

ELECTRICAL AGE

July, 1916

ELECTRIFICATION of the CHICAGO, MILWAUKEE & ST. PAUL R.R.

The tracks of the mountain district of the Chicago, Milwaukee & St. Paul Railway, in surmounting the obstacles imposed by the Rocky Mountain and coast-wise ranges, represent the solution of one of the most difficult problems ever mastered by railway engineers. To provide adequate motive-power for the economical movement of freight and passenger trains over this section of rugged mountain railway, including many long grades and short-radius curves, has taxed the ingenuity of both railway men and locomotive designers. As nearly all trains cross the mountains intact, the longer they are the less is the labor-cost for moving them. The demand for larger and ever-larger engine-units led to the adoption of Mallet articulated locomotives, having a weight on driving-wheels of 325,500 lbs. In cold weather the difficulty of making steam prevented the use of the full power of the locomotives and stalled trains were a frequent occurrence. Induced by the growing traffic and the presence of many sources of hydro-electric power, officials of the railroad began to study the possibilities of electrification. Decision was finally made in favor of a trolley-voltage of 3,000, direct current, generated by synchronous motor-generator sets and converted into mechanical power by 1500-volt geared motors. The contract for the entire electrical equipment was let to the General Electric Company.

General Outlines

Four steam engine divisions were selected for electrification, aggregating 440 miles in length. Steam engines were first abandoned on the Three Forks-Deer Lodge Division, 115 miles long, and crossing the main Continental Divide, thus giving the electrical equipment its initial tryout under the severest service conditions of the entire system. The first electric locomotives were placed in regular service on December 9, 1915, and during the month of April, 1916, service was extended to Harlowton, making a total of 220 miles of electrically operated road. By the first of November, 1916, it is expected that steam engines will be superseded over the entire distance of 440 miles from Harlowton, Montana, to Avery, Idaho.

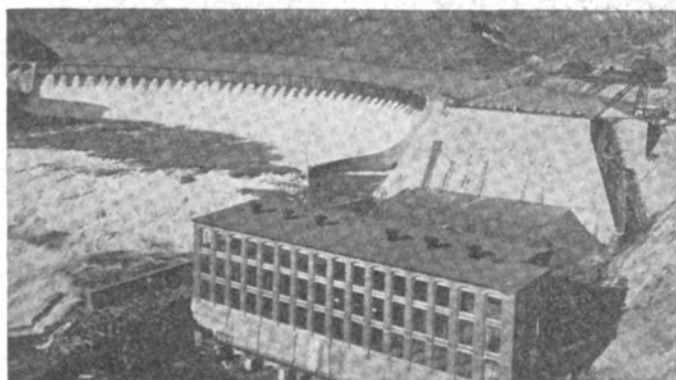
This project is the most extensive steam railway electrification in the world, the length of haul being nearly six times as great as any trunk line now operating with electric locomotives. In crossing the three mountain ranges included in the electric zone, there are several grades of one per cent. or more, the most difficult of which is the 21 mile two per cent. grade between Piedmont and Donald, and the longest the 49 mile one per cent. grade on the west slope of the Belt Mountains. The curvature is necessarily heavy, the maximum being 10 degrees. There are also numerous tunnels in the electric zone, 36 in all, of which the longest is the St. Paul Pass tunnel, over a mile and a half in length, through the ridge of the Bitter Root Mountains.

The passenger service consists of two all-steel finely equipped transcontinental trains in each direction, the "Olympian" and "Columbian," and a local passenger train in each direction daily between Deer Lodge and Harlowton. Freight traffic through the electric zone comprises from four to six trains daily in each direction. Westbound, the tonnage is made up of manufactured products and merchandise for Pacific Coast points and foreign shipment. Eastbound tonnage includes grain, lumber, products of the mines and some live stock. As a larger part of the traffic is through freight, trains are made up of an assortment of foreign cars, including box and flat cars, coal and ore hoppers, stock cars, refrigerators, etc., varying in weight from 11 to 25 tons empty and as high as 70 tons loaded. These cars being owned by many different railway systems are equipped with air brakes adjusted for different conditions of operation, and in accordance with different standards as to braking power and type of equipment, thus making the problem of holding the long trains on the heavy down grades by air brakes, a most difficult one.

