GENERAL ELECTRIC REVIEW

Published by
General Electric Company's Publication Bureau
Schenectady, N. Y.

CONTROL EQUIPMENT OF PAULISTA LOCOMOTIVES

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REPRINT

From Issue of March, 1922

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Control Equipment of Paulista Locomotives

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Work is nearing completion on the new electrified section of the Paulista Railway of Brazil, and it is expected that electric operation will be in full swing within a very short time. The electrification of this line has been of particular interest, as it marks the inauguration of electrification of the main lines of South America, where wood has been used extensively for locomotive fuel, and the problem of cutting and transporting this fuel from the gradually receding forests has brought the electrification question abruptly to a head. In steam road electrification the locomotive is always of particular interest; for after all the sole purpose of a railroad is to get the tonnage over the road, and the power, reliability and performance of the locomotive determine, possibly to a greater extent than anything else, the success and sufficiency of the whole project.

It should therefore be of interest in connection with the general information that has already been published on this electrification, to give a detailed description of the locomotive control and its functioning.

The Locomotive

As the control is determined by the weight and required performance of the locomotive, a brief description of the locomotive will be given. Fig. 1 shows the profile of the road over which the locomotives are to operate with freight trains of 700 metric tons and passenger trains of 400 metric tons trailing. The rolling profile of the road, characteristic of so many railroads of South America, stands out in striking contrast to our American roads, and has a particular bearing on the selection of control and especially the regenerative braking control. The present electrification extends only from Jundiahy to Campinas, 44 kilometers of double track, but the plans involve a future extension to the entire broad gauge section of the line shown in the profile.

TABLE I

DATA ON ELECTRIC LOCOMOTIVES FOR PAULISTA RAILWAY

	Freight	Passenger
Length overall	39 ft., 2 in.	55 ft.
Width	10 ft., 1¼ in.	10 ft., 1¼ in.
Height over trolley down	14 ft., 3 in.	14 ft., 3 in.
Total wheel base	26 ft., 8 in.	46 ft., 0 in.
Rigid wheel base	8 ft., 8 in.	7 ft., 9 in.
Total weight	200,000 lb.	240,000 lb.
Weight on drivers	200,000 lb.	160,000 lb.
Weight per driving axle	50,000 lb.	40,000 lb.
Weight per guiding axle	None	20,000 lb.
Weight of mechanical equipment	118,800 lb.	158,900 lb.
Weight of electrical and brake equipment	81,200 lb.	81,100 lb.
Diameter of drivers	42 in.	42 in.
Diameter of guiding wheel	.....	36 in.
Number of motors	4	4
Gear ratio	82/18	70/30
Total continuous rating, h.p.	1,600	1,600
Total (1-hour rating) h.p.	1,680	1,680
Tractive effort, continuous	27,300 lb.	13,900 lb.
Tractive effort, one hour	28,900 lb.	14,750 lb.
Speed, continuous rating, m.p.h.	22.1 (35.6 km.)	43.4 (69.8 km.)
Speed, one hour rating, m.p.h.	21.8 (35.1 km.)	42.8 (68.8 km.)
Maximum safe speed	30.5 (50 km.)	55 (90 km.)
Tractive effort, 30 per cent coef. adh.	60,000 lb.	48,000 lb.

Power for the locomotive is obtained at 3000 volts from an overhead of twin catenary construction, and is supplied to the trolley by three 1500-kw. motor-generator sets from a single substation located at Louveira.

The passenger and freight locomotives differ in construction and gear ratio, but the same control is used on both types. The locomotives are equipped with four GE-267 self-ventilated motors. The general data are given in Table I.

The train is equipped with vacuum brakes, while the locomotive is equipped with compressed air brakes. Air and vacuum are furnished by a combined compressor-exhauster set operated by a 3000-volt motor running continuously. A control generator geared to the compressor-exhauster shaft furnishes control power at 65 volts and charges an auxiliary storage battery which may be used to supply current for control in an emergency, and for lights and testing when the compressor-exhauster is shut down.

Current Collection

The system of current collection is the same as that used on the C., M. & St. Paul locomotives. The pantagraph is of the sliding type with two independent contact pans, each of which has four copper contact strips with a groove for lubrication. The pans are equipped with long horns to prevent fouling with the overhead when the pan runs off the wire. The range in working height is about 9 ft., and throughout this entire range the pressure against the wire is approximately constant.

The pantagraph is air raised and gravity lowered. This assures that the pantagraph cannot rise accidentally. This is very important from the standpoint of safety. The pantagraph is shown in Fig. 2.

To provide for raising the pantagraph when there is no air on the locomotive, a hand pump is used by which air may be pumped either directly into the air cylinders of the pantagraph, or into a trolley reservoir from which the pantagraph may be raised later. The trolley reservoir is equipped with a globe valve which may be closed after shutting down the compressor when the locomotive is to be out of service for some time. By this means sufficient air can be held in the reservoir to raise the pantagraph after a period of eight or ten hours or more. It will therefore seldom be necessary to operate the hand pump.

