square center of solid iron with four branches at each end containing half the amount of iron in the central core (Fig. 9 standing). This arrangement provides a natural spool-shaped design, around the middle leg of which the coils are wound when it is placed in a winding lathe designed to properly hold it. This done, the magnetic circuit is completed by interweaving the laminations of the four outside legs with those of the end branches. The laminations of the core are secured by steel clamps placed at top and bottom, which in turn are retained by straps of the same material extending somewhat above the top clamp and supporting the connection-board to which are carried the coil leads. The transformer is then subjected to a vacuum and filling process, after which the construction is finished by attaching flexible insulated cables to the connectors and assembling the transformer within its case.

(To be Continued)

KEY FOR THE COMPLETE CALCULATION OF A TRANSMISSION LINE

Part VII

By Milton W. Franklin

Given:

(a) Kilowatts load
(b) Length of line
(c) Power factor of load
(d) Frequency
(e) Number of phases
(f) Estimated cost of power per kw. year
(g) Cost of conductor per lb.
(h) Interest rate on line investment.

To Be Determined:

(1) Voltage (see page 447, Vol. XII No. 10)
(2) Choice of conductor (see page 276, Vol. XII No. 6)
(3) Most economic loss (see page 139, Vol. XIII No. 3)
(4) Cross-sectional area of conductor (equations *c*, *e*, *g*, *i*, page 140, Vol. XIII No. 3)
(5) a-Pounds of conductor (equation 3, page 139, Vol. XIII No. 3)
    b-Total cost of conductor
    c-Interest on line investment
(6) Resistance of line (equation 6, page 139, Vol. XIII No. 3)
    a-Skin effect (see page 450, Vol. XII No. 10)
    b-Recalculation of loss for cable selected (equation *l*, page 141, Vol. XIII No. 3)
(7) a-Kilowatts loss on line
    b-Kilowatts delivered (generated)
    c-Kilovolt amperes delivered (generated)
(8) Line spacing of conductors (see table, page 449, Vol. XII No. 10)
    a-Capacity (see table)
    b-Charging current (see table)
    c-Self induction (see table)
    d-Inductive reactance (see table)
(9) Natural period of line—see page 447, Vol. XII No. 10)
(10) Voltage and current at generating end (under full load conditions)
(11) Regulation of line (unity power factor)
(12) Summary of results

The use of the key may best be illustrated by means of a worked example.

Example:

Proposition:
To transmit 40,000 kw. (power at generator end)
Length of line, 100 miles
Frequency, 60 cycles
Number of phases, 3
Power factor of load .85

Given:
a. Kilowatts load, 40,000
b. Length of line, 100 miles
c. Power factor of load .85
d. Frequency, 60 cycles
e. Three-phase
f. Estimated cost of power per kw. year $10.00
g. Cost of conductor per lb.—copper $.15
—aluminum $.38
h. Interest rate on line investment 5 per cent.

Since 20,000 kw. is the maximum load that can be economically transmitted over a single line we shall assume two parallel lines of 20,000 kw. capacity, and consider each individually.

The order of solution as outlined on page 139, Vol. XIII No. 3, will be followed:

1. Voltage receiver end 100,000 volts.

2. Choice of conductor: Aluminum $.38 per lb. Copper $.15 per lb.

From curve (see page 276, Vol. XII No. 6) it can be seen that copper will prove the cheaper conductor, aluminum will cost 18 per cent. more for the same percentage power loss on the line.

Hard drawn copper wire is chosen for the conductor.

3. Most economic loss: See page 140, Vol. XIII No. 3, Equations (*f*) and (*a*).

$$x = \sqrt{\frac{3K}{4\,cE_R^2 + 3\,K}}$$

$$K = \frac{4000\;p c_1 K_1 K_2 L^2}{\cos^2\theta}$$

The values of the constants for this particular case are given below:

P = power at generating end, 20,000 kw.
c = estimated cost of power per kw. year, $10.00
E_R = receiver voltage, 100,000
L = length of line in miles, 100
$\cos\theta$ = power factor of load, .85
c_1 = cost of conductor per lb. $.15
p = interest rate .05
K_1 = resistance of conductor per mil mile, 56,700
K_2 = weight of conductor per mil mile, lbs., .0161

From formula (4) page 450, Vol. XII No. 10, we have

$R_t = R_{\omega f}\, y$

$R_{\omega f} = 55{,}810$ (table 6) $y = 1.016$ (curve, page 449, Vol. XII No. 10

$R_t = 55{,}810 \times 1.016 = 56{,}700 = K_1$

Substituting the values of the various constants in the equation for K we have

$$K = \frac{4000 \times .05 \times .15 \times 56{,}700 \times .0161 \times \overline{100}^2}{.85^2}$$

$K = 379{,}040{,}000$

and

$$x = \sqrt{\frac{3\times 37904\times 10^4}{4\times 10\times 10^{16}+3\times 37904\times 10^4}} = .053$$

Thus we derive a value of 5.3 per cent. for the most economic loss, and hence can calculate the size of conductor $= S$.