Electrical Operation

Electrification promises a material reduction in running time. It has been found, for example, that on the 21 mile two per cent. grade from Piedmont to Donald, the electric locomotive can reduce the running time of

passenger trains from an hour and five minutes to approximately 40 minutes. On the run from Deer Lodge to Butte which, under the steam locomotive schedule, required an hour and 20 minutes, a saving of approximately 30 minutes can be made. In the freight service, it has been found that on the first division where the steam locomotives have required 10 to 12 hours to make 115 miles, electric locomotives can meet a schedule of from seven to eight hours for the same distance. The heavy grades and frequent curves at certain points offer serious obstacles



Great Falls Dam and Power House

to steam locomotive operation even in the summer time and with winter temperatures as low as 40 deg. F. and heavy snowfalls in the Bitter Root Mountains, serious delays have occurred, owing to engine failures or to inability to make steam.

During a series of record-breaking temperatures in December, 1915, Mallet engines were frozen up at different points on the system and the new electric equipment was rapidly pressed into service to replace them. On several occasions electric locomotives hauled in disabled steam engines and trains which would otherwise have tied up the line.

During the initial operation on the Rocky Mountain Division, the capacity of the new locomotives has been thoroughly tested. Trains of 3,000 tons trailing have been hauled east and 2,800 tons west, using a helper on the heavy grades. From the operating data obtained on the first division, it is evident that much heavier trains can be hauled with the electric locomotives than with steam engines, and all passing tracks are being lengthened to take advantage of longer trains. On some of the runs where the grades are less than one per cent. trains of as many as 130 cars and as heavy as 4000 tons have been hauled with a single locomotive.

The four through passenger trains, "Olympian" and "Columbian," are taken across the two mountain ranges by a single passenger locomotive. These trains at present consist of eight full vestibuled steel coaches, weighing approximately 650 tons. Instead of changing locomotives at Three Forks, as has been the practice under steam operation, the same locomotive is run through the 220 miles from Deer Lodge to Harlowton, changing crews midway. Passenger trains will travel over the entire electrified division in approximately 15 hours, including all stops, and the tourist thus will have an opportunity of traversing by daylight some of the most beautiful scenic regions in the United States and without suffering the annoyance of cinders and smoke incident to the use of steam locomotives. The local passenger train operating in the electric zone between Deer Lodge and Harlowton is handled by a

half unit weighing about 150 tons with equipment similar to the main line locomotives.

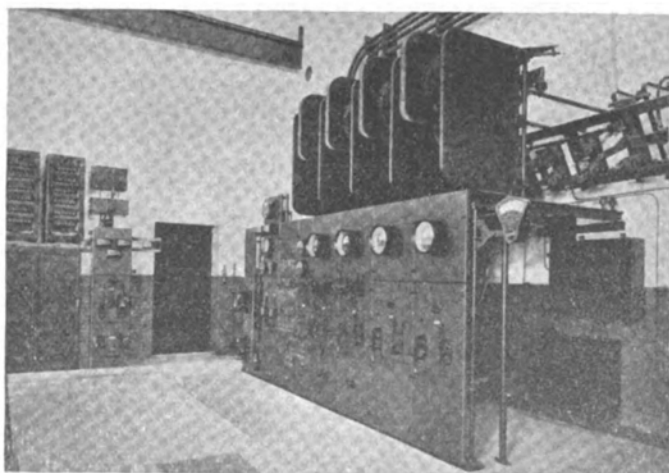
The Electrical Equipment: Power Supply

The scheme of electrification includes the generation of electricity from the several water power plants of the Montana Power Company; transmission at 100,000 volts, three-phase, 60 cycles; conversion in substations to 3,000 volts direct current and distribution over catenary overhead construction to electric locomotives.

Utmost precautions were taken by the Railway Company in making plans for this electrification to insure a reliable source of power. The Montana Power Company, with whom the contract was closed for electric power, operates a network of transmission lines covering a large part of Montana, which are fed from a main plant at Great Falls, and a number of other widely separated water power plants of adequate capacity at all seasons of the year.