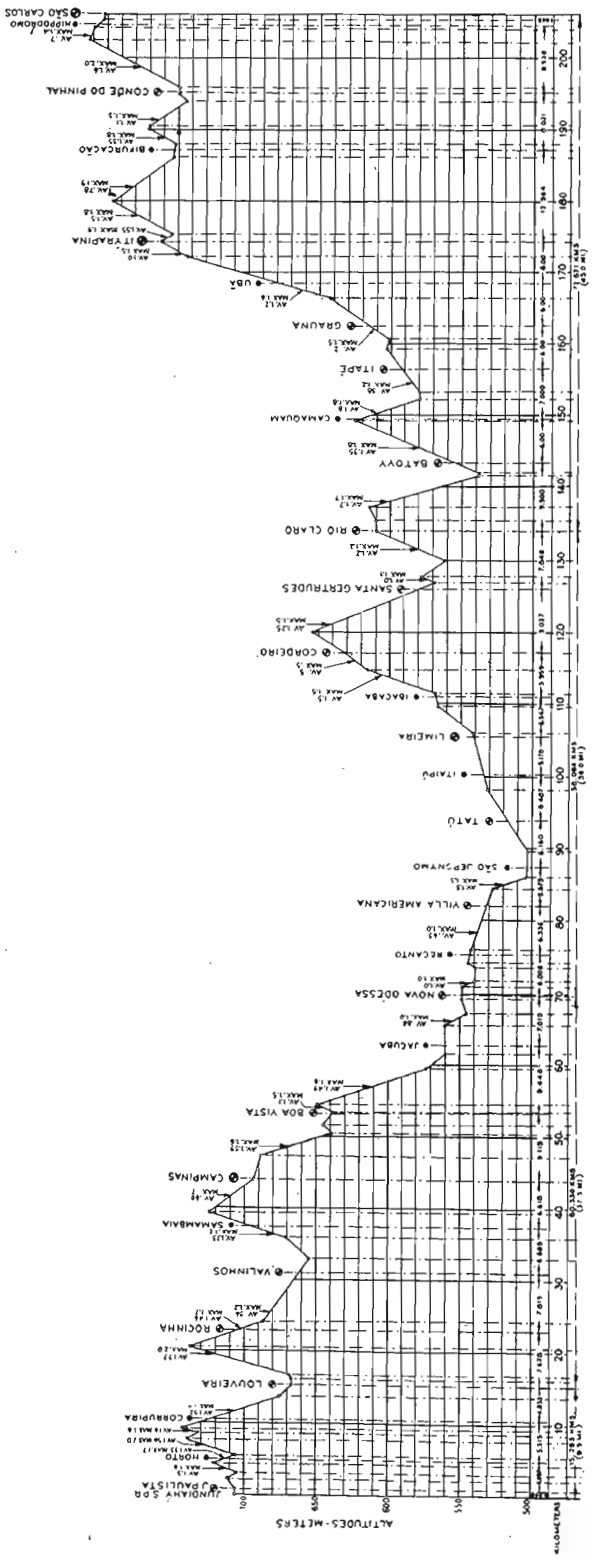

Fig. 1. Condensed Profile Showing Maximum and Average Grades. Gauge 1 M, 60

Accelerating and Motoring

There are two combinations of motors, viz., series with all four motors in series, and series-parallel with two groups of two motors in series. The control provides for 14 accelerating steps in series and 10 in series-parallel.

Fig. 2. 3000-volt Pantagraph Trolley Shown in Raised Position

The 14th step series and the 10th step series-parallel are running steps with all resistance cut out. Two additional running steps are provided by shunting the motor fields either in the full series position or in the full series-parallel position. Figs. 3 and 4 show the accelerating and running characteristics of the freight and passenger locomotives. These curves show the even distribution of steps for acceleration, and especially the small torque steps between 10 and 25 per cent tractive effort with the locomotive at rest. This is a very important point in the starting of heavy freight trains, for if the steps in this area were large the train might not be able to start on one point but might slip on the next, which would lead to difficulty in starting a heavy drag.

Transfer from series to series-parallel is accomplished by merely moving the main controller handle from full series to the 1st step series-parallel, or one notch on a progressive dial. When passing from the full series position to the 1st parallel position on the master controller, the series resistance is automatically cut in and then an air-operated cam switch throws, which short circuits a pair of motors and disconnects them from the line, leaving the other pair with their torque maintained, after which the disconnected pair are connected in parallel with the other pair. This allows a smooth transfer, as the timing of the insertion of resistance and the throwing of the switch is always the same, and is out of the control of the operator. The sequence of the cams on the transfer switch insures against any false connections during transfer. Torque is maintained during transfer in going back from series-parallel to series as well as from series to series-parallel, which insures against a sudden loss of torque when turning back, and reduces the chances of pulling draw bars or causing severe strains on the train, by allowing a gradual decrease in torque.