4. Cross sectional area of conductor [equation (g) page 140, Vol. XIII No. 3].

$$S = \frac{1000(1-x)^2 P K_1 L}{E_R^2 \cos^2\theta\ x}$$

$$S = \frac{1000(1-.053)^2\times 20{,}000\times 56700\times 100}{10^{10}\times .85^2\times .053}$$

$S = 265{,}500$ circular mils.

But the nearest size standard cable is 250,000 circular mils. This size cable (stranded cable) is adopted, and all the following computations based upon that size. This will alter our value of x as found under economic loss, hence a new value x_1 must be calculated, as given under (6 *b* of this problem).

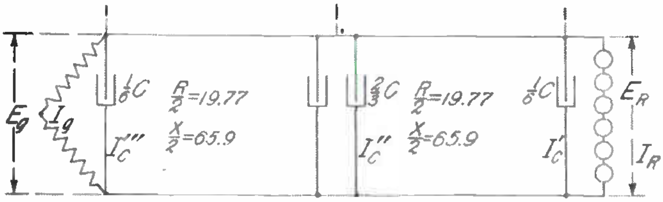


Fig. 15

5-*a*. Pounds of conductor [equation (3) page 139, Vol. XIII No. 3]
Pounds of conductor $= 3LK_2S$
$Lbs = 3\times 100\times .0161\times 250{,}000 = 1{,}207{,}500$

b. Cost of conductor (\$.15 per lb.) \$.15 × 1,207,500 = \$181,125.

This cost is for one line transmitting 20,000 kw.

c. Interest on line investment (conductor only) per annum \$181,125 × .05 = \$9,056.25

6. Resistance of line (single wire). Eq. (6) page 139, Vol. XIII No. 3

$$R = \frac{K_1 L}{S} = \frac{56700\times 100}{250{,}000} = 22.68 \text{ ohms.}$$

The per cent. increase in resistance for 60 cycles (see Skin Effect page 451, Vol. XII No. 10) equals 0.8 per cent. for the size cable adopted.

This is an increase of 0.8 per cent. in the resistance hence the resistance per wire will be $22.68\times 1.008 = 22.86$ ohms.

b. Having the resistance of our cable we are now in position to recalculate the loss for 250,000 circular mil cable, this being slightly different from the economic loss x as calculated under (3) due to the fact of choosing a 250,000 circular mil cable as opposed to a 265,500 circular mil cable as given by formula. See page 140, Vol. XIII No. 3

$$\frac{1000\ R_1 P}{E_R^2\cos^2\theta} = \frac{x_1}{(1-x_1)^2} \qquad \frac{1000\ R_1}{E_R^2\cos^2\theta} = a$$

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

In this case $R_1 = 22.86$

$$a = \frac{22.86\times 20{,}000\times 1000}{10^{10}\times .85^2} = .0633$$

$$x_1 = \frac{(1.1266)\pm\sqrt{1.2532}}{.1266} = .0561$$

The economic loss for this particular case is hence 5.61 per cent.

7-*a*. Kilowatts loss on line (RI^2 loss)
Kilowatts loss on line $= Px_1$
$20{,}000\times .0561 = 1122$ kw.

b. Kilowatts delivered at 100,000 volts, $\cos\theta = .85$
$20{,}000 - 1122 = 18{,}878$ kw.

c. Kilovolt amps. delivered receiving end
$$\frac{18878}{\cos\theta} = \frac{18878}{.85} = 22{,}209 \text{ k.v.a.}$$

d. Receiver current $\frac{k.v.a.}{\sqrt{3}E_R} = \frac{22{,}209}{\sqrt{3}\times 100{,}000}$
$= 128.2$ amps.