The plants now in operation are:

	Capacity K. W.
Great Falls, on Missouri River.....	60,000
Rainbow Falls, on Missouri River near Great Falls	27,000
Black Eagle Falls, on Missouri River near Great Falls	3,000
Hauser Lake, on Missouri River, northeast of Helena	18,000
Canyon Ferry, on Missouri River, northeast of Helena	7,500
Madison No. 1, on Madison River, 60 miles southeast of Butte	2,000
Madison No. 2, on Madison River, 60 miles southeast of Butte	10,000
Big Hole, on Big Hole River, 22 miles southwest of Butte	3,000
Livingston, on Yellowstone River	1,500
Billings No. 1, on Yellowstone River	1,080
Lewistown, on Spring Creek	450
Steam Plants	5,920
Thompson Falls, on Clark's Fork of Columbia River	20,000
	<u>159,450</u>



Switchboard of Morel Substation

The available capacity of the storage reservoirs now in service is 447,150 acre-feet. Of this, more than 325,000 feet is in the Hebgen reservoir on Madison River which is so located that it supplies in turn the installations on both the Madison and Missouri Rivers.

As provisions for future need, there are available:

Hydro-electric powers in course of development or definitely projected.....	50,000
Power-sites undeveloped	121,500
Total horsepower	171,500

Transmission Lines

The Montana Power Company's transmission lines, which are carried in some cases on steel towers and in others on wooden poles, tap into the railway system at seven different points where the power is most needed. The Railway Company's transmission line extends the entire length of the system on wood poles. In most cases this line is built on the company's right-of-way, although at several points there are cutoffs which make a considerable saving in the length of line. On January 1, 1916, there were in service:

Steel tower lines, 100,000 volts.....	305 miles
Steel tower lines, 50,000 volts.....	35 miles
Pole lines, pin type, 11,000 to 60,000 volts...	635 miles
Pole lines, suspension insulator type, 50,000 to 100,000	512 miles
Bridge type, 100,000 volts	341 miles

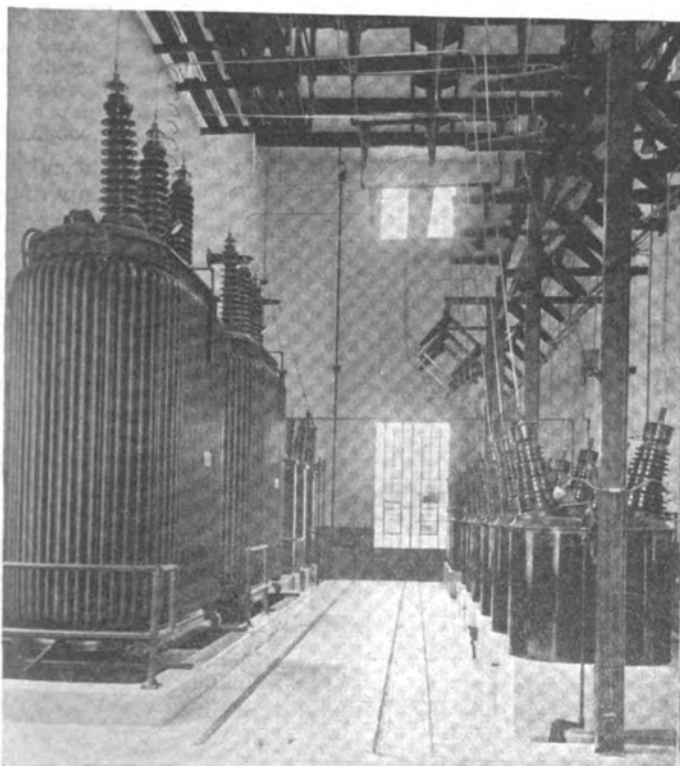
Total 1,828 miles

The Railway Company will pay 0.536 cents per kw.-hr., this very low rate being justified by the ample hydro-electric facilities available and the low cost of line-construction. Energy will be metered on the alternating-current side of the substations. It is expected that the power-cost will be lower for electricity than for coal for the former steam-locomotives.

With this completely inter-connected transmission system, each substation may be fed from either direction and also at the tie-in points from a third source of power.

Railway Substations

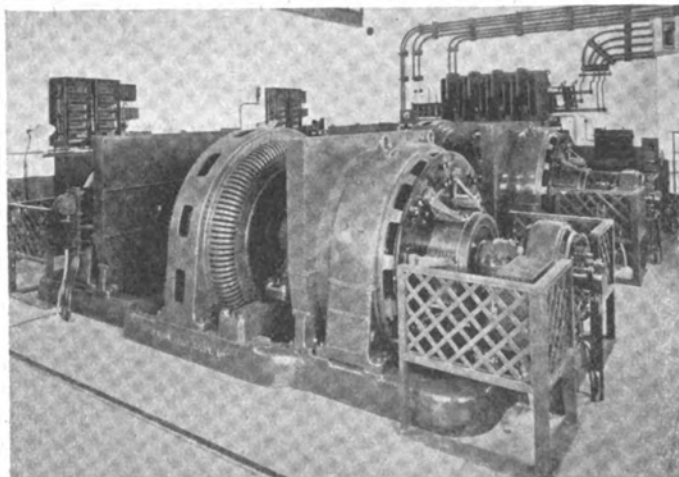
Fourteen substations are equipped for converting the 100,000-volt alternating current to 3,000 volts di-



