RAILWAY MOTIVE POWER OF THE FUTURE

Electric locomotive and train on the Chicago, Milwaukee and St. Paul railroad, descending a two per cent grade on the eastern slope of the Rockies.

Commission of Conservation

Canada

SIR CLIFFORD SIFTON, K.C.M.G., Chairman
JAMES WHITE, Assistant to Chairman, Deputy Head

REPORT

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Electrification of Railways

BY

S. T. Dodd

General Electric Company, Schenectady, N.Y.

THE subject of the electrification of trunk line railways has been discussed by eminent engineers for a number of years and the advantages claimed for it, including the possible economies hoped for by the elimination of the losses characterizing the steam locomotive, have been set forth at length. It would, therefore, be somewhat of a presumption on my part to repeat the substance of such discussions without adding something new to the subject. I believe I shall be able to add such new material if, instead of attempting to give a discussion of generalities, I take up a particular electrification and show the operating results which have been accomplished on it.

An example of heavy railway electrification that is of interest to Canadians is that of the Montreal terminal of the Canadian Northern railway, the equipment of which was supplied by the Canadian General Electric Company. This electrification was installed to handle the suburban and trunk line traffic from a passenger station in Montreal to the suburban territory beyond Mount Royal, at which point the trunk line traffic will be transferred to regular steam locomotives. This electrification could be made the subject of a very interesting discussion, but the fact is that terminal conditions do not present all the problems for solution that are presented in trunk line traffic; and I believe it would be preferable to discuss the results of trunk line electrification.

This is my reason for dealing with the electrification of the Rocky Mountain and Missoula divisions of the Chicago, Milwaukee & St. Paul railway, which have been in electric operation for over a year. In particular, I wish to emphasize, what will be presented more clearly in the body of my paper, that this should not be referred to as a typical electrification, although it is, in fact, at the present time the premier railway electrification of the world.

The Western extension of the Chicago, Milwaukee & St. Paul railway is the latest transcontinental line to be completed, the company having commenced construction from the western terminus of their lines, Bismarck, N.D., about ten years ago. The line represents not only the latest, but, in some respects, the most difficult, railway construction in the country. The grades, curves and frequent tunnels in the mountain section, and, in winter, the deep snow and excessively cold weather, present difficulties in engineering, construction and operation which it was foreseen would test the capacity of steam locomotives when handling heavy trunk line traffic. As a consequence, it was probably kept in mind from the beginning of this construction that, at least part of the line, would eventually be equipped electrically.

Physical Condition

The section which is now operated electrically crosses three mountain ranges, the Belt mountains, the Rockies and the Bitter Roots. There are numerous grades of 1 per cent or more, the heaviest of which is 21 miles of 2 per cent on the eastern slope of the Rockies, and the longest is 49 miles of 1 per cent on the western slope of the Belt mountains. The maximum curvature is 10 degrees, and there are numerous tunnels through the mountains, of which the longest is the St. Paul Pass tunnel, over 1½ miles in length through the ridge of the Bitter Roots.

Traffic consists of 2 all-steel passenger trains daily in each direction, the 'Olympian' and the 'Columbian,' also 4 to 6 freight trains daily in each direction. Westbound tonnage is made up of manufactured products and merchandise for the Pacific coast and foreign shipment. Eastbound tonnage includes grain, lumber, mining products and live stock. As a large portion of the traffic is through freight, the trains are made up of a miscellaneous assortment of box, flat, stock, refrigerator and other cars, varying in weight from 11 to 25 tons empty, and as high as 70 tons loaded. Since electrification, the standard weight of a freight train is approximately 2,500 tons trailing westbound, against the 2 per cent grades, and 3,000 tons trailing eastbound against the 1.6 per cent grades.

Coal in this region is expensive and requires a long haul from the mines. Water-power on the other hand is abundant and affords a very cheap source of power.