8. *Line spacing* of conductors. (Table) page 449, Vol. XII No. 10. 114 in. line spacing.

a. *Capacity.* (Table)

For 114 in. (by interpolation between 108 in. and 120 in.) capacity per 1000 feet of line (2 conductors) $= .001415$ *m.f.* For 100 miles $= 100\times 5.28\times .001415 = .7471$ *m.f.*

b. *Charging current.* (Table)

For 114 in. (by interpolation between 108 in. and 120 in. we get $.06165\times 10^{-3}$ amp. per 1000 feet per 1000 volts.

Approximation of charging current per wire for the line:

$$.0615\times 10^{-3}\times 100\times 5.28\times 100 = 32.5 \text{ amps.}$$

c. *Self induction.* (Table)

For 114 in. (by interpolation between 108 in. and 120 in.) we get .3847 milli-henries per 1000 feet.

Self induction (single wire) for line $= .3847\times 100\times 5.28 = 203.12$ milli-henrics.

d. *Inductive reactance* (ohms). (Table)

Values as given in table $= \sqrt{3}\times x$. $x =$ reactance for a single wire. These values multiplied by the current per wire give the reactance drop per phase.

Reactance for 114 in. (by interpolation between 108 in. and 120 in.) we get .2512 ohms per 1000 feet.

For total line (per phase) $= .2512 \times 100 \times 5.28 = 131.8$ ohms.

9. Natural period of line.

$$P = \frac{7900}{\sqrt{LC}}$$

$L = 203.12$ milli-henries.

$C = .7471$ microfarads.

$$P = \frac{7900}{\sqrt{203.12 \times .7471 \times 2}} = 454$$

From this we conclude that 60 cycles is a safe frequency.

10. *Voltage and current at generating end under full load conditions.*

Under this heading we shall make certain assumptions which will greatly facilitate the calculations, and while they introduce approximations, still the results attained are very close to the true state of affairs, and do not seriously affect the accuracy of the problem.

Consider the capacity of the line as concentrated at points as shown in figure below.

The calculations are based on a single-phase of the line as shown in Fig. 15.

Reactance per phase (calculated 8*d*) $X = 131.8$ ohms.

Resistance per phase $= \sqrt{3} \times 22.86 = R = 39.55$ ohms.

$$\frac{X}{2} = 65.9 \qquad \frac{R}{2} = 19.77$$

Values of X and R just calculated are not the true values of reactance and resistance per phase, but are thus designated to avoid the continual multiplying by the factor $\sqrt{3}$. Thus the drop in any phase can be found by taking these values and multiplying by the current per leg.

Consider the current along the line as separated into its components, power and wattless, and calculate the drop due to each.

Assume the following notation:

E_R = receiver voltage.

E^1 = voltage across center of line.

E_g = voltage at generating end.

I_R = current in receiving circuit.

$I_P = I_R \cos\theta$ = power component of current, I_R.

$I_{W} = I_R \sin\theta$ = wattless component of current, I_R.

I_c' = charging current per wire for condenser at receiver end.

I_c'' = charging current per wire for condenser at middle of line.

I_c''' = charging current per wire for condenser at generator end.

I_{W}' = wattless component current in section 1 of line.

I_{W}'' = wattless component current in section 2 of line.

I_{W}^{g} = wattless component current in generator.

I_g = total generator current.

The quantities together with their values for this particular problem are clearly shown in the vector diagram (Fig. 16).

$E_R = 100{,}000$

$I_R = 128.2$

$I_P = I_R \cos\theta = 128.2 \times .85 = 109$ amps.

$I_W = I_R \sin\theta = 128.2 \times .527 = 67.6$ amps.

$\cos\theta = .85$

Charging current I_c' for condenser at receiving end.

$$I_c' = \frac{2}{\sqrt{3}}\left(\frac{1}{6}\omega C E_R\right) \quad \omega = 2\pi f = 377$$

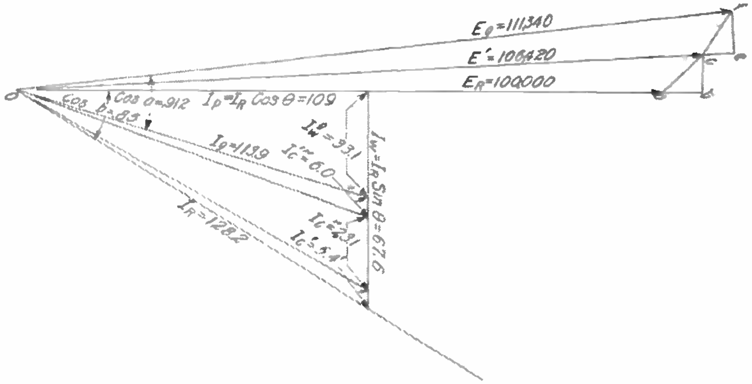


Fig. 16

$$C = \frac{.7471}{10^6}$$

$$E_R = 10^5$$

$$I_c' = \frac{2 \times 377 \times .7471 \times 10^5}{\sqrt{3} \times 6 \times 10^6} = 5.4 \text{ amps.}$$

This is shown plotted in Fig. 16.