2 2500 kv.-a. 3-phase 100,000 to 2300v. Transformers and Oil Switches in Morel Substation

rect current. They are distributed along the route at average intervals of 32 miles. Each station contains step-down transformers, motor-generator sets, switch-board and the necessary controlling and switching equipment. The transformers receive the line current at 100,000 volts and supply the synchronous motors at 2,300 volts. Each synchronous motor drives two 1,

500-volt, direct current generators connected permanently in series, thus supplying 3,000-volt current for the locomotives. These generators are compound wound to maintain constant voltage up to 150 per cent.



2—2000 kw. Motor Generator Sets in Morel Substation

load and will stand momentary loads of 300 per cent. They are equipped with commutating poles and compensating pole-face windings. The fields of both the synchronous motors and the direct current generators are separately excited by small direct current generators direct connected to each end of the motor-generator shafts.

Overhead Construction

The overhead construction is of the modified flexible catenary type designed by the General Electric Company and installed under the direction of the Railway Company's engineers.

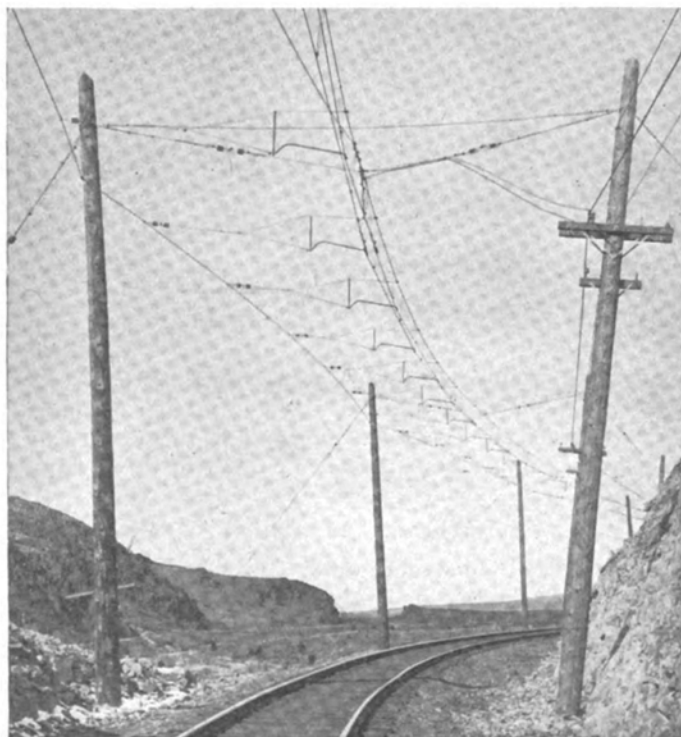
As may be seen from the illustrations, the construction comprises two 4-0 copper wires flexibly suspended side by side from the same steel messenger by independent hangers alternately connected to each wire. This is equally suitable to the collection of large currents at low speed, and smaller currents at speeds up to 60 miles per hour. Bracket construction is used wherever the track alignment will permit, and cross span construction on passing tracks and in the switching yards. All of this work is supported on 40-foot wooden poles suitably guyed and spaced.

A 500,000 c.m. feeder is installed the entire length of the electrification and a supplementary feeder on heavy grades. The feeder is tapped to the trolley wire at every seventh pole, or approximately every 1,000 feet. On top of the poles is carried a supplementary 4-0 negative feeder which is tapped to the middle point of every second reactance bond. These bonds are used for insulating the 60-cycle signal circuits and are installed at points averaging from 5,000 to 6,000 feet apart. Each track is bonded with a 250,000 c.m. bond on each joint and double bonded on the heavier grades.