At each of the full running positions the fields may be shunted by throwing a separate selective handle to the shunting position.

Regenerative Braking

Regenerative braking as applied to the Paulista locomotives is of particular interest

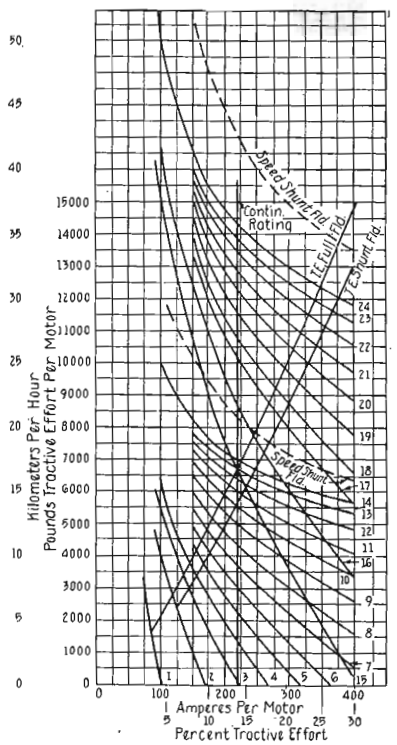

Fig. 3. Accelerating Characteristics of Freight Locomotive

as it involves a radical departure from any system used heretofore, and the small increase in cost, weight and complications required over simply a motoring locomotive has opened a field for the use of regeneration on locomotives where it has hitherto been

impractical to apply it on account of the limitations in space, cost and weight per axle.

When deciding upon the system of regeneration to be used, the characteristic of the profile and the method of train handling were considered. The profile is very broken with numerous short grades, and it was possible to take advantage of this condition to furnish a regenerative system which is very simple and reliable, and yet fully adequate for the service. No system of regeneration is justified for this service that does not fulfill the following requirements:

(a) No reduction in reliability of operation.
(b) Low additional cost and weight.
(c) Ruggedness and reliability of apparatus.

It was with these points in view that this system of regeneration was adopted. The particular feature of the regenerative system is that the same apparatus is used for controlling the regeneration as is used for acceleration. One of the motors is used to excite its own field and the field of the other three, and the regeneration is controlled by the same controller, contactors and resistors as are used for acceleration. By this means the maximum economy in the use of apparatus

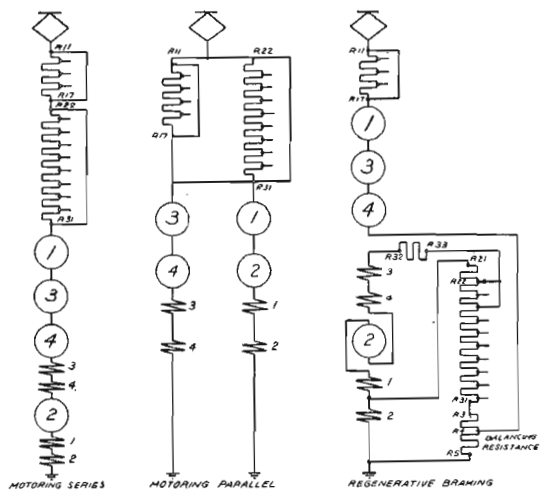

Fig. 5. Simplified Diagram Motoring and Regenerative Braking

is obtained, together with the additional advantage of using the same rugged and reliable apparatus for regeneration as for acceleration and motoring. Thus the necessity of using extra relays, contactors, controllers and motor-generator exciter sets, all of which involve added complications, is eliminated, maintenance costs lowered and reliability of operation increased.

Fig. 5 shows in a simplified form the connections for motoring, series and series-parallel, and for regenerative braking. This