$I_W' = 67.6 - 5.4 = 62.2$ amps.

Drop section 1 of line.

$$\text{In phase}\begin{cases} \frac{R}{2} I_P = 19.77 \times 109 & = \quad 2155 \\ \frac{X}{2} I'_W = 65.9 \times 62.2 & = \quad 4100 \end{cases}$$

$$ab = \underline{6255}$$

$$\text{In quadrature}\begin{cases} \frac{R}{2} I'_W = 19.77 \times 62.2 & = -1230 \\ \frac{X}{2} I_P = 65.9 \times 109 & = \quad 7183 \end{cases}$$

$$bc = \underline{5953}$$

Generator voltage full load 111,340.

Charging current I_c''' for condenser at generating end of line.

$$I_c''' = \frac{2}{\sqrt{3}}\left[\frac{\omega C E_g}{6}\right]$$

$$I_c''' = \frac{2}{\sqrt{3}}\left[\frac{1 \times 377 \times .7471 \times 111,340}{6 \times 10^6}\right] = 6.0$$

amps.

Current at generating end:

$$I_g = \sqrt{\frac{I_g}{I_P + I_{W''}^2}}$$

$I_{W''}^{g} = 67.6 - 34.5 \quad = 33.1$

$I_P = \quad = 109$

$I_g = \sqrt{109^2 + 33.1^2} = 113.9$ amps.

K.v.a. **at Generating End**

$k.v.a. = \sqrt{3} E_g I_g \quad = \sqrt{3} \times 111,340 \times 113.9 =$ 21.965

Power factor generator end $= \frac{20000}{21930} = .912.$

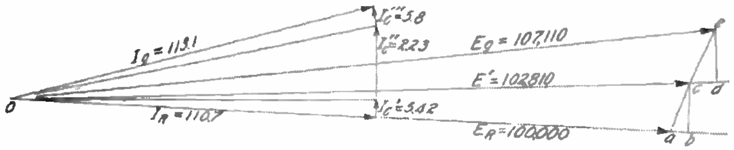


Fig. 17

Add on the drop in Fig. 16 as shown.

$E' = \sqrt{\overline{Ob}^2 + \overline{bc}^2}$

$Ob = Oa + ab = 100,000 + 6255 = 106,255$

$bc = \quad 5,953$

$E' = \sqrt{106,255^2 + 5,953^2} = \quad 106,420$

Charging current for condensers at middle of line.

$$I_c'' = \frac{2}{\sqrt{3}}\left[\frac{4 \omega C E'}{6}\right]$$

$$I_c'' = \frac{2}{\sqrt{3}}\left[\frac{4 \times 377 \times .7471 \times 106,420}{6 \times 10^6}\right] = 23.1$$

amps.

$I''_W = I'_W - I''_c = 62.2 - 23.1 = 39.1$ amps.

Drop Section (2):

$$\text{In phase}\begin{cases} \frac{R}{2} I_P = 19.77 \times 109 & = \quad 2155 \\ \frac{X}{2} = 65.9 \times 39.1 & = \quad 2577 \end{cases}$$

$$ce = \underline{4732}$$

$$\text{In quadrature}\begin{cases} \frac{R}{2} I''_W = 19.77 \times 39.1 & = -\ 773 \\ \frac{X}{2} I_P = 65.9 \times 109 & = \quad 7183 \end{cases}$$

$$ef = \underline{6410}$$

$E_g = \sqrt{\overline{Oe}^2 + \overline{ef}^2}$

$Oe = Oc + ce = 106,420 + 4.732 = 111,152$

$ef = \quad 6,410$

$E_g = \sqrt{111,152^2 + 6,410^2} = \quad 111,340$

Full load conditions.