Locomotive Equipment

The main line Chicago, Milwaukee & St. Paul electric locomotives are constructed in two units permanently coupled together, the halves being duplicates and each capable of independent operation. There are 42 of these main line locomotives (30 freight and 12 passenger) and two switching locomotives. The locomotives are the first to be used for railroad service with direct current motors operating at a potential as

high as 3,000 volts and the first to use direct current regeneration. The passenger locomotives are equipped with a gear ratio permitting the operation of 800 ton trailing trains at speeds of approximately 60 miles per hour on tangent level track. The average passenger train weighs from 650 to 700 tons and is hauled over the two per cent. grade without a helper. The freight locomotives are designed to haul a 2,500 ton trailing train at approximately 16 miles per hour on all grades up to and including one per cent. On two per cent. grades the trailing load was limited to 1,250 tons, although this figure has been exceeded in actual operation.



Typical Overhead Construction on a Curve

Each locomotive is equipped with eight Type GE-253-A, 1,500-volt motors, insulated for 3,000 volts to ground. This motor has a normal one hour rating of 430 h.p. and a continuous rating of 375 h.p., so that the locomotive power plant has a normal one hour rating of 3,440 h.p. and a continuous rating of 3,000 h.p. Each motor is twin geared to its driving axle in the same manner as on the Butte, Anaconda & Pacific, the Detroit River Tunnel, and the Baltimore & Ohio locomotives, a pinion being mounted on each end of the armature shaft. Additional flexibility is obtained by the use of a spring gear and a spring nose suspension which minimize the effect of all shocks and also reduce gear wear to a minimum. The motor is of the commutating-pole type and is constructed with longitudinal ventilating ducts in the armature for forced ventilation from a blower in the cab.

The control equipment is the well-known Sprague General Electric Type M arranged for multiple unit operation. The main control switches are mounted in steel compartments inside the locomotive cab with convenient aisles for inspection and repairs. A motor-generator set in each half of the locomotive furnishes low-voltage current for the control circuits, headlights, cab lighting and for charging the storage batteries on the passenger coaches. Under steam operation, the

charging current for these batteries is furnished by a steam turbo-generator set located on the locomotive. The blower for ventilating the traction motors is also direct connected to one end of this set.

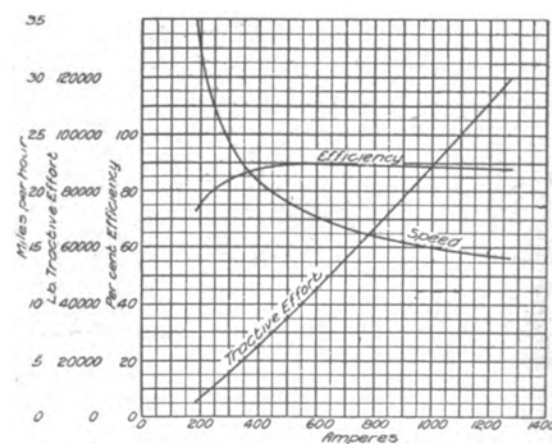
The pantograph collectors, one of which is mounted on each half of the locomotive, are of the double pan type with a working range of from 17 feet to 23 feet above the rail. The contact elements are of the same metal as the trolley wires, so that current passes from copper to copper.

The air brake equipment is practically the same as that used on steam locomotives except that motor driven air compressors are used to furnish compressed air. Aside from the air brakes, compressed air is also used for signals, whistles, bell-ringers, sanders, flange oilers, pantograph trolleys, part of the control equipment, and on the passenger locomotives for the oil-fired steam boilers.

Data on the main line locomotives follows:

Length overall	112 ft.
Total wheel base	102 ft. 8 in.
Rigid wheel base	10 ft. 6 in.
Total weight	564,000 lb.
Weight on drivers	448,000 lb.
Weight per driving axle	56,000 lb.
Weight per guiding axle	29,000 lb.
Diameter of driving wheel	52 in.
Diameter of guiding wheel	36 in.
Number of driving motors	8
Gear ratio, freight service	4.56
Gear ratio, passenger service	2.45
Total output (continuous rating)	3,000 h.p.
Total output (1 hour rating)	3,440 h.p.
Tractive effort (continuous rating)	71,000 lb.
Per cent. of weight on drivers (trac. coef.)	15.83
Speed at this tractive effort at 3000 volts	15.75 m.p.h.
Tractive effort (1 hour rating)	85,000 lb.
Per cent. of weight on drivers (trac. coef.)	19.00
Speed at this tractive effort at 3000 volts	15.25 m. p. h.
Tractive effort available for starting 30% coef.	136,000 lb.