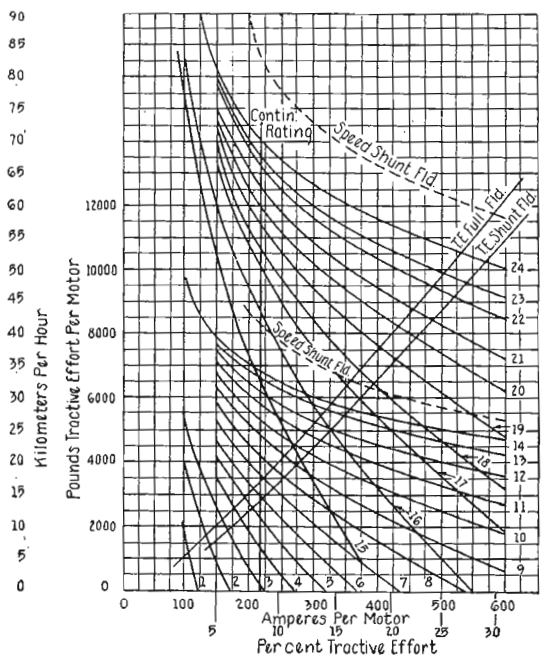

Fig. 4. Accelerating Characteristics of Passenger Locomotive

diagram shows the simple changes that are necessary in the series motoring connection to give the braking connection. The balancing resistance, which is used to stabilize the excitation and compensate for line voltage fluctuations, is connected in a particularly advantageous location with respect to the exciting motor field, so as to give the maximum protection to the motors against disturbances on the line. A heavy surge of regenerated current may entirely kill, or even reverse the field of the exciter, thereby lowering the voltage and reducing the surge before excessive currents are reached. Figs. 6 and 7 show the regenerative characteristic of the freight and passenger locomotives, giving the range of regeneration in tractive effort and speed.

Operation and Connections

The schematic diagram of the main and control connections is shown in Fig. 8, which indicates the extreme simplicity of the

control. The master controller, the development of which is given in the diagram, is shown in Fig. 9. The contact segments are screwed on a sheet iron cylinder making a particularly rigid but light construction. The mechanical interlocking is contained in the upper section.

the acceleration and regenerative braking. To accelerate the locomotive the main handle is notched up on the dial. At each of the full running positions the selective handle may be thrown to shunt the field. If regeneration is desired it is simply necessary to move the main handle back to the 1st notch and throw

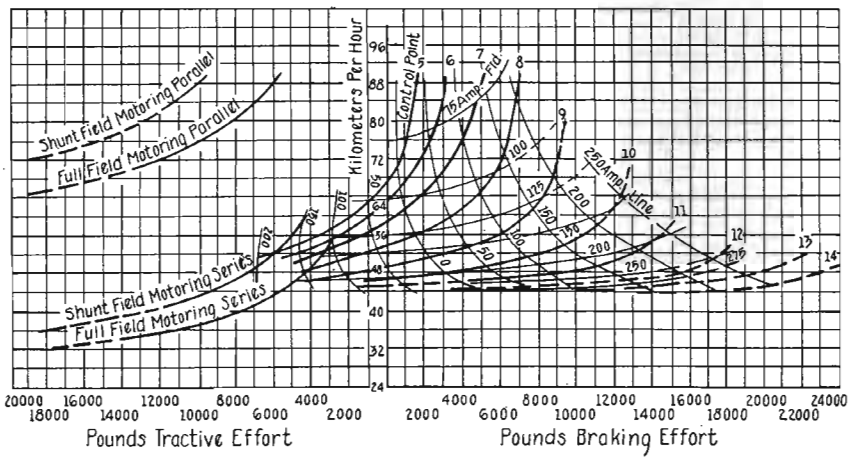

Fig. 6. Regenerative Braking Characteristics Freight Locomotive

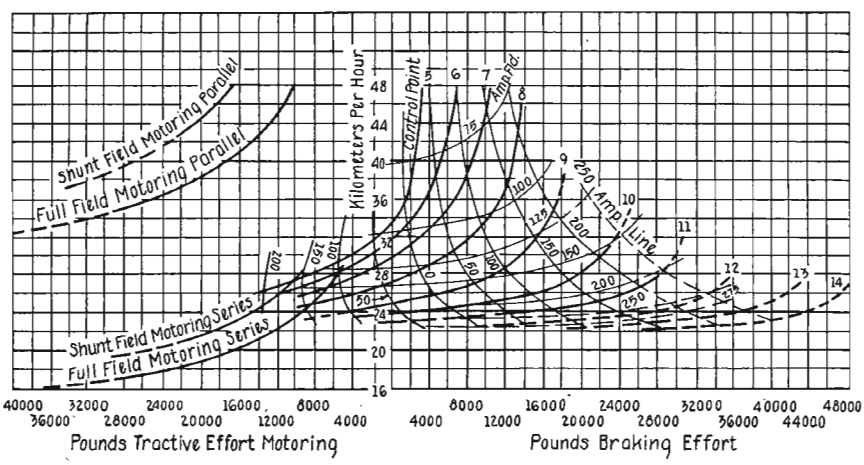

Fig. 7. Regenerative Braking Characteristics Passenger Locomotive

The locomotive is controlled from the operator's position shown in Fig. 10. The controller is shown at the left, the ammeters and air gauges in the center, and the brake valves to the right. At the left is also the pantagraph operating valve for raising or lowering the pantagraph. The controller has three handles, viz., reverse handle (top), selective handle by which motoring, braking or field shunting may be selected (middle), and the main handle (bottom) for controlling the selective handle to the braking position, and then notch up on the main handle until the desired braking effort is obtained. The manipulation is very simple, and always assures a smooth transfer from motoring to regeneration by a gradual decrease of motoring torque to a very low value and then a gradually increasing braking torque. The controller is mechanically interlocked so that no false manipulation is possible.

