General Electric Company
Schenectady, N.Y.
RAILWAY DEPARTMENT

July, 1914 *Bulletin No. 44011*

THE ELECTRIFICATION OF THE BUTTE, ANACONDA & PACIFIC RAILWAY

The Butte, Anaconda & Pacific Railway is, in many ways, the most remarkable example of steam road electrification in this country. Besides being the first 2400-volt, direct current road, it is also credited with being the first steam road operating both freight and passenger schedules, to electrify its lines purely for reasons of economy. A number of steam railway electrifications have been made because of peremptory factors, such as terminal and tunnel operation or for rapid suburban service. This road, however, cannot be classed as an "enforced electrification," since no such special limitations have been the determining factors.

The first electric locomotives were put in service May 28, 1913, hauling ore cars between the East Anaconda yards and the smelter. The entire freight traffic was gradually taken over and since November all trains have been handled by electric locomotives. During the first year's operation the electric locomotives made approximately 430,000 miles and hauled about 4,500,000 tons of ore.

160-TON ELECTRIC LOCOMOTIVE HAULING 4550-TON ORE TRAIN IN SILVER BOW CANYON

The unusually successful operation of this electrified steam road marks an epoch in the annals of heavy electric traction. The first locomotives were put in service hauling ore up Smelter Hill against a 1.1 per cent. grade and it is a significant fact that during the first year of operation service has never been discontinued and no material interruptions have occurred from any cause. The loco-

NOTE.—The data in this publication are for the convenience of customers, and every effort is made to avoid error, but this Company does not guarantee their correctness, nor does it hold itself responsible for any errors or omissions in this publication. Subject to change without notice.

Class 110

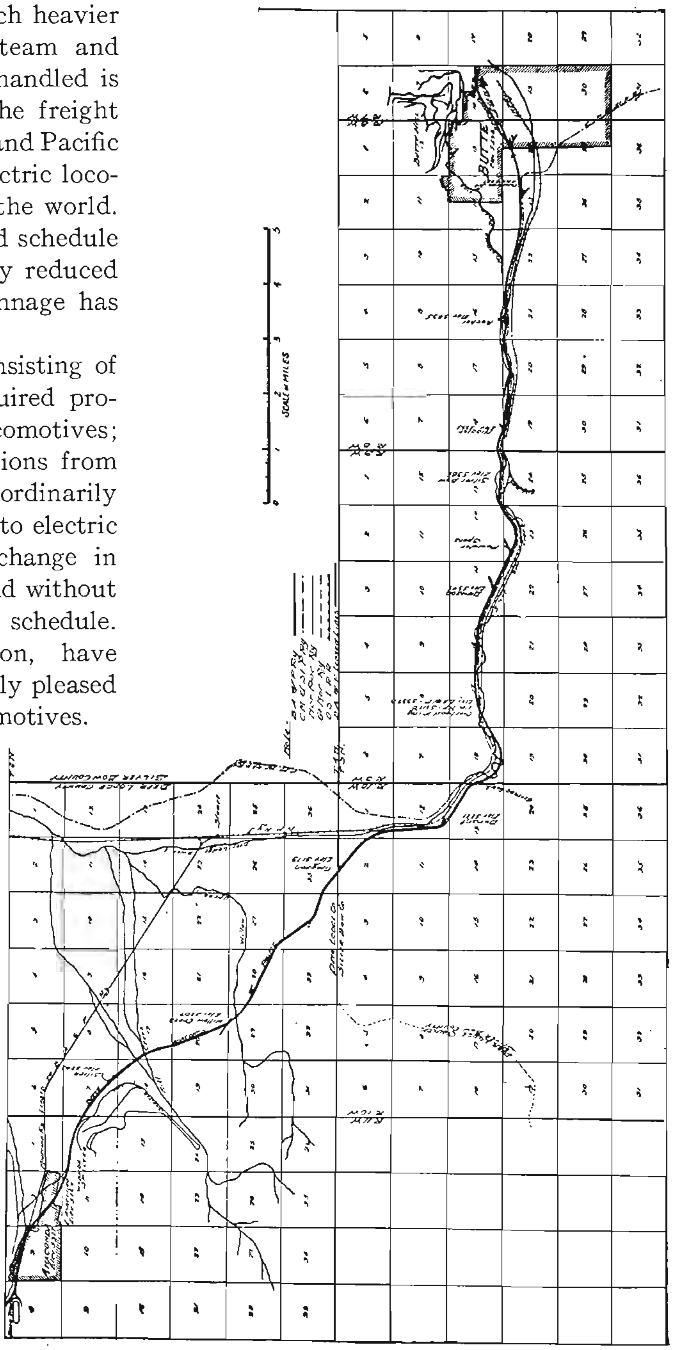
motives, substation equipment and overhead construction have proven equally reliable. This point has been of greatest importance since no reserve substation units or extra locomotives were purchased.

