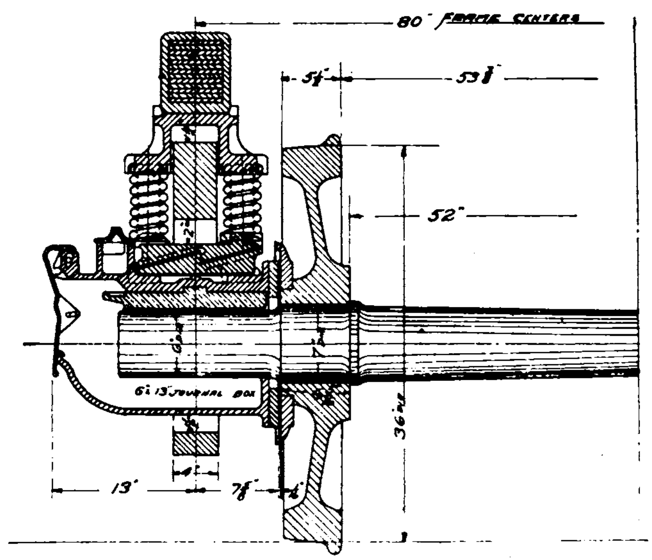
The Two Designs for the C., M. & St. P. Locomotives*

A. F. Batchelder and S. T. Dodd of the General Electric Company and N. W. Storer of the Westinghouse Electric & Manufacturing Company Give Details of the Two Designs to Meet the Chicago, Milwaukee & St. Paul Railroad Specifications—Some New and Individual Characteristics Are Emphasized

THE Chicago, Milwaukee & St. Paul Railroad electrification of the 440 miles of line from Harlowton, Mont., to Avery, Ida., proved sufficiently successful to convince the railway of the economic advantages of electric operation. As a logical consequence, as has been previously noted in these pages, the company decided to equip an additional section over the Cascade Mountains between Othello and Tacoma, Wash., a distance of 212 miles. In the summer of 1917 the railway issued specifications covering the apparatus required on account of this additional electrification and a contract for part of the locomotives was given to the General Electric Company and for the others to the Westinghouse Electric & Manufacturing Company. These locomotives are being delivered and put into service.

Engineers of the two companies, men who had much to do personally with the development of the locomotives, presented details of the two locomotives with some analysis of the reasons entering into the designs at the Pittsburgh meeting of the A. I. E. E. The ELECTRIC RAILWAY JOURNAL has published† data and other information regarding both of these locomotives from time to time. The publication of the abstracts of the papers presented at Pittsburgh serves to complete the descriptions and at the same time affords an opportunity for a comparison of the two designs.



JOURNAL BOX SHOWING WEDGES TO GIVE RESISTANCE TO LATERAL MOVEMENT. GENERAL ELECTRIC LOCOMOTIVE

The Chicago, Milwaukee & St. Paul Railroad specifications required that the