	Generating end.	Receiving end.
Load	20,000 kw.	18,878 kw.
Voltage	111,340	100,000
Power factor	.91	.85
K.v.a.	21,965	22,209

Loss on line 1122 kw.

Per cent. total drop 11.1 per cent.

11. Regulation of line ($\cos\theta = 1.00$). See page 141, Vol. XIII No. 3

Kilowatts generating end	20,000
Voltage receiving end E_R	100.000
Resistance per wire, R_1	22.86

From formula page141. Vol. XIII No. 3, we have

$$\frac{R_1 P}{E_R^2 \cos^2\theta} = \frac{x_1}{(1 - x_1)^2}$$

In this case $\cos\theta = 1$

$$\frac{R_1 P}{E_R^2 \cos^2\theta} = a = \frac{22.86 \times 20,000 \times 10^3}{10^{10}} = .0457$$

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

$$= \frac{(1.0914) \pm \sqrt{1.1828}}{.0914} = .0415$$

x_1 per cent. loss = 4.15 per cent.

Loss in kw. = 20,000 × .0415 = 830

Kw. delivered at receiving end, 20,000 − 830 = 19,170

I_R = Amperes at receiving end $\frac{19,170,000}{\sqrt{3} \times 100,000}$

= 110 7

Charging current I_c' for condenser at receiving end $= 5.42$ (calculated in 10)
See Fig. 17 for graphic outline of problem.

Drop Section (1).

$\frac{R}{2} \times I_R = 19.77 \times 110.7 \qquad = 2189$

$\frac{X}{2} \times I_c' = 65.9 \times 5.42 \qquad = 357$

$ab = 2546$

$\frac{R}{2} \times I_c' = 19.77 \times 5.42 \qquad = 107$

$\frac{X}{2} \times I_R = 65.9 \times 110.7 \qquad = 7295$

$bc = 7402$

Add these drops in Fig. as shown.
Voltage at middle of line $= E'$.

$E' = \sqrt{\overline{Ob}^2 + \overline{bc}^2}$
$Ob = Oa + ab = 100.000 + 2,546 = 102,546$
$bc = \qquad = 7,402$
$E' = \sqrt{102,546^2 + 7402^2} \qquad = 102.810$

Rise of Voltage at No Load.

Consider the voltage at generating end as held constant between full load ($\cos\theta = 1$) and no load. At no load the voltage will rise in value from the receiving end of line toward the generating end.

It will be sufficiently accurate to calculate the charging current using the value E_g (generator voltage) in each case since the variation in voltage along the line will not be so great as to seriously affect the results.

See Fig. 18.

$E_g = 107,110$

$I_c'' = \frac{2}{\sqrt{3}} \left[\frac{4 \times 377 \times .7471 \times 107,110}{6 \times 10^6} \right] = 23.2$ amps.

$I_c' = \frac{1}{4} \times 23.2 = 5.8$ amps.

Voltage Rise Section 2.

$\frac{R}{2}(I_c'' + I_c') = \frac{R}{2}(23.2 + 5.8) = 19.77 \times 29 = (bc) = 573$

$\frac{X}{2}(I_c'' + I_c') = 65.9 \times 29 \qquad = (ab) = 1911$

$E' = \sqrt{\overline{Ob}^2 + \overline{bc}^2}$
$Ob = 107,110 + 1911 \qquad = 109,021$
$bc = \qquad 573$
$E' = \sqrt{109.021^2 + 573^2} \qquad = 100,022$

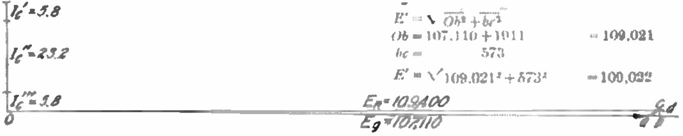


Fig. 18

$I_c'' = \frac{2}{\sqrt{3}} \left[\frac{4 \times 377 \times .7471 \times 102,810}{6 \times 10^6} \right] = 22.3$ amps.

Drop section (2).

$\frac{R}{2} \times I_R = 19.77 \times 110.7 \qquad = 2180$

$\frac{X}{2} \times (I_c' + I_c'') = 65.9 \times 27.72 \qquad = 1827$

$cd = 4016$

$\frac{R}{2} \times (I_c' + I_c'') = 19.77 \times 27.72 \qquad = 548$

$\frac{X}{2} \times I_R = 65.9 \times 110.7 \qquad = 7295$

$de = 7843$

$E_g = \sqrt{\overline{Od}^2 + \overline{de}^2}$
$Od = 102,810 + 4,016 \qquad = 106,826$
$de = \qquad = 7,843$
$E_g = \sqrt{106,826^2 + 7,843^2} = 107,110$ volts.