It is worthy of note that the ore trains now being hauled by electricity are much heavier than those formerly hauled by steam and that the speed at which they are handled is approximately twice as great. The freight movement on the Butte, Anaconda and Pacific Railway now being handled by electric locomotives is one of the heaviest in the world. Owing to increased train weight and schedule speed, night work has been greatly reduced and at the same time a larger tonnage has been hauled than ever before.

The steam locomotive crews consisting of engineman and fireman easily acquired proficiency in handling the electric locomotives; in fact, two or three days instructions from a competent electrical man were ordinarily sufficient. The change from steam to electric haulage was made without any change in the personnel of the train crews and without any delays or alterations in the schedule. The engineers, without exception, have expressed themselves as being greatly pleased with the easy operation of the locomotives.

The electrified lines of this system extend from the Butte Hill yard to the smelter, a distance of 32 miles. There are numerous sidings, yards, and smelter tracks that have been equipped with overhead trolley, making a total of about 95 miles on a single track basis.

The Butte, Anaconda & Pacific Railway is essentially an ore hauling road, the freight traffic from this source originating at the copper mines located near the top of Butte Hill. From the mines, the ore trains are lowered down the mountain a distance of 4½ miles to the Rocker yards located a few miles west of the city of Butte. At this point, new main line trains are made up for transportation to the smelters at Anaconda. The main line division extends through a rough mountainous country, a distance of about twenty miles, with grades as high as 0.3 per cent

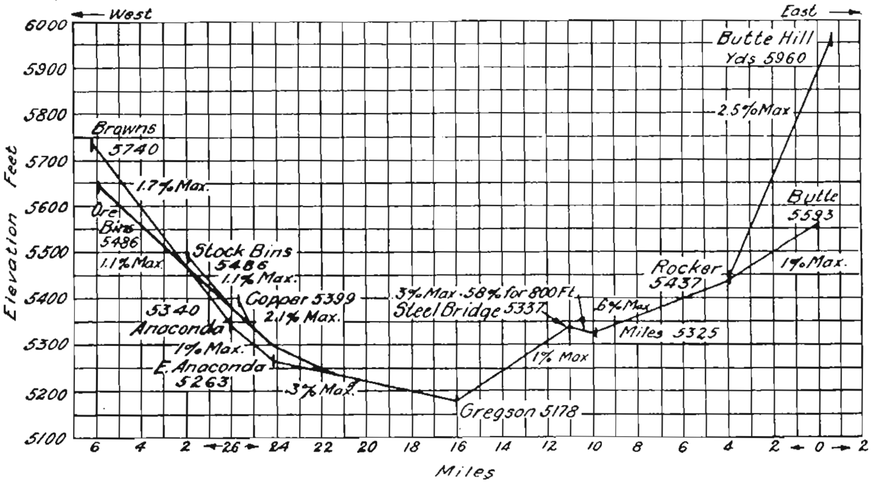


MAP OF ELECTRIFIED SECTION OF THE BUTTE, ANACONDA & PACIFIC RAILWAY against the loaded trains and 1 per cent against the trains of empty cars.

At East Anaconda, the main line trains are broken up and hauled up Smelter Hill to the stock bins, where each car is run over the scales and weighed. The shifting of cars in connection with weighing and subsequent delivery to the concentrators is done by single locomotives.

The east bound traffic consists in returning empty cars to the mines and the transportation of copper ingots to the Butte yards, from which it is shipped over other roads to refineries.