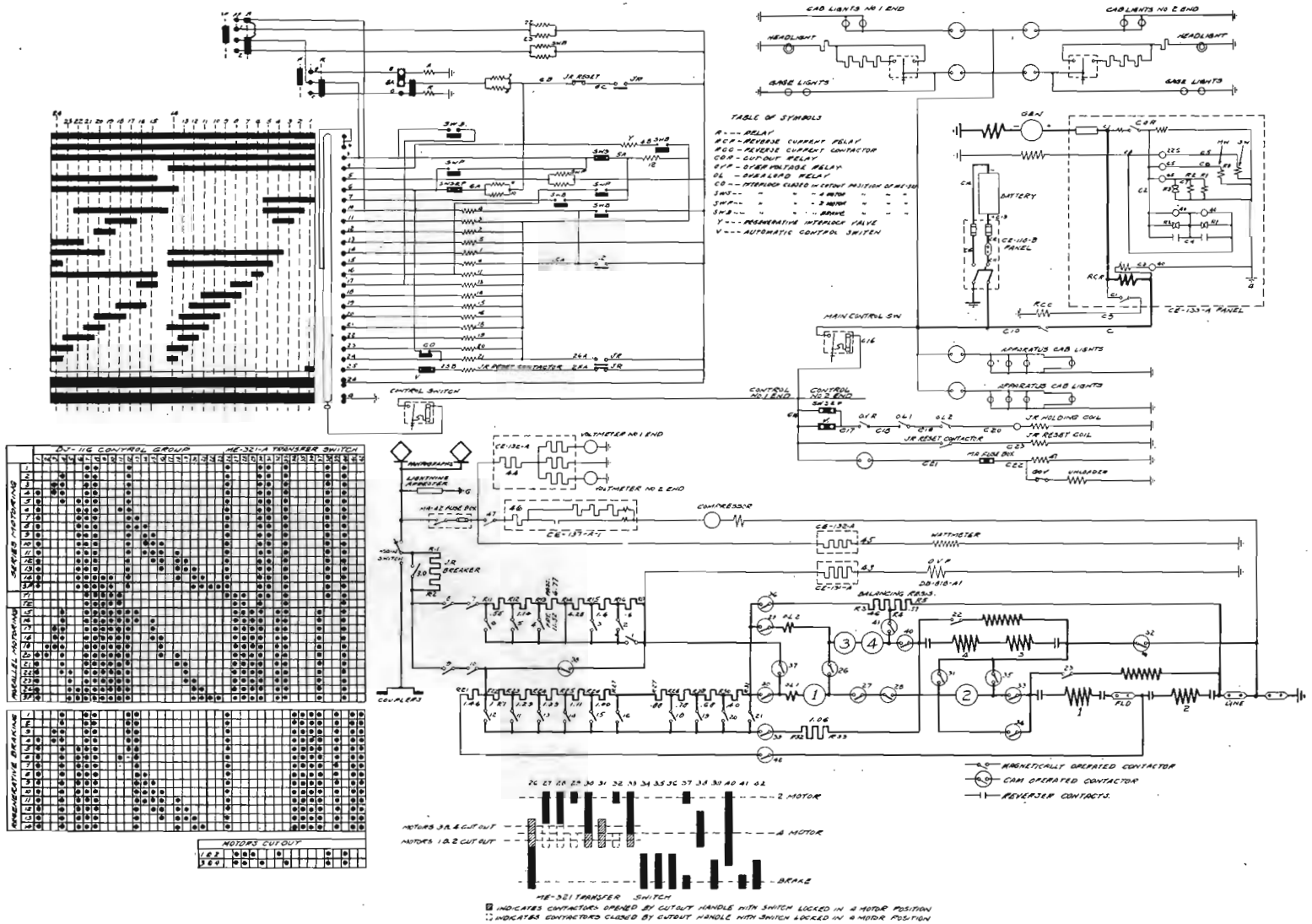

Fig. 8. Schematic Connections of Locomotive

Main Circuit Apparatus

The principal pieces of apparatus in the main circuit are:

2 sliding pantagraph trolleys,

Fig. 9. Master Controller with Covers Removed and Arc Chutes Swung Back

1 high speed circuit breaker,
1 group magnetically operated resistor and line contactors,
1 group electrically controlled, pneumatically operated cam contactors for series-parallel and regenerative transfer,
1 electrically controlled, pneumatically operated cam switch for reversing the motors,
32 grid resistors.