Passenger and freight locomotives are identical, with the exception of gear ratio and the adoption of an oil-fired steam boiler in each half of the passenger locomotives for heating the trailing coaches. The two boilers are capable of evaporating 4,000 pounds of



*Characteristics of a Main Line Freight Locomotive
Diameter of Drivers 62 in. Gear Ratio 4.56*

water per hour and this equipment with tanks for oil and water brings the weight of the locomotive up to approximately 300 tons. The interchangeability of all electrical and mechanical parts of the locomotives is considered of great importance from the standpoint of operation and maintenance.

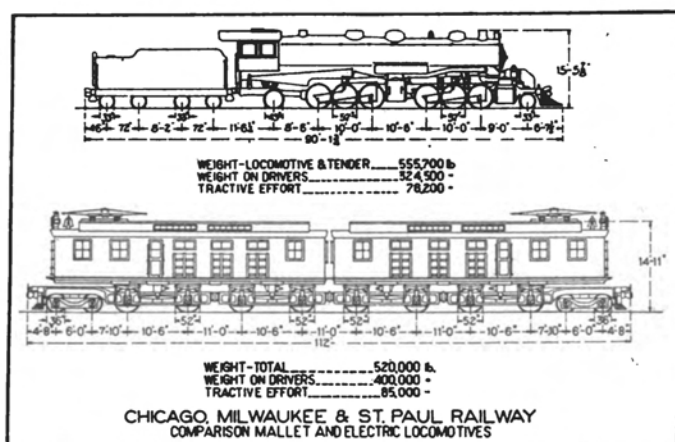
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Electrification of the Chicago, Milwaukee and St. Paul Railway

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Switching Locomotives

The switching locomotives are of the swivel truck type, weighing 70 tons each, and equipped with four geared motors. A single pantograph of construction similar to that used on the main line locomotives is mounted on the cab and in other ways the locomotives represent the standard construction commonly used with the steeple cab type of switcher. The motors (known as Type GE-255) are of box frame, commutating-pole, single-g geared type designed for 1500 volts with an insulation of 3,000 volts to the ground. Many of the switching locomotive parts are interchangeable with those used on the main line locomotives; for example, the air compressors, small switches, headlights and cab heaters.



Other data on the switching locomotives are:

Length inside knuckles	40 ft.
Height over cab	13 ft. 10 in.
Height-trolley down	16 ft. 8 in.
Width overall	10 ft.
Total wheel base	29 ft. 4 in.

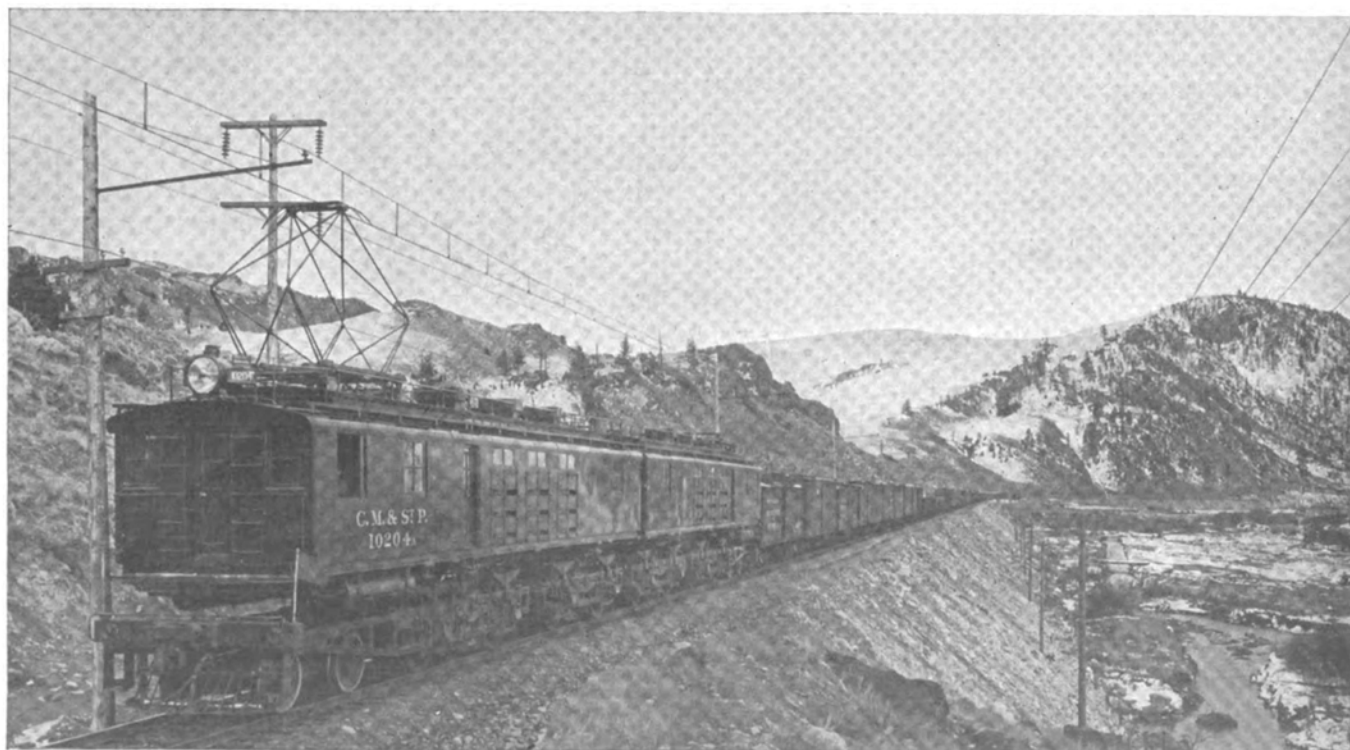
Rigid wheel base	8 ft.
Diameter of wheels	40 in.
Weight-locomotive complete	140,000 lb.
Weight per driving axle.....	35,000 lb.
One hour rating of locomotive.....	542 h.p.
Tractive effort at one hour rating.....	18,400 lb.
Speed at this rating	12 m.p.h.
Continuous tractive effort.....	13,480 lb.
Speed at continuous rating.....	13.2 m.p.h.
Tractive effort 30%.....	42,000 lb.