Between the cities of Butte and Anaconda, which are located at the ends of the electrified portion of the system, there is considerable local traffic, both passenger and freight. The



PROFILE OF BUTTE, ANACONDA AND PACIFIC RAILWAY

STANDARD ELECTRIC PASSENGER TRAIN ON MAIN LINE BETWEEN BUTTE AND ANACONDA city of Butte and vicinity has a population of about 65,000, and Anaconda about 10,000. At Butte, the Butte, Anaconda & Pacific connects with the Great Northern Railway, the Northern Pacific, and the Chicago, Milwaukee & St. Paul Railroad; and at Silver Bow, about six miles from the city, connection is made with the Oregon Short Line.

STEAM ENGINE DISPLACED BY ELECTRIC LOCOMOTIVE

For a distance of 16 miles, the Butte, Anaconda & Pacific Railway is paralleled by the transcontinental lines of the Northern Pacific, and the Chicago, Milwaukee & St. Paul. In this connection it is of interest to note that the last named company has already contracted for power for the operation of electric trains from Harlowton, Montana, to Avery, Idaho, a distance of 440 miles.

The maximum curvature on the system (20 degrees, 285 ft. radius) occurs on the Butte Hill line. On this part of the road, there is an average curvature of 6 to 10 degrees. The locomotives are designed with sufficient flexibility to take a curve of 31 degrees (180 ft. radius) at slow speed.

Train Service

The freight traffic consists largely of copper ore and amounts to more than 5,000,000 tons per year. This material is handled in steel ore cars weighing about 18 tons and having a capacity of 50 tons each. Trains of 30 to 40 loaded cars weighing 2000 to 3000 tons are made up at the Butte Hill yards and hauled by two-unit locomotives to the Rocker yards, where 4000 to 4500-ton trains are made up for the main line. At the East Anaconda yards, the trains are again broken up and 1400-ton trains are sent up Smelter Hill to the ore bins. All of the shifting and "spotting cars," at the smelters and in the sorting yards, is done by single locomotive units. The customary train make up for both east and west bound traffic is shown in the table on the opposite page.

Eight passenger trains per day are operated between Butte and Anaconda, four in each direction. The main line passenger trains were first hauled by electric locomotives on October 1, 1913, and promptly demonstrated their ability to make better time than was possible with steam engines. Single locomotives are used, hauling trains of from three to five passenger and baggage cars.

Power Supply

Energy for the operation of electric trains is purchased from the Great Falls Power Company. The generating plant is located at Great Falls, Montana, on the Missouri River, and has for some time been supplying electric power for the operation of the mines and smelters at Butte and Anaconda. Six hydro-electric units are installed, having a nominal rated capacity of 21,000 kw. The machines are of the horizontal type, generat-

80-TON ELECTRIC LOCOMOTIVE

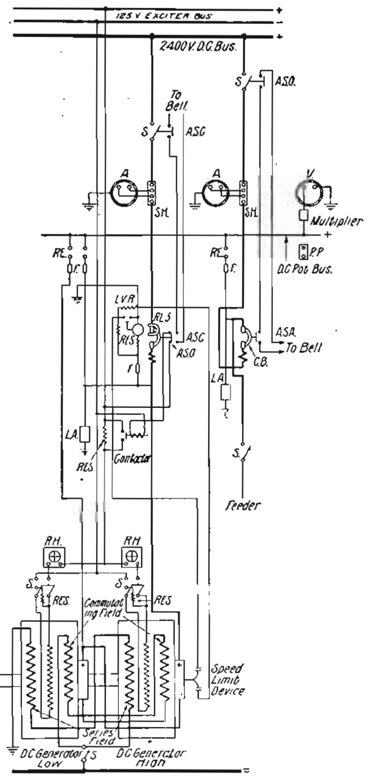
CONDENSED INFORMATION ON FREIGHT MOVEMENT

	WEST BOUND			EAST BOUND		
	Butte Hill Line	Main Line	Smel-ter Hill	Smel-ter Hill	Main Line	Butte Hill Line
Trailing load in tons	2000	4000	1400	1000	1260	650
Number of cars	30	60	20	55	70	35
Number of 80-ton locomotives per train	2	2	2	2	2	2
Approximate grade against load—per cent	—2.5	0.3	1.1	—1.1	1	2.5
Approximate speed on level tangent track, miles per hour		21			25	
Approximate speed on maximum grade	12	16	16	20	16	16
Average trolley voltage	2200	2200	2200	2200	2200	2200
Length of run in miles	4.6	20.1	7	7	20.1	4.6

ing 6600 volts, three-phase, at a frequency of 60 cycles. The power is stepped up to 102,000 volts for transmission to the transformer substation at Butte, a distance of 130 miles, over two separate, parallel lines constructed on the same right-of-way. An extension of the system transmits power at 60,000 volts to a second transformer station at Anaconda, 26 miles beyond.