Charging Current Generator End I_c'''.

$I_c''' = \frac{2}{\sqrt{3}} \left[\frac{377 \times .7471 \times 107,110}{6 \times 10^6} \right] = 5.8$ amps.

Generator current $= I_g$

$I' = \sqrt{110.7^2 + 5.42^2} = 110.8$

$I'' = \sqrt{110.8^2 + 22.3^2} = 113.$

$I_g = \sqrt{113^2 + 5.8^2} = 113.1$ amps.

Rise Section 1.

$\frac{R}{2} \times I_c' = 19.77 \times 5.8 \qquad = 115$

$\frac{X}{2} \times I_c' = 65.9 \times 5.8 \quad = \quad cd = 382$

$\left[\frac{R}{2} \times I_c'\right]$ is negligible.

$\therefore E_g = 100,022 + 382 = 109,400$

Regulation.

$$\begin{array}{r} 109,400 \\ 100,000 \\ \hline 9,400 \end{array}$$ rise from full load to no load

$\frac{9400 \times 100}{100,000} = 9.4$ per cent.

SUMMARY

	Generating End	Receiving End
1. Load	40,000 kw.	37,750 kw.
Voltage full load	111,340 volts	100,000 volts
Power factor	.91	.85
K.v.a.	43,930	44,418

Loss on line	2244 kw.
Total drop full loaf	11.1 per cent.
Regulation ($\cos\theta = 1$)	9.4 per cent.
2. Pounds of conductor (copper)	2,415,000
Total cost of conductor (both lines)	\$362,250
Annual interest on investment	\$18,112.50
Cost of lost power	\$22 440.00

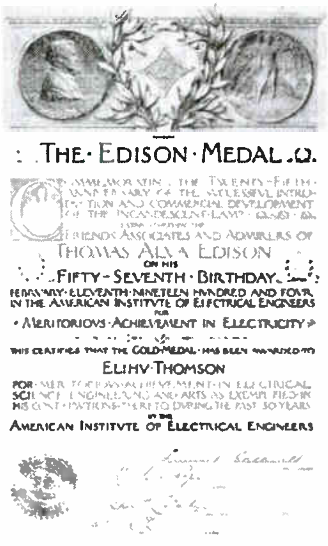
(To be Continued)

PRESENTATION OF EDISON MEDAL

The Edison Medal was instituted by the American Institute of Electrical Engineers in commemoration of the twenty-fifth anniversary of the commercial introduction of the Edison incandescent lamp, and for the first time was awarded to Prof. Elihu Thomson for meritorious achivement in electrical science, engineering, and the arts. The presentation was made at the annual dinner of the A.I.E.E., New York City, February 24, 1910. In acceptance, Prof. Thomson spoke as follow:

Anything which I might say on this occasion could only express in small measure my appreciation of the honor done me in the award of the first Edison medal. To be selected by such a representative body of men, as distinguished in the electrical profession as the Edison Medal Committee, is itself a sufficient recognition; one to be prized most highly. I most heartily thank the Committee.

It is a source of great satisfaction that the award bears the name of the chief of pioneers in the field of large electrical application, the name of one to whose energy and courage, to whose ingenuity and resourcefulness the art owes so much. I know that all present will agree that the name of Edison is peculiarly fitting to characterize an award given for electrical achievement. While the period of invention and technical advancement through which we have been recently passing has affected all fields, with none has the influence upon our conditions of life been more profound than with the applicaitons of electricity.



The· Edison· Medal

Commemorating the Twenty-Fifth Anniversary of the Successful Introduction and Commercial Development of the Incandescent Lamp · [illegible]

[illegible]

Friends Associates and Admirers of

Thomas Alva Edison

on his

Fifty-Seventh · Birthday

February · Eleventh · Nineteen Hundred and Four

in the American Institute of Electrical Engineers

for

· Meritorious · Achievement in Electricity ·

This certifies that the Gold Medal · has been awarded to

Elihu · Thomson

for meritorious achievement in electrical science engineering and arts as exemplified in his contributions thereto during the past 30 years

by the

American Institute of Electrical Engineers

Certificate of Award

When we look back to the early beginnings, we can realize the privilege of having lived at such a time so as to take some part in all that wonderful progress which has filled the succeeding years.