Regeneration

Regeneration, or the recovery of energy on the descending grades, by reversing the function of the electric motors reduces the cost of operation and furnishes a ready solution of the difficult braking problem. On the long sustained grades encountered in crossing the three mountain ranges, great skill is required to handle either the heavy and varied freight or the high speed passenger trains with the usual air brakes. The entire energy of the descending train must be dissipated by the friction of the brake shoes on the wheels, and it approximates 3500 kw. or 4700 h.p. for a 2500 ton train running at 17 miles per hour on a two per cent. grade, thus explaining why brake shoes frequently become red-hot and other serious damage is done.

With regenerative braking, the motors become generators which absorb the energy of the descending train and convert it into electricity, thus restricting the train to a safe speed down the grade and at the same time returning electric power to the trolley for use by other trains. The strain on draw bars and couplings is reduced to a minimum since the entire train is bunched behind the locomotive and held to a uniform speed. The electric-braking mechanism automatically controls the speed by regulating the amount to the periodical slowing down and speeding up of a train controlled by air brakes.

The usual speed of the electrically hauled train is 15 miles per hour ascending and 17 miles per hour descending the maximum grade, but half these speeds can easily be maintained with series connections of the motors should conditions require it.



An 82-car Freight Train Weighing 2680 tons

In case there are no other trains between the substations to absorb the power generated by a descending train, this power passes through the substation machinery, is converted from direct to alternating current and fed into the distribution system connecting all substations. The Power Company's lines are so extensive and the load of such a diversified character that any surplus power returned by regenerating locomotives can readily be absorbed by the system; credit is given for all energy returned.

Electric locomotion has been adopted by the Chicago Milwaukee & St. Paul Railway as "a newer, better foundation on which builders shall rear the structure of railroading to undreamed-of efficiency and comfort." The enterprise has been undertaken with the expectation of effecting a sufficient reduction in the cost of operation to return an attractive percentage on the investment required, as well as to benefit by all the operating advantages of electric locomotives. According to statements made by the railroad officials, about \$12,000,000.00 will be expended, and with the work more than half completed there is every reason to believe that the cost of construction will come inside the estimates.

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Electrical Fathers—Lord Kelvin

(Continued from page 34)

The demand for his apparatus led to the formation of a partnership with the university instrument-maker, under the name of Kelvin & James White, Ltd. Much excellent material was turned out by this firm, among its products being some of the very earliest recording volt-meters and watt-meters.