GENERATOR ROOM IN THE RAINBOW STATIONS OF THE GREAT FALLS POWER COMPANY

The Butte station forms the center of the extensive power system operated by the Montana Power Company. In addition to the Great Falls 102,000-volt transmission lines, there are several 60,000-volt trans-



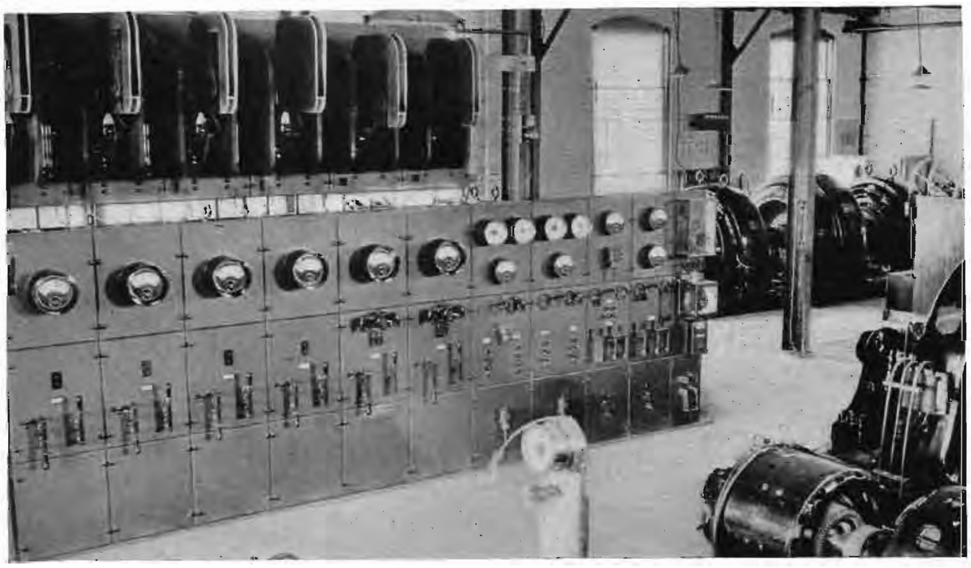
WIRING DIAGRAM OF 2400-VOLT SUBSTATION

system. These lines bring in power from the Hauser Lake, Canyon Ferry, Madison and Big Hole plants. At the Butte substation, this power is stepped down to 2400 volts, three-phase, and all of these lines are tied in on the 2400-volt alternating current bus. Ample protection is therefore afforded against interruption of service.

It is an interesting fact that the railway load was taken on without any increase in the high tension transmission facilities. It is estimated that the additional load from this source is approximately 20 per cent of the railway, industrial and lighting load furnished by the street railways, mines, and smelters at Butte and Anaconda.

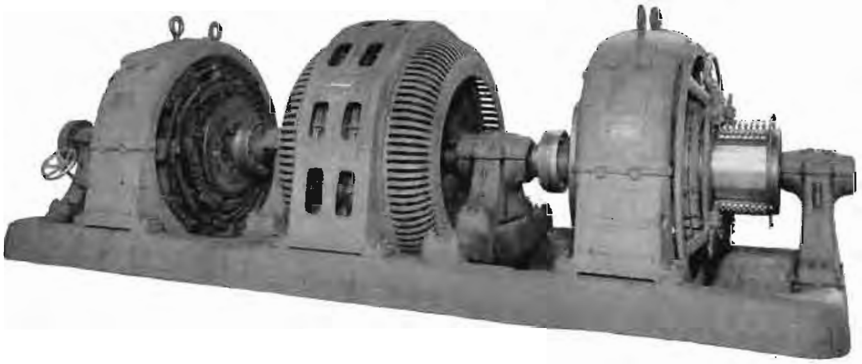
Railway Substations

The two existing substations at Butte and Anaconda were used to house the 2400-volt motor-generator sets required for operating the electric trains, so that no additional buildings were constructed for this purpose. Power is furnished by two 1000-kw., three-unit motor-generator sets in each substation, taking power from the 2400-volt alternating current busses. These units operate continuously 24 hours per day, seven days of the