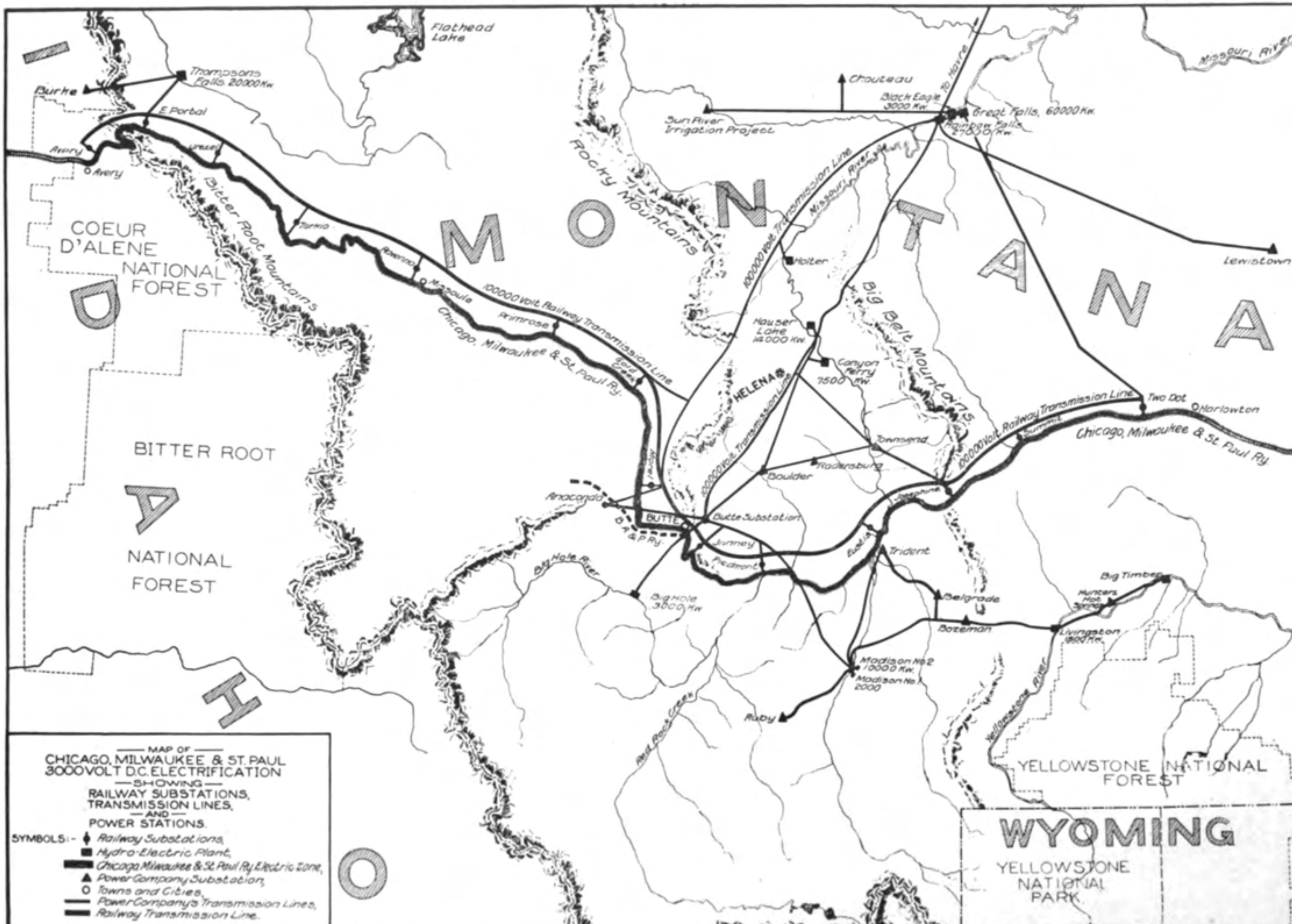
The section selected for electrification includes four engine divisions in the heaviest grade sections of the system, extending from Harlowton on the east to Avery on the west, a distance of 440 miles. This comprises 590 miles of electrically equipped single track. To get some conception of the magnitude of this electrification, it might be pointed out that 440 miles is comparable to the distance from Ottawa to St. John, N.B., on the east, or to Detroit on the west, or the distance from Ottawa to New York. The extent of this electrification is not generally appreciated, but, when a proper conception of the territory covered is really understood, it can easily be seen that there is no exaggeration in making the statement that it is the greatest railway electrification in the world. At present, there is, in the United States about 1,100 miles of electrified steam railway track comprising 2,300 miles of single track. The Milwaukee electrification, therefore, constitutes about 40 per cent of this mileage.

In addition, the Chicago, Milwaukee & St. Paul has let contracts for the electrification of another section consisting of two engine divisions, 211 miles in length, extending eastward from Seattle over the Cascade mountains, to Othello. On the completion of this section, the total electrified track on the system will be about 650 miles of route, or 860 miles of single track.

The present electrified section from Harlowton to Avery was formerly operated under steam in four engine divisions of approximately 110 miles each. The first electric locomotive was put in service on the section from Three Forks to Deer Lodge, across the Rockies, on Dec. 9th, 1915, and, during 1916, the electrification was extended to the whole 440 miles. Immediately upon the commencement of electric operation these four divisions were consolidated into two divisions, one running from Harlowton to Deer Lodge, 220 miles, known as the Rocky Mountain division, the other running from Deer Lodge to Avery, 220 miles, known as the Missoula division. A locomotive run is now 220 miles where the steam locomotive run was previously 110 miles. Some train crews are changed every 110 miles, others make 220 miles on a run, depending on the speed of the train and the time they are on the road. There seems to be no particular reason why 220 miles should be the limit of an engine run except convenience in maintenance of locomotives by keeping all rolling stock on its own divisions. As a matter of fact, when necessary, a locomotive is run through with a train from one end of the electrification to the other. When one thinks of the possibility of running one engine without change over a distance comparable to that from Ottawa to New York, one realizes the tremendous advance that has been made in railway operation by electricity.