High Speed Circuit Breaker: Short Circuit and Overload Protection

A Type JR high speed circuit breaker is connected between the line and the rest of the apparatus in the main circuit. This breaker is shown in Fig. 11 and is similar to the ones used on the C., M. & St. Paul bipolar locomotives. It is used to protect the apparatus and motors against short circuits.

The principle of operation of this breaker will be understood by referring to the diagrammatic sketch shown in Fig. 12. The breaker is closed by a magnetic reset coil and held in by a holding magnet. The armature *A* of the contact arm is held by the poles of the holding magnet which are separated by a relatively small air gap. In this air gap a series bucking bar is inserted which carries the line current. When the current in the

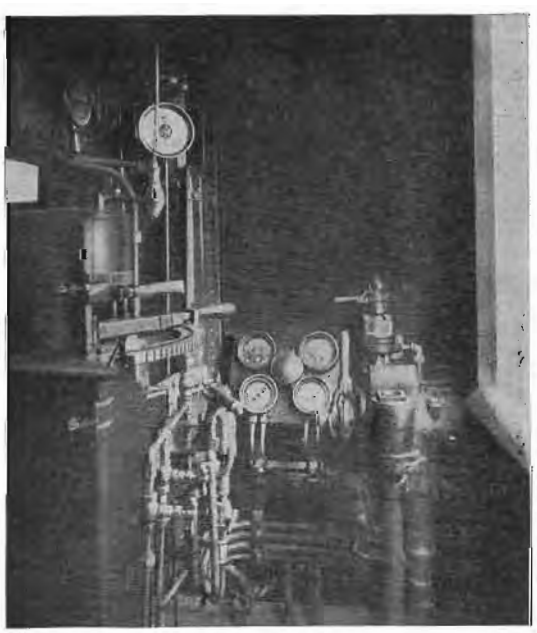

Fig. 10. Operator's Position on the Locomotive Showing Master Controller Ammeters, Gauges and Brake Valves

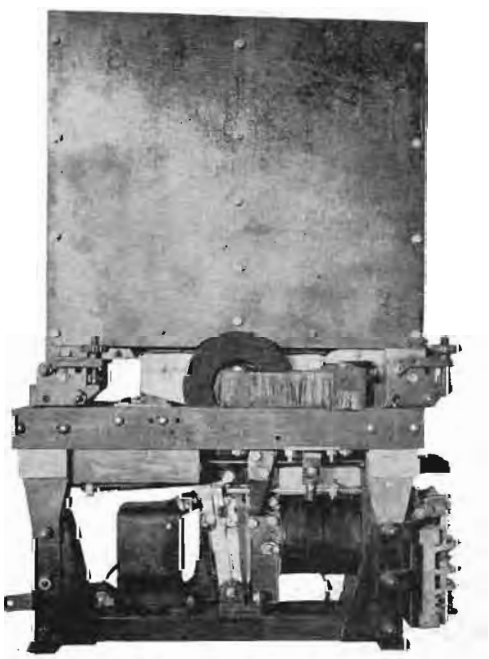

Fig. 11. Locomotive High Speed Circuit Breaker

bucking bar reaches a certain value a flux is set up which opposes the flux in the armature, causing it to shift from the armature to the holding magnet air gap. This releases the armature and it is tripped by a powerful tension spring. Since the armature is released by a shifting of flux with practically no change in the flux of the holding coil, there is no inductive delay in tripping; the operation does not depend upon any latches or triggers; and the result is an extremely rapid operation which is particularly effective in protecting the motors and the apparatus. Tests have shown that on a short circuit the breaker will trip in *eight thousandths of a second*, which is about the time required for a commutator bar to pass from one brush to the next with the motor running at its maximum speed. The value of these breakers in protecting motors and apparatus has been well demonstrated in actual service on the C., M. & St. Paul Railway.

To protect the motors against abuse by heavy overloading, an overload relay is connected in each motor circuit. This relay trips at a predetermined setting and in turn trips the high speed breaker.

The breaker is automatically reset when the controller handle is brought back to the first notch.

Resistance Contactors and Line Breakers

A departure from former designs was made in the main circuit contactors of the Paulista locomotive. The contactor is magnetically operated and is the same in principle as the contactors used on the C., M. & St. Paul and Butte, Anaconda & Pacific locomotives. An improved arrangement is provided whereby the contactors may be assembled in a small space.