2400-VOLT SWITCHBOARD AND MOTOR-GENERATOR SET IN BUTTE SUBSTATION

missions terminating at this point, which form a part of the Montana Power Company's week, to supply the necessary current for train operation. Each set consists of a three-phase, 60-cycle, 1450-kv-a., 720-r.p.m., synchronous motor direct connected to two 500-kw., 1200-volt generators, insulated to operate in series for 2400 volts. The generators are compound-wound and have both commutating poles and compensating pole face windings. These fields are connected on the grounded side of the armature, and the main fields are separately excited from 125-volt exciters.



THREE UNIT 1000 KW., 2400-VOLT D-C. MOTOR-GENERATOR SET

The 1200-volt generators are provided with heat-proof insulation and, owing to their unusually good commutating characteristics, will carry three times normal load for periods of five minutes, as well as the usual 50 per cent overload for two hours.

An automatic voltage regulator is used to maintain an approximately constant voltage at the terminals of the motor by power-factor regulation. The motors are protected against overload by inverse time-limit relays, which are set to open at four times normal load. These relays have been adjusted to open under sustained overload in about two seconds and upon short circuit their action is practically instantaneous.

Exciters

Excitation for the two generating units in each substation is obtained from two induction-motor-driven sets, rated 50 kw. each at 125 volts. One set is used for supplying current to the synchronous motor fields and is controlled by the automatic voltage regulator. The second unit supplies current to the separately excited fields of the direct current generators.

Switchboards

The 2400-volt switchboards for controlling these sets are the first direct current boards to be constructed for this high voltage. In general, they are similar to the standard 1200-volt types with increased insulation and special provision for interrupting the 2400-volt current. The circuit breakers and switches are also arranged for remote control, and all apparatus on the panels is provided with ample insulation to insure safety to the operators.

The 2400-volt circuit breakers and switches are installed on separate panels above and back of the main panels, and are operated by connecting rods from handles mounted on the front of the main switchboard. These handles are similar in appearance; therefore, to avoid confusion, the circuit breaker handles are inverted. The breakers are equipped with special magnetic blowouts and arc chutes. Provision is also made for automatically inserting a high resistance in the generator fields (as shown in the diagram) at the instant the main circuit breaker opens, thus reducing the generator voltage.

The alternating current switchboard contains two panels for controlling the synchronous motors by means of remote control, solenoid-operated, oil switches; two panels for the motor fields, and a panel for the automatic voltage regulator. These panels

OVERHEAD CONSTRUCTION ON SINGLE TRACK CURVE

also contain other necessary instruments, including frequency and synchronism indicators, ammeters, wattmeters and relays.

Overhead Construction

The overhead construction for this system was especially designed to give maximum flexibility for operation of the pantograph trolleys used on the locomotives. The 4/0 grooved copper trolley wire used over all tracks is supported by an eleven-point cantenary suspension from a stranded steel messenger cable. Both side bracket and cross span construction are used as required by the local conditions. There is a large amount of special work on account of the many yards and sidings, and in one case twelve tracks are spanned. The cross span construction used at this point is supported by a third pole between the eighth and ninth tracks. The hanger used on the straight line construction is a rolled steel strap looped over the messenger wire. This loop is closed at the car and the wire is clamped in place by a single bolt. Special pull-offs are used to increase the flexibility of the suspension.

The section breakers were designed for the 2400-volt service, and at six points insulated crossings are necessary at the intersection of the 2400-volt trolley with the 600-volt trolley of the city system. On the main line a very simple section insulator is used. This consists of paralleling the two trolley wires from the ends of each section at a suitable distance for insulation so that the pantograph bridges the two circuits for a short distance, thus avoiding interruption of the power supply to the locomotive. The construction in the yards and sidings is simplified by paralleling the trolley from the side tracks for a short distance along the main line. This avoids the use of switch plates or similar devices. At some of these junction points the pantograph engages as many as six trolley wires.