Power Supply

Electric power for operation of the railway is obtained from the lines of the Montana Power Co., which has a number of power plants feeding a network of high tension distribution lines throughout the state. Like many other large corporations, the Montana Power Co. has



MAP OF CHICAGO, MILWAUKEE AND ST. PAUL RAILROAD, 3,000 V.D.C. ELECTRIFICATION, SHOWING RAILROAD been built up by the consolidation of a number of small companies. About 1898, the first of these, the Big Hole Power Co., was formed to build a 4,000 h.p. plant for furnishing power at 15,000 volts over a 22-mile line to Butte for use in smelters and around the mines. About the same time, the Canyon Ferry plant of 4,000 h.p. was developed for power transmission to the city of Helena and was, later, increased to 10,000 h.p. In 1910, the Rainbow Power development at Great falls was completed, furnishing 33,300 h.p., with a possible extension to 40,000 h.p. About 1912, these companies, together with a number of other independent power companies, were consolidated into one large company known as the Montana Power Company. In 1913, in view of the electrification of the Chicago, Milwaukee & St. Paul Ry., construction was started on an 80,000 h.p. development at Great falls on the Missouri river, and a 40,000 h.p. development at Thompson falls on the Columbia river. All these plants are tied together in one big transmission system at 100,000 volts, distributing electricity for lighting and power purposes to the various cities and industries in the state of Montana. Altogether, there are 12 hydro-electric power houses and 4 steam power houses feeding into the transmission system. It is sometimes urged against railway electrification that an accident to the power house will tie up the whole railway system, but when the railway company obtains its power from an extensive system such as this, the possibility of such an accident is reduced to a minimum. The Montana Power Co. obtains its power from the Missouri, the Yellowstone and the Columbia rivers and any accident that would shut down its transmission lines entirely would be a disaster state-wide, if not national, in importance.

Parallel to the line of the railway is a 100,000-volt transmission line which feeds power to the 14 substations along the line. As this transmission line is crossed at seven points by the lines of the Montana Power Co., power may be drawn for the railway service, at all or any of the seven crossings.

Substations

There are 14 substations distributed along the railway, at intervals of approximately 30 miles, which transform power from 100,000 volts, three-phase, to 3,000 volts, direct current, at the trolley. The standard substation equipment consists of two 2,000-k.w. motor generator sets, each consisting of a 60-cycle, three-phase, 2,300-volt motor driving two 750-k.w., 1,500-volt generators connected in series. Three of the stations, those at Piedmont, Janney and Avery, are equipped with three 1,500-k.w. units, and one at East Portal with three 2,000-k.w. units. This is due to the greater concentration of load at these points.

Locomotives

The most important portion of the whole electrification is the locomotive equipment used for handling trains across this electrified zone. The standard locomotive weighs approximately 280 tons and has eight driving axles with a guiding truck at either end. This design of locomotive, and the weight and the arrangement of axles, are dictated by operating conditions. The fundamental requirement is the handling of trains weighing 2,000 to 3,000 tons, total, on grades of 1½ to 2 per cent. On a 2 per cent grade, this will require a tractive effort to be developed by the locomotive of approximately 150,000 lbs. Figuring on a coefficient of adhesion of 20 per cent, this means that the locomotive must have 750,000 lbs., on drivers and, in the present case, to provide due allowance for starting effort, the locomotives weigh 900,000 lbs., on drivers. Each train as described above is to be handled by two locomotives weighing approximately 450,000 lbs. each on drivers. Steam railway practice limits the weight on axles to 50,000 or 60,000 lbs. As a consequence each locomotive must be equipped with eight driving axles. For freight service each locomotive must exert this tractive effort at a speed of 15 miles per hour, which is equivalent to 3,000 h.p. The motor equipment of each locomotive must therefore be capable of developing 3,000 h.p. for considerable periods of time.

The following are the principal data applying to the freight locomotive:

Weight on each driving axle..........	56,250 lbs.
Total weight on drivers..............	450,000 "
Weight on guiding trucks............	110,000 "
Weight, total.......................	560,000 "
Distance between driving axles.......	10′ 6″
Length over all.....................	112′ 0″

The weights of different locomotives will vary somewhat. The weight of the passenger locomotives, which are equipped with oil-burning steam boilers and with water and oil tanks for heating passenger trains, is approximately 300 tons.

On account of the great length of the locomotive, the cab is divided into two halves with a motorman's compartment or operating room at the outer end of each half. This compartment contains the controller, air brake, gauges, valves and other apparatus requisite for handling the locomotive. The remainder of the cab is an apparatus compartment. Through the centre of this compartment is placed in a solid bank, the rheostats, contactors and the motor generator set which drives the blower for ventilating the motors and furnishes exciting current for control. An ample aisle is left down each side of the apparatus bank for inspection of contactors and wiring. The oil-fired heater, with water and oil tanks, which furnishes steam for the heating of the passenger train is in the back end of the cab. The two cabs of each locomotive are duplicates, each equipped with apparatus similarly arranged. For very small trains the two halves of the locomotive can be uncoupled from each other and one of them used as a single-ended unit.