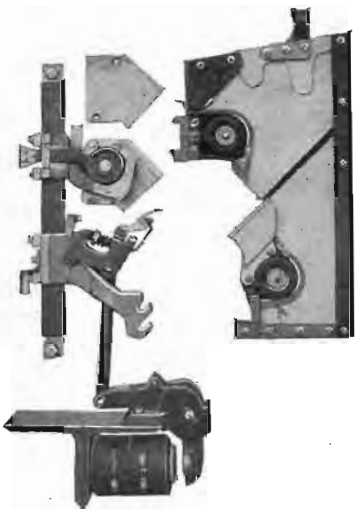

Fig. 13. Exploded View of a 3000-volt Contactor

Fig. 13 is an exploded view of the contactor. This figure shows the extreme simplicity and the few parts that make up the contactor. The coils in the arc chutes are auxiliary blowout coils

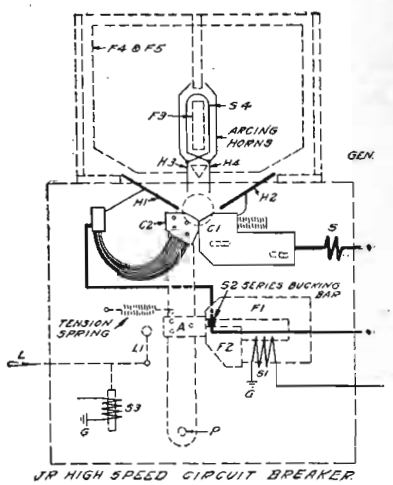

Fig. 12. Schematic Diagram of the High Speed Circuit Breaker

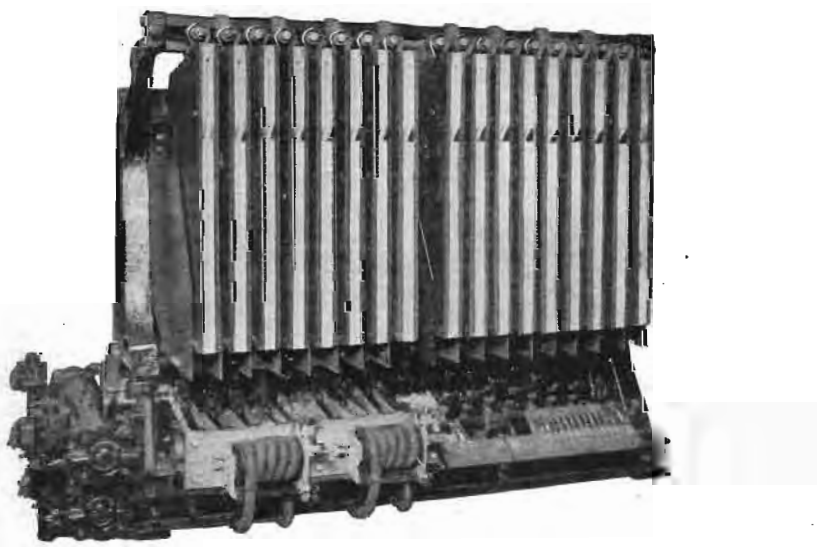

Fig. 14. 3000-volt Transfer Switch for Changing Over the Main Circuits for Motoring, Series and Series-parallel and Regenerative Braking Overload Relays Are Mounted in Front

which carry current only when an arc is being blown out. The arc catches on the arcing horns, which are shown bent around the coils, and travels out on the horns. A very powerful blowout is obtained, capable of clearing even a dead short circuit on the locomotive. In spite of the narrow spacing the contactor is easily accessible and easily removed. By taking out one bolt the arc chute may be swung down and removed. The entire contact element on the insulated rod may be removed by taking out two bolts and one cotter pin. These are points that can be fully appreciated by the maintenance man.

Series-parallel Switch

All contacts for rearranging the main circuits for series, series-parallel or regenerative braking are combined in one pneumatic switch in which the contactors are opened and closed by means of cams. The contactor parts are the same as those used for the individual contactors, thereby allowing an interchangeability of parts, with a minimum of supply parts to be carried in stock. By making these switches cam-operated from a common shaft, the proper sequence of transfer is always assured and no false connections are possible. Fig. 14 shows the transfer switch with its pneumatic engine. The overload relays are mounted on the support below the contactors.

In addition to the three positions obtained by pneumatic operation, a hand switch is added by which contactors may be opened and closed to cut out pairs of motors. Either pair of motors may be cut out in emergency.

Auxiliary Apparatus

The principal pieces of auxiliary apparatus are:

1 compressor-exhauster-generator set,
1 high-voltage auxiliary group, comprising panels for high resistances for wattmeters and voltmeter coils, and compressor starting apparatus.
1 lightning arrester,
1 storage battery.