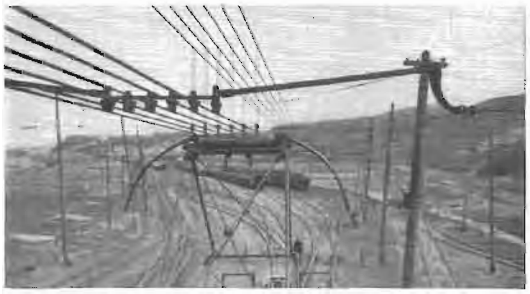
The uniformly successful operation of this overhead work is largely due to its very simple and flexible construction and the absence of frogs at meeting points.

INTERSECTION OF 2400-VOLT SYSTEM WITH TROLLEY CROSSING

The overhead lines are protected from lightning by 2400-volt direct current Type ME arresters installed on poles at intervals of one-third of a mile the entire length of the system.

Feeders

The 4/0 trolley is reinforced between the substations with two 500,000-c.m. bare copper cables tapped to the trolley at intervals of 1000 feet. A 4/0 negative return wire is also installed between Rocker and East Anaconda. This wire is carried on the trolley poles and is connected to the cross bonds at intervals of 1000 feet. The rails are connected by 4/0 bonds at every joint. The substations are normally connected together by these feeders, allowing an interchange of current. In emergency either station can supply current to the entire system.



PANTOGRAPH ENGAGING SIX TROLLEY WIRES

Locomotives

The locomotive equipment consists of seventeen 80-ton units, fifteen for freight and two for passenger service. The freight locomotives are geared for slow speed and are operated in pairs for the main line service. The maximum free-running speed is 35 miles per hour.

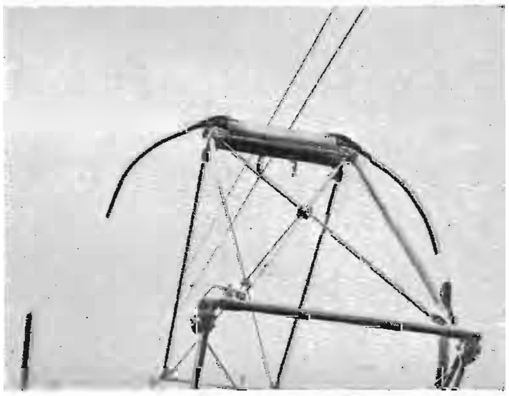
The two passenger locomotives are of the same construction as the freight units, but are geared for a maximum free-running speed of 55 miles per hour. A speed of 45 miles per hour is made with three passenger coaches on straight level track.

The continuous tractive effort of a single 80-ton freight locomotive is 25,000 lb. at 15 miles per hour. The maximum tractive effort for a period of five minutes is 48,000 lb. based on a tractive coefficient of 30 per cent.

These locomotives are of the articulated double truck type with all the weight on the drivers. The cab contains an engineer's compartment at each end and a control compartment for control apparatus. This cab is of the box type extending the entire length of the locomotive and is provided with both end and side doors. The entire weight of the locomotive is carried on semi-elliptic springs suitably equalized.

The central channels forming a part of the underframe are enclosed and are utilized as a distributing air duct for the forced ventilation of the motors. The air is conducted through the center pins, which are hollow, into the truck transoms and thence to the motors. The engineer's compartment at either end of the cab contains the operator's seat, controller, air brake valves, bell and whistle ropes, ammeter, air gauges, sanders and other control apparatus within immediate reach of the engineer.

The contactors, reverser and rheostats, which are located in the central portion of the cab, are mounted in two banks running lengthwise of the compartment and are conveniently arranged for cleaning, inspection and repair. All apparatus and circuits carrying 2400 volts are thoroughly protected from accidental contact.