We have seen in earlier papers of this series how versatile were many of the men of science of an older generation. Sir William Thomson showed in himself a fine example of this ability to engage in widely different fields of endeavor and always with distinction. One of his earliest interests was in the subject of heat, and here he showed that wish to consider problems from the viewpoint of energy. There was no absolute scale of temperature, and to create one Thomson started from the theory that the heat reected in a perfect engine is inversely proportional to the absolute internal temperature of the working agent. From this he deduced the location of the absolute zero, with reference to such a point as the temperature of melting ice. His value coincides very nearly with other values determined in many different ways.

Lately it has been proposed to recognize this work by naming the scale which has its beginning that absolute zero the "Kelvin" scale.

To an unusual degree Thomson had the happy ability of being able to put scientific concepts into popular language. One famous expression of this sort was that if a mass of water the size of a (British) football should be magnified into a sphere the size of the earth, the molecules would be larger than cricket-balls, though probably not so large as foot-balls. His interest in geology led him to formulate a theory as to the age of the earth, and to predict the probable amount of coal which might be available for future generations. Toward the end of his life he withdrew from the earlier position in which he had attempted to explain by means of kinetics the fundamental problems of matter and force. No conclusion in these matters has yet been reached by scientists, but we may be very sure that his work will always command respect.

The honors which were heaped upon Sir William Thomson have been without parallel in the history of science. In 1892 he was created a Peer of the Realm, with the title of Baron Kelvin. His own sovereign conferred on him as well a

Privy Councillorship, the Grand Cross of the Victorian Order of Merit. He was also an officer of the Legion of Honor of France and a Knight of the Prussian "Ordre Pour Le Mérite." Three times he was elected president of the Institution of Electrical Engineers and the other offices he held, and the degrees conferred on him would fill a column. Best of all, his lovable personality and warm heart brought him troops of friends and when on December 17, 1907, the cables carried the news of their master's death, all the world of science mourned.

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Book Reviews

THE ENGINEER IN WAR, by P. S. Bond. 187 pp. New York: McGraw-Hill Book Co.: \$1.50.

With the National Guards of many States being mobilized, there is unusual interest in all things pertaining to the military art. Major Bond's book, while addressed primarily to civil engineers and contractors, will be of value to any man whose inclination is toward the engineering side of military operations. While it does not pretend to be exhaustive, it covers the field in a very complete manner, being thus of value to the busy man who wants a comprehensive survey of what is to be known concerning military engineering. Every man who expects to fight for his country at some time should read this volume with care; if his inclination is to become more fully informed, the bibliography at the end will guide him to the best sources for what he seeks.

Technical readers cannot but be impressed with the often-emphasized need for speed, above all other considerations. The conscientious constructor in peaceful life cannot tolerate "short-cuts" which may weaken the finished work. Major Bond makes it clear that military works are of the most ephemeral character, and that in the presence of the enemy, time is of the essence. War moves are made rapidly, and the volunteer engineer must adapt his "rules of practice" with that in view.

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EXPORTERS' ENCYCLOPEDIA, 1916 Edition. New York: Exporters' Encyclopedia Company: \$7.50.

This volume is full of information for the exporter. Its principal section contains a brief description of the area, population, commerce, etc., of each country in the world, with a list of the points to which through bills of lading are issued, the banks which collect shippers' drafts the shipping routes from New York, and their regulations. There is also information on postal rates and regulations, the preparation of shipping papers, cable rates, tables for the conversion of foreign money, weights, and measures and many other items make this book well-nigh invaluable. The subscription price includes a monthly bulletin of corrections and the "Exporters' Review" for one year.

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A HANDBOOK ON INCANDESCENT LAMP ILLUMINATION. Harrison, N. J.: Edison Lamp Works of General Electric Co.: 75 cents.

For so small a book (2¾ by 5½ inches), the amount of information which this handbook holds is surprising. In 211 pages it covers the incandescent lighting field so explicitly that any one can find the solution for his particular problem, or hints from which he can readily work it out. Section 1 treats of lamps and their characteristics; Section 2 of illumination terms and calculations; Section 3 of lighting practice, and Section 4 of electric circuits and apparatus. The book should be the pocket companion of everyone who has to do with the design or selection of illuminants.

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The Utah Copper Company and its allied interests have placed orders with the Westinghouse Electric & Mfg. Co., of East Pittsburgh, Pa., for 211 vertical agitator motors for separating copper from low grade ore and trailings by the use of the flotation system.