Compressor-exhauster-generator Set

To reduce complications the compressor-exhauster and low-voltage control generator are combined in one set operated by a single 3000-volt series motor. The set is shown in Fig. 16. The compressor has a displacement of 48 cu. ft. of free air, and the exhauster a displacement of 150 cu. ft. The motor is connected to the line by a magnetic

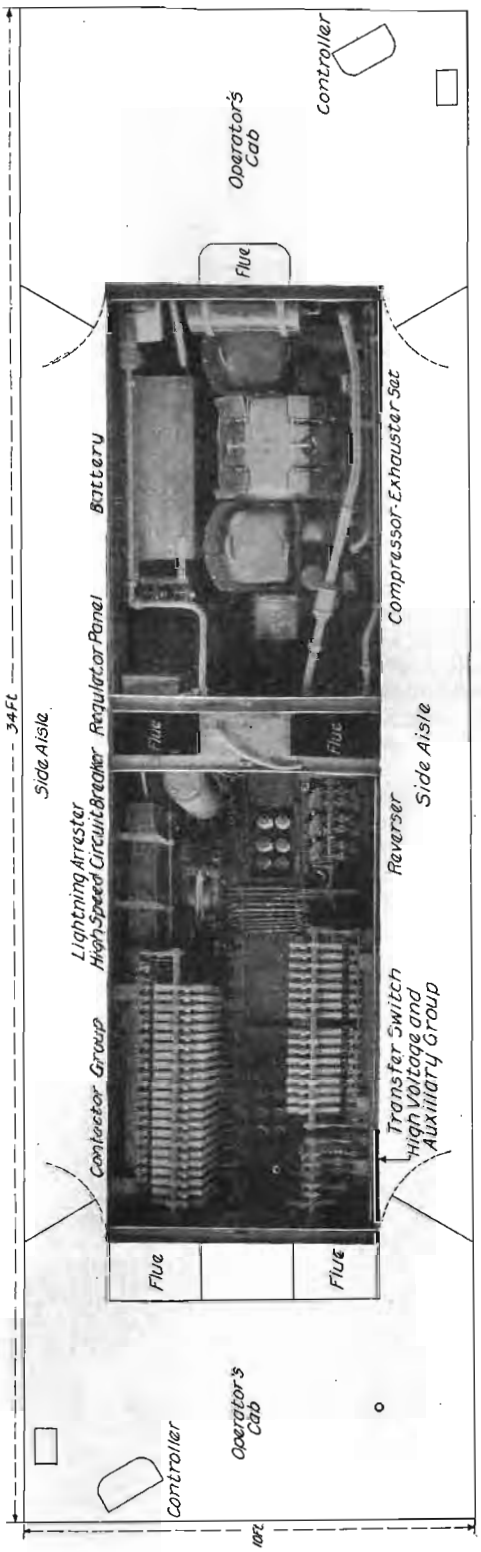

Fig. 15. View of Arrangement of Apparatus in Locomotive Looking Down with Hatches Removed

tactor, through a starting panel which consists of a series resistor and a series contactor which closes when the current has dropped to a predetermined value, shorting out the resistance.

Fig. 16. 3000-volt Compressor Exhaust Set Geared to Control Generator

The set runs continuously. When the pressure reaches 90 lb. an unloader operates and allows the compressor to pump to atmosphere. The exhaust system is equipped with "snifters" similar in principle to a feed valve, which allow air to leak into the system when the vacuum has reached 22 inches of mercury.

The control generator, which is geared to the shaft of the compressor, furnishes control power and also charges an auxiliary storage battery. The generator is connected through a regulator panel, by which its voltage is held constant through a wide range of speed. A reverse current relay between the generator and the battery assures against the battery discharging into the generator when the set is shut down.

Lightning Arrester

The lightning arrester is of the electrolytic aluminum cell type and is protected by an expulsion fuse. This is the standard railway type of arrester, which has given excellent service through years of operation.

Arrangement of Apparatus

Fig. 15 shows the arrangement of apparatus in the apparatus cab, looking down with the hatch removed. At the left is shown the half of the apparatus cab which contains the contactor group, series-parallel switch, reverser, high speed breaker, lightning arrester and high-voltage auxiliary group. The floor covers are removed to show the insulators beneath the floor for hanging the accelerating grids. This view shows the neat arrangement and especially the accessibility of the apparatus. There is an aisle on each side of the apparatus cab from which, by the removal of covers, the backs of the groups where all high-voltage connections are made are readily accessible. The flues for ventilating the accelerating grids are shown on both ends and in the center.

At the right is shown the other half of the apparatus cab containing the compressor-exhauster set, storage battery, regulator and battery panels.

Fig. 17 is a view of the accelerating grids and shows the method of hanging. This view is taken from the side aisle. The apparatus is mounted above the grids, and the grids are mounted in a compartment entirely separated from the other apparatus. They are easily accessible from the side aisles by the removal of covers.

In the design of the apparatus and in the layout of this locomotive a long stride ahead has been made. Economy of apparatus, reliability, simplicity; these must be the keynotes of locomotive design. Unnecessary

Fig. 17. View of 3000-volt Accelerating Grids Showing Method of Hanging

refinements, while not adding a single ton to the hauling capacity of the locomotive, always mean additional and a greater variety of apparatus, and consequently decrease the reliability of operation.