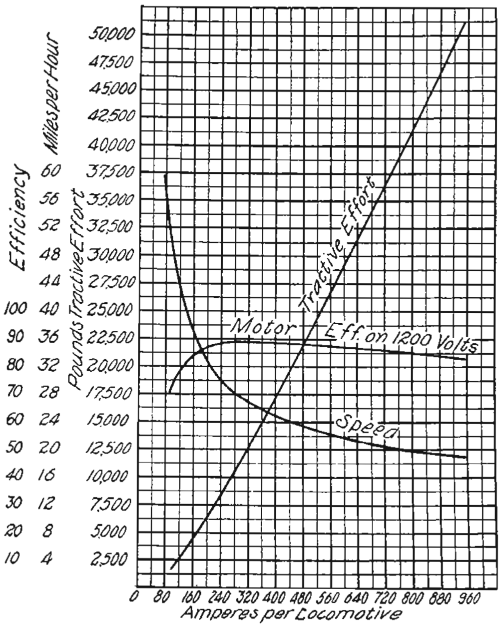


PANTOGRAPH IN OPERATION ON SINGLE TROLLEY WIRE

The motors are of the GE-229-A commutating-pole type, wound for 1200 and insulated for 2400 volts. These motors were designed for locomotive service and are provided with forced ventilation. The method of venti-

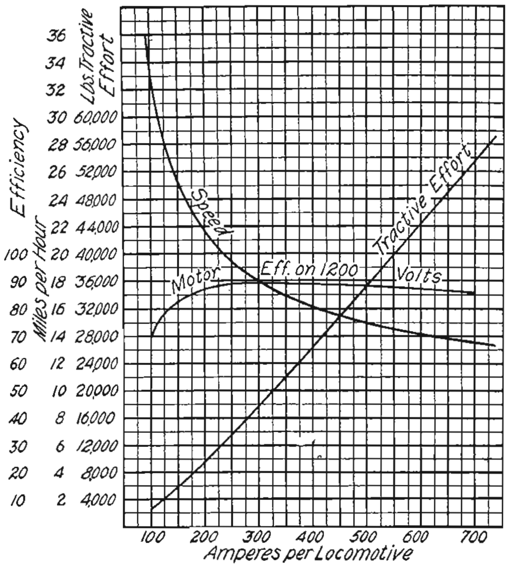
GE-229 1200 VOLT MOTOR SHOWING OPENING FOR VENTILATING PIPE

lation is similar to that of the well-known ventilated motors, but the air is circulated by an auxiliary blower mounted on an extension

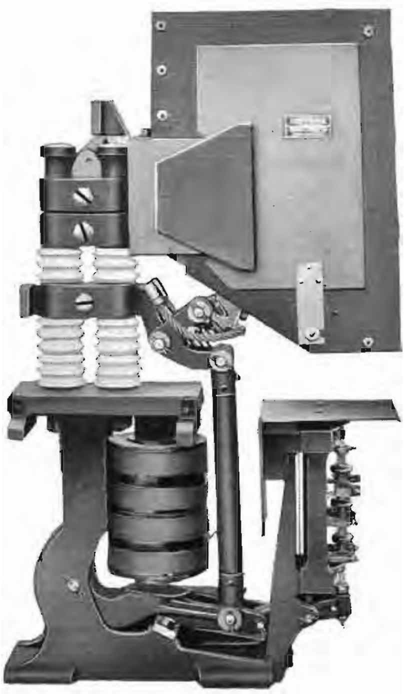


CHARACTERISTIC CURVES OF PASSENGER LOCOMOTIVE

of the dynamotor shaft. The gear reduction on the freight locomotive is 4.84 and on the passenger locomotive 3.2. The double unit 160-ton locomotive is capable of giving a continuous sustained output of 2100 horse



CHARACTERISTIC CURVES OF FREIGHT LOCOMOTIVE



DB-254-A 2400-VOLT CONTACTOR

power. The motors are connected to the driving wheels by twin gears similar to those used on the Detroit River Tunnel, Baltimore & Ohio, and the Great Northern locomotives.

The control equipment is Sprague-General Electric Type M, multiple unit, operating the four motor in series and in series-parallel. Two 1200-volt motors are permanently connected in series. The controller provides ten

rod. The contacts, magnetic blowout and arc chutes are also especially designed to rupture the 2400-volt arc.

Current is collected by overhead roller pantographs, pneumatically operated and controlled from either engineer's compartment by an air valve. A 2400-volt insulated

PASSENGER TRAIN AT ANACONDA STATION

EMPLOYEES LEAVING MINE HOIST

steps in series and nine in series-parallel. The transition between series and series-parallel, is effected without opening the motor circuit and there is no appreciable reduction in tractive effort during the change. The transfer of circuits at this point is made by a special change-over switch, which is operated electro-pneumatically.

bus line runs along the center of the cab roof. These bus lines are connected together by couplers between the two freight units, so that current may be obtained from either one or two collectors. The air brakes are the combined straight and automatic type; and the compressor is of the CP-26, 600-volt type, having a piston displacement of 100 cu. ft.