Who can enumerate the many conquests of man over nature's forces; the unlocking of the treasure house of knowledge of the universe around us? Through it man at last acquires the ability to navigate the air itself; an achievement which the most sanquine of us could scarcely have thought would come so soon. Let us hope that all this is the beginning of an age of still greater advances, in which man will build more and more upon the foundations already laid.

I have sometimes been asked whether I did not like to read what may be called scientific fiction; in which an author tried to picture future scientific progress. I have usually answered "No," for "Truth is stranger than fiction." It is the unexpected which happens. A speaking tube might suggest a telephone, but what writer of fiction was there to predict that such an inexpressibly simple arrangement of wire and iron could transmit speech before Bell did it. Who of them told us of the wireless telegraph, and that an ordinary simple induction coil could stir the ether and transmit signals over hundreds of miles? What fiction writer had imagination so penetrating as to tell us that we could some day see our bones, and that surgery would be helped thereby? Who knew of the wonderful properties of radium, or ever imagined them possible? To come nearer home, who could picture—as the many triumphs of electrical engineering—a dozen or more different kinds of electric lights; transmission of thousands of horsepower of energy over hundreds of miles; the electric railroad, and the other developments which in so short a time have far outstripped our most extravagant expectations?

As an instance of what was in the minds of people at the early inception of our art, I will read a little extract which I happened to find in one of the issues of the Gas Light

Journal of 1878, when a discussion of the forthcoming Edison light, then the platinum wire lamp, was had. The following colloquy took place:

> Mr. D.—The gas we are now burning comes from Birchington, a distance of four and a quarter miles. Would it be possible for me, if I wished to do so, to send electricity from here to Birchington to give light there?
>
> Mr. G.—It would be possible, but not economical.
>
> Mr. D.—Then how am I to light Birchington?
>
> Mr. G.—I should say, decidedly, take your machines to Birchington.
>
> Mr. D.—What am I to do for light along the road between here and Birchington?
>
> Mr. G.—Place machines at convenient distances.
>
> Mr. D.—In other words, several stations in such a short distance!

That was the view of a gas man and actually occurred at a meeting of gas engineers at the time reported, and will be found in the Gas Light Journal.

I could go on and multiply instances of that kind, but that is merely a statement of conditions as they existed, and we have not time to go so far into ancient history.

I have but little more to say in response. I did not intend to make a speech of any length.

I shall always value very highly the distinction which has been accorded me. But however much one may be rewarded for doing that which his tastes and inclinations have led him to do, there is, indeed, another and more immediate reward, the hope of attaining, which is after all the strongest stimulus; I have sometimes referred to it as the "joy of accomplishment." It is the sense of satisfaction which accompanies the doing of a thing, the surmounting of an obstacle, the attainment of a goal. It is the pleasure of having tried, and in spite of difficulties, succeeded. Those who have done this can understand what it meant. I confess that where a result is brought about by compelling taste or aptitude, in whole or part, the question of how much credit is to be accorded is not easy to determine. I am not arguing for the view of the ascetics that there belongs the greatest credit to those who make themselves most miserable.

It is sometimes the case that a difficult thing is a sort of challenge, appealing to the imagination. After all, to the artist, the inventor, the scientific investigator, the engineer and the broad man of business, imagination is often the chief mainspring of action. It enables him mentally to picture a thing as done or accomplished before the doing, and so to seek out the plan to be followed or the measure to be taken. Imagination furnishes the dreams that may come true; they are carried into practice, and if the things done are worth while, success and its accompanying "joy of accomplishment" follow.

What matters it that there are many and unlooked for hardships, setbacks, and struggles, against adverse circumstances, if the end in view is at last attained? There will always be need of energy, self denial and persistence, if we would follow out our plans. Too often success is measured by financial outcome and this we must guard against. We need the broader view which causes us to sympathize with all progress and assist in it.

I wish now to add that in honoring me you should not forget that there were faithful co-workers—some of whom I see now here—without whose help at times when it was most needed much less could have been accomplished. I mean also to include in this those through whose wisdom and business sagacity the means were provided for doing such things as seemed needful at the time. To them a high tribute is due, for they contributed in large measure to render possible that for which the Edison medal has been so graciously accorded.

Ladies and gentlemen, members of the Institute: I thank you all with the utmost sincerity for the honor you do me in being present on this occasion.