There are eight motors on each locomotive each geared directly to a driving axle. The motor is known as the GE-253 and is rated at 430 h.p., with a continuous rating of 375 h.p. The weight of one motor and gears is approximately 7 tons. The motor is geared with twin gears, one at each end of the armature shaft. The gear ratio is 4·55 for freight service and 2·45 for passenger service. The eight motors on a locomotive will develop at their one-hour capacity a tractive effort of 84,500 lbs., at a speed of 19 miles per hour, and at their continuous capacity, a tractive effort of 70,700 lbs., at a speed of 15·9 miles per hour. These correspond to 19 per cent and 16 per cent of the weight on drivers, respectively. With the passenger gearing, the locomotives will develop tractive efforts of approximately half of this amount at double the speeds.

The capacity of the complete locomotive is 3,440 h.p. at the one-hour rating of the motors and 3,000 h.p. at the continuous all-day rating.

In spite of the enormous capacity of the locomotives and the splendid results attained by the electrification, it will be noted that there is nothing spectacular or revolutionary in their design and construction. The same construction which has demonstrated its efficiency, simplicity and low cost of maintenance in street car service has simply been extended to steam railway conditions with corresponding increase in power of motor equipment and in strength of mechanical equipment.

It might be of interest to discuss for a moment this question of mechanical transmission in electrical locomotives. Various methods of mechanical transmission, such as combinations of side rods with, and without, gears, have been tried for electric locomotive service, particularly in Europe, where a bewildering variety of different designs has been experimented on. The *Electric Railway Journal*, in an editorial in its issue of April 21st, 1917, puts its finger on the weakness of all of these designs. The editor points out that gear losses are usually assumed at approximately 5 per cent and, as side rod losses are at least of the same amount, the side rod seems to be rather a high price to pay for the advantage to be obtained by it. The editor might well have gone further than he did. According to the A.I.E.E. standard rules, gear loss on a railway motor may be assumed at 2.5 per cent at full load of the motor. The power loss in side-rod friction is proportional to the pressure on the crank pins multiplied by the speed of rubbing and by the coefficient of friction. Reducing this to a formula, we can express the loss in tractive effort due to crank pin losses, on a single crank pin, by formula:

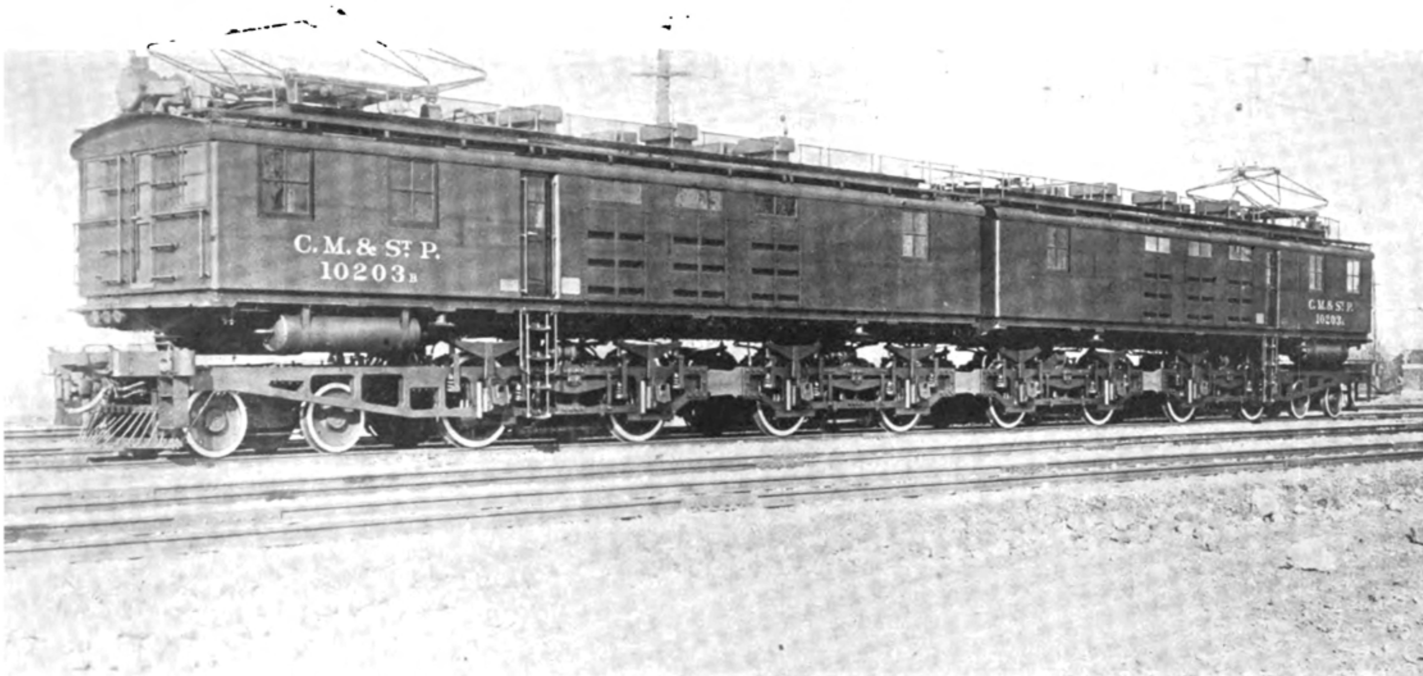
$$\text{Loss} = \text{T. E.} \times f \times \frac{d}{D}$$

where

T.E. = T. E. at the wheel rim
f = Coefficient of friction at the crank pin
d = Diameter of the crank pin
D = Diameter of the driving wheel

As crank pins in practice are from 6 in. to 9 in. in diameter, while coefficients of friction of lubricated surfaces are from 3 per cent to 6 per cent, it is an easy matter to calculate the loss in a single crank. Since, on every side rod there are at least two crank pins, one on each end, while in many designs of side-rod locomotives, such as those employing jackshafts, there are several such cranks in series and, remembering that to these must be added the friction losses in jackshaft bearings and the additional losses in armature bearings produced by side-rod pressure, it is easy to see that the side-rod losses often amount to a very serious item. In these days, when an engineer buying a turbine figures closely the efficiency and steam consumption of his turbine and capitalizes the losses in order to determine what he can pay for every 1 per cent in efficiency, we are justified in eliminating every loss in efficiency due to complicated methods of transmission and in gearing our motors directly to the axle.

Maintenance of equipment is another item which enters seriously into consideration. Unquestionably the most economical design of locomotive from the maintenance standpoint is the locomotive without gears or with motors geared directly to the axle. Referring to the Interstate Commerce Commission's report, we



THE KING OF THE RAILS

A 3,000-volt electric locomotive on the Chicago, Milwaukee and St. Paul railroad.

find the following among the records of cost of maintenance of electric locomotives:

Butte, Anaconda & Pacific	1915	3.9c	per loco. mile
" " "	1916	4.02c	" " "
New York Central........	1915	3.28c	" " "
" " "	1916	2.89c	" " "
Baltimore & Ohio.........	1914	4.9c	" " "

These costs of maintenance present one of the great arguments for the use of electric rather than steam locomotives, and such costs as I have quoted are not duplicated by any type of locomotive employing more complicated methods of transmission.

As compared with this, the cost of maintenance of a steam locomotive will run from 10c. to 20c. per locomotive mile, depending on the capacity of the locomotive and its service.

Regenerative Control

The locomotive is equipped with regenerative control; that is, the control system is so arranged that, when the train is going down grade, the driving motors can be used to retard the train by acting as generators and converting the energy of the train into electric energy which is returned to the trolley line. This regenerated energy may be returned to another train ascending the grade in the same section or, if there is no such train, it will be retransformed through the substations and delivered to the transmission line for general power purposes. A 3,000-ton train going down a 2 per cent grade may represent a kinetic energy of 3,500 h.p. and, if only a fraction of that amount can be recovered electrically, it may represent an economy that is well worth considering.

This regeneration is obtained by exciting the fields of the motors during braking to such an extent that the counter electro-motive force builds up higher than the line voltage and returns the current to the line. The control is so arranged that the equipment can drift over from motoring to braking by simply changing the position of the proper controller handles. That is, if a train running on the level approaches a curve, tunnel or other obstruction for which the engineer wishes to slow down, he can change his equipment from motoring to braking, gather up the train as he approaches the obstruction and then let out his train to full speed after he has passed the danger point. In the meantime, the power of the train has not been wasted by brakes but has been returned economically to the trolley line.

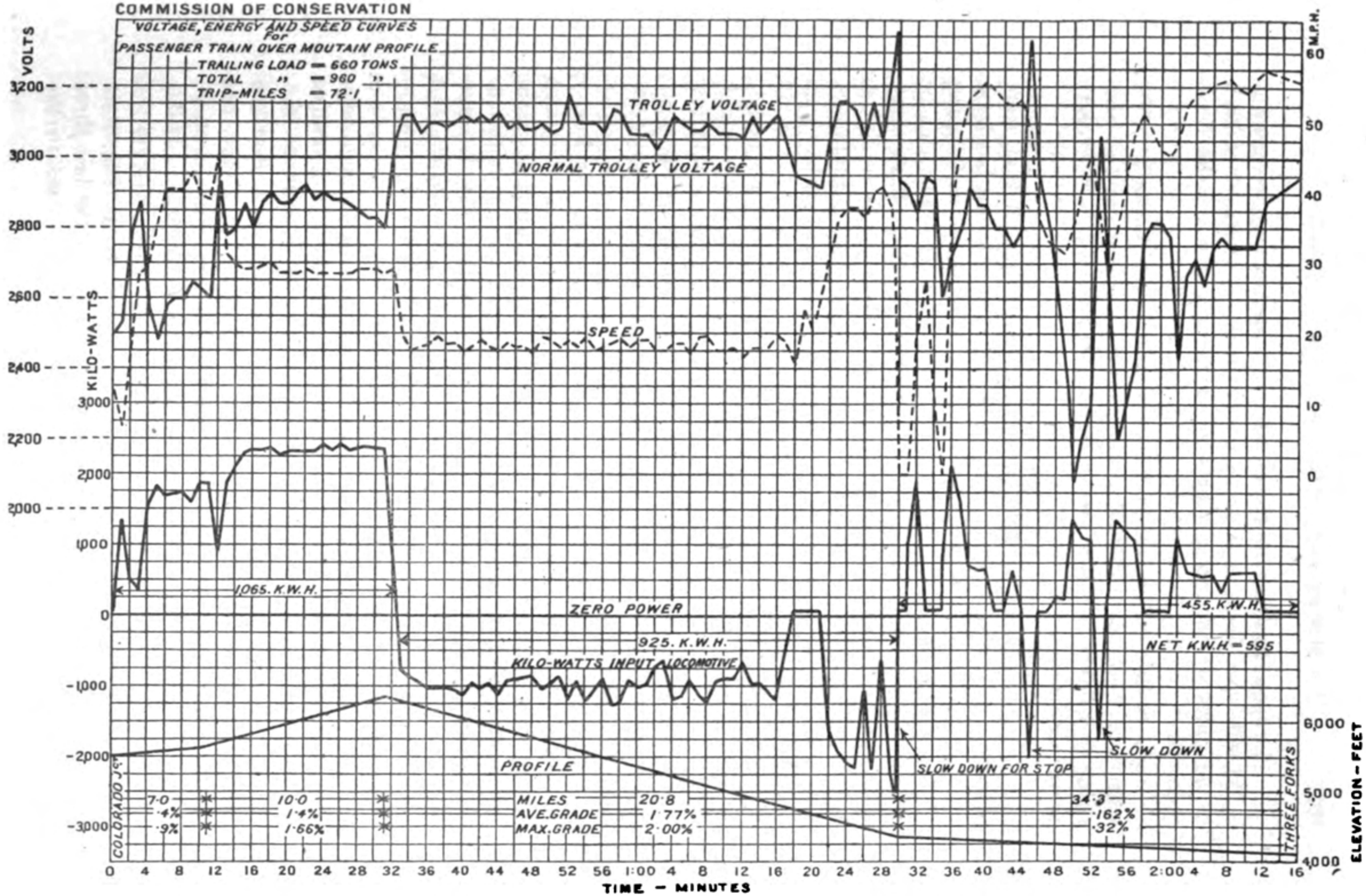
It has long been known that on a three-phase system the motors automatically act as a regenerative brake but at a constant speed. With a three-phase system, as soon as the train speed exceeds the speed of synchronism, the motors automatically return power to the line, but, by the series direct current motor and the regenerative system which has been installed on the Chicago, Milwaukee & St. Paul, it is possible to return power to the line through a wide range of speed.

A marked advantage of electric braking is that it is not subject to the alternating variations of speed which are produced by air braking, due to the leaking off of pressure and recharging of auxiliaries. In addition to this, the wear of brake shoes is eliminated, which amounts to a serious item when heavy trains are to be handled on long grades. The disasters which are sometimes due to overheating of brake shoes or brakeheads on such grades are also avoided by the use of electric braking. The electric braking takes place entirely at the front end of the train, the train is held steadily bunched up against the engine, and, at the same time, the air reservoirs are fully charged and the air brakes are held in reserve for an emergency.

The amount of power returned to the trolley by regeneration varies with the amount of the grade and the type of train. On specific tests, it has been shown that a train on a 2 per cent grade has regenerated 42.8 per cent of the power required to pull the same train up the grade. On the 1.66 per cent grade, 23.1 per cent has been regenerated. The records for the month of November, 1916, over the entire Rocky Mountain division for both freight and passenger trains show that the regeneration was equivalent to 11.3 per cent of the total power used at the motors.

Possibly the clearest idea of the electric operation of this system is to be obtained by study of the speed energy curves of a locomotive and train in operation. Such a set of curves is shown in one of the figures. This represents the record made by a train of 960 tons over a run of 72 miles up grade and down grade.

The lowest curve in the figure shows the profile of the track, the distances and gradients encountered. The next curve above shows the power input, or output, of the locomotive. Going up the grade of 1.4 per cent the locomotive draws approximately 2,400 k.w. from the trolley. As it goes over the peak of the grade the power drops to zero and reverses, and from this point, going down the grade, the curve indicates that the locomotive is pumping approximately 1,000 k.w. back into the trolley. When it reaches the level, the power swings from 2,000 k.w. positive in accelerating the train to approximately 2,500 k.w. negative in slowing down for stops.



Voltage, Energy and Speed Curves for Passenger Train over Continental Divide, Chicago, Milwaukee and St. Paul Railroad

The speed as shown on the next curve is approximately constant at 18 miles per hour when going down the grade and rises as high as 50 miles per hour for spurts when running free on the level sections.

The trolley voltage shown on the next curve is normal at 3,000 volts and drops to 2,900 volts when taking power from the line, rising to 3,100 volts when the train going down grade is delivering power to the line.

Operation

The results of operation have been all that were anticipated. The schedule speed of trains has been materially increased. For example, on the 20 miles of 2 per cent grade the running time of passenger trains can be reduced from 65 minutes, under steam, to approximately 40 minutes, with electrical operation. On the run from Deer Lodge to Butte, which, with a steam locomotive, required one hour and 20 minutes, a saving of 30 minutes can be made. In freight service, it has been found that, where the steam locomotives have required 10 to 12 hours to make 110 miles, electric locomotives can meet a schedule of 7 to 8 hours for the same distance. The serious delays which were often encountered in the winter time due to snow and low temperatures have been eliminated, as the electric locomotives are not delayed by excessively cold weather or by inability to obtain fuel and water in case of snow blockades.

The winter of 1914-15 was exceptionally severe in the Rocky Mountain division. Temperatures of 40 degrees below zero and heavy snow storms interfered seriously with the operation of steam locomotives and the electric locomotive had many opportunities to demonstrate its abilities and its superiority over the steam locomotive in such weather. Frequently, when a train was stalled and its steam locomotive was frozen and dead in the drifts, the electric was sent out to bring it in and to clear the tracks.

It is too early to speak very conclusively as to operating costs. We hope in a short time to have definite records of the cost of operation and its relation to similar costs prior to electrification.

The records on the Butte, Anaconda & Pacific show that the cost of maintenance of locomotives was reduced from 13.45c. per locomotive mile in the last six months of 1913, under steam operation, to 4.5c. in the corresponding months of 1914. We expect a similar reduction will be shown on the Chicago, Milwaukee & St. Paul.

From the records of power used upon the Rocky Mountain division, we can compare the amount of coal used in the last three months of 1915 with the amount of electric power used in the corresponding months of 1916. In 1915, the coal used on the Rocky Mountain division alone was 50,310 tons. In 1916, under electric power, a movement of the same tonnage required 17,821,000 kilowatt hours. In general, from the records of both the Butte, Anaconda & Pacific and the Chicago, Milwaukee & St. Paul, it appears that 1 k.w.h. of electric power will do approximately the same work in handling tonnage that 6 to 7 lbs. of coal will do upon the tender of a steam locomotive. To make this comparison more concrete, I may say that the records of the last three months of 1916 on the Rocky Mountain division showed a power consumption of 39.4 k.w.h. per 1,000 ton-miles, or that 1 k.w.h. delivered at the substation will handle 25.5 ton-miles. In 1915, under steam operation, 276 lbs. of coal were required per 1,000 ton-miles. In other words, a movement of the same amount (25.5 ton-miles) will require 7 lbs. of coal. If electric operation had depended on a steam-driven station instead of a hydro-electric station, the coal consumption would have been approximately half of this amount, or 3½ lbs. of coal, for a movement of 25.5 ton-miles. To put the same statement in terms of dollars and cents, it indicates that, by electrification of a trunk line railway, the cost of coal for operation of trains can be cut in two if electric power is produced from a steam-driven station. On the other hand, if electric power is produced from a hydro-electric station, the cost of power can be estimated on the basis of the unit costs of coal and electric power, keeping in mind the fact that 1 k.w.h. of electric power will do about the same amount of work that 7 lbs. of coal will on the steam locomotive.

The mountain sections have long been the limiting feature in the operation of the Chicago, Milwaukee & St. Paul railway, and perhaps the most emphatic conclusion which I can give to this paper is a quotation from a recent article by Mr. C. A. Goodnow, in charge of their electrification, in which he says, "Electrification has been such a tremendous success on the Milwaukee road that it is difficult to state the results without seeming exaggeration, but I think it quite within the fact to say that the Milwaukee road has forgotten that the Continental Divide exists."

The King of the Rails

The paper was concluded by showing a moving picture film that represented the story of the development of transportation.

Beginning with the earliest method of transportation it showed the Indian pack trains through the forests, after which came the settler clearing the forest and skidding on stone sleds and logs and boulders. The ox and horse showed a still further development in methods of transportation. Then came the steam locomotive, the 'De Witt Clinton' and train on the Hudson & Mohawk railway, followed later by the powerful steam locomotives of the present day. In the meantime, city transportation beginning with the horse-car had been followed by electric surface cars and heavy trains of elevated and subway expresses. Finally, came the application of electricity to heavy trunk line operation. Pictures were shown of the locomotive shops of the General Electric Company at Erie, Pa., where the Chicago, Milwaukee & St. Paul locomotives were built. The details of building and assembling the locomotive were also included. Finally, the completed electric locomotive was shown coupling up to a train at the beginning of the electrified division. Then followed a trip across the Rocky mountains, showing views from the train and also passing trains, both freight and passenger, pulled by electric locomotives. The latest form of transportation illustrated by this mighty modern engine gives the film its name, 'The King of the Rails.'

Discussion

Sir John Kennedy: I am glad to be here, and to learn from the reading of Mr. S. T. Dodd's excellent paper, and the illustrations with which it is accompanied, how satisfactorily the electrification of railways is proceeding, and the conditions under which it can be most successfully carried out, especially as regards main line transportation. Incidentally, too, it is shown how progress is retarded and kept within safe limits by cautious conservatism, and the very heavy expense of installation. Where the method of production and use of transportation power is so radically different as it is between a steam engine running on rails and a water-power in the mountains, the progress must be gradual to be safe, and the field limited. In the early days of bridge building, for instance, it was safe to enlarge step by step 10, 20 or 30 per cent at a time, but it is a wholly different thing to multiply several times up to the Quebec bridge. Looked at in this light, the electrification of railways is really proceeding rapidly and satisfactorily, and its field of application is being definitely ascertained.

I again express my thanks to the author for presenting a paper which so happily combines the popularly interesting and the scientifically sound and informative.

Mr. R. A. Ross: I do not think I have any remarks to make except to express wonder at what has been done. One point which Mr. Dodd has not emphasized is that the limitation to the extension

A Question of Cost

of this system of electrification is purely economic. The physical equipment is commercial to-day and electric traction could be extended over all our lines in Canada if the cost were not too great. Whether electric haulage can be used depends very largely on the density of traffic. You will find that electric locomotives are used to-day where conditions are favourable, such, for instance, as in New York where the density of traffic is high and they wish to keep down smoke, etc., or on mountain sections where the haulage is heavy. In both those cases the economics can be worked out. But, on longer, straight hauls where trains are few, the cost for power stations, overhead equipment, etc., is very high; so that, even though your platform labour is the same, and you pay less for power, you have to consider the heavy capital cost and charges for equipment.

At the same time, the electrification of the Chicago, Milwaukee & St. Paul railway marks a great step in advance. Four hundred and forty miles of continuous road, much of it mountain section, operating in a satisfactory way and regenerating its power so beautifully as it does on those grades, with the wonderful improvement in operation under winter conditions where there is no water to freeze or water tanks to take care of, forms an object lesson indeed. There are many phases of this subject and many possible economies and advantages, upon which Mr. Dodd has not touched.

A MEMBER OF THE COMMISSION: Does the cold affect the electric locomotive?

MR. DODD: No. The cold in winter, of course, greatly lowers the steaming power of the steam locomotive. If a steam locomotive is stalled in a storm, there is a possibility that valves and piping may freeze up, but there is no danger of this in the electric locomotive.

MR. SNOWBALL: What is the comparative cost of steam and electricity for railway traction?

MR. DODD: It depends upon the price paid for coal and for electric power. It is rather difficult to make a definite estimate because we must include not only the price paid for coal but the cost of transportation and the expense of operating coal chutes, ash dumps and other expenses involved in the handling of coal. Possibly $4 per ton might represent a fair figure for the total expense due to coal, while electric power in large quantities might cost in the neighbourhood of $\frac{1}{3}$c per k.w.h. During the last three months of 1915, approximately 50,000 tons of coal was used on the Rocky Mountain division, whereas the electric power for the corresponding three months of 1916 was 17,800,000 k.w.h. On the basis of costs suggested above, this would mean approximately $200,000 for coal as compared with approximately $88,000 for electricity. These figures may not be correct for the Milwaukee road but they give an idea of the order of difference. In some parts of the country electric power would cost more and coal would cost less.

There are the same number of men on an electric locomotive as on the steam locomotive. The labour men insist on the force not being reduced. Morever, with a locomotive at the head of a 2,000-ton train, it is a good thing to have a second man, if he does nothing but wander through the locomotive and see that all the machinery is in good condition.

There has been no change in the rate of pay, but many men have applied for transfer from steam to electric locomotives.

Mr. Snowball: When the saving is as eighty-eight to two hundred on motive power and as eight to eighteen in equipment and maintenance, why has the Milwaukee road not electrified a greater mileage.

Mr. Dodd: Four hundred and forty miles of road is a pretty long section. It is the first big electrification that has been made. The company has now let contracts for the electrification of 220 miles of road through the Cascade mountains, leaving a gap of about 200 miles between the two electrified sections. It will, I have no doubt, finally electrify the connecting section. It costs money to change from steam to electricity and at the present time the railways experience great difficulty in raising capital. With this long section of the Chicago, Milwaukee & St. Paul in operation, I do not think that question will have to be asked very much longer.

Railway Electrification in Canada

Mr. W. F. Tye, C.E., Montreal, late Chief Engineer of the Canadian Pacific railway, was invited to address the Commission on the electrification of railways in Canada, but was forced to decline as he felt that the short time available debarred him preparing an adequate address on this important question. Mr. Tye's letter of declination, however, is such an admirable, though brief, summing up of the subject that it has been-printed below:

"The question is a very important one, and very complicated. It is not now so much a problem in mechanical or electrical engineering as one in economics. The ordinary man who has seen the miracle wrought by the application of electricity to industrial plants, imagines that the same result can be obtained by its application to the railways. It must not be forgotten, however, that