ELECTRIC LOCOMOTIVE DELIVERING ORE TRAIN TO CONCENTRATOR BINS

HOIST AND STORAGE BINS ON BUTTE HILL

The 2400 volt contactors are operated from the 600-volt control circuit, and are specially constructed to separate the 2400-volt parts from the coils and interlocks which carry the 600-volt current. The necessary insulation is obtained by large clearances and by the use of porcelain and mica. The armature is connected to the contact lever by a wooden

of air per minute when pumping against a tank pressure of 135 pounds. Radiating pipes are provided on the roof of the cab for reducing the temperature of the compressed air before it reaches the high pressure cylinder.

For operating the control equipment and air compressor and for lighting the locomotive and cars, 600-volt current is supplied from the 2400/600-volt dynamotor installed on each locomotive. This machine is similar in construction to the 1200/600-volt dynamotor, having two distinct sets of armature coils wound on the same core and brought out to a commutator at each end. One of these windings is designed for 1800 volts and the other for 600 volts, the two commutators being connected in series across the 2400-volt circuit. The load current is taken from the 600-volt commutator.

The mechanical load furnished by the direct connected blower supplies sufficient current in the series field windings to provide for the necessary excitation, so that no shunt windings are required. The blower which supplies ventilating air to the motors consists of a multi-vane fan mounted on an extension of the dynamotor shaft. It has a capacity of 7200 cu. ft. per minute at 4 inches water pressure.

LOCOMOTIVE DATA

The principal data and dimensions applying to the locomotives are as follows:

Length inside of knuckles	37 ft. 4 in.
Length over cab	31 ft.
Height over cab	12 ft. 10 in.
Height with trolley down	15 ft. 6 in.
Width overall	10 ft.
Total wheel base	26 ft.
Rigid wheel base	8 ft. 8 in.
Track gauge	4 ft. 8½ in.
Total weight	160,000 lb.
Weight per axle	40,000 lb.
Wheels, steel tired	46 in.
Journals	6in.by 13 in.
Gears,forged rims,freight locomotives	87 teeth
Gears, forged rims, passenger locomotives	80 teeth
Pinions, forged, freight locomotives	18 teeth
Pinions, forged,passenger locomotives	25 teeth
Tractive effort at 30 per cent coefficient	48,000 lb.
Tractive effort at one hour rating	30,000 lb.
Tractive effort at continuous rating	25,000 lb.

The locomotives have been maintained by the regular shop force with the assistance of one man experienced in electrical apparatus.

Lighting the Passenger Coaches

Standard 600-volt lighting fixtures will be used on the cars, and each passenger and baggage coach will be wired for five groups of five lamps in series. The lights in each car will be controlled by a suitable master switch and fuse with snap switches in the individual circuits. Thirty-six-watt railway type MAZDA lamps are used, giving about 26 c-p. at 110 volts per lamp. Lighting current will be taken from a 600-volt train line bus, which is connected to the dynamotor on the locomotives.

Electric Hot Air System

All of the passenger and baggage cars now used between Butte and Anaconda will be heated as well as lighted by electricity as soon as the equipment can be installed. Each car will be heated from a single heating unit installed underneath the car floor and supplied from a 2400-volt bus connected directly to the 2400-volt bus on the locomotive. This unit will have a maximum capacity of 25 kw. and will be used to heat the air which is distributed to different parts of the car by means of a small motor-driven blower. Cool air will be drawn into the insulated case enclosing the heating units from some point on the roof of the car. After passing over the heating coils the air will be carried through ducts under the floor of the car to radiators placed between alternate seats. The blower has a capacity of from 500 to 1000 cu. ft. of air per minute, and the motor is connected in series with the heating units.

In order to increase the range of the heating equipment to meet the requirements of varying temperatures, provision is made for connecting the coils to give a total consumption of 10, 15, 17.5 or 25 kw. The temperature of the car is regulated at all times by a thermostat.

All apparatus for the electrification of this road was furnished by the General Electric Company of Schenectady, N. Y., U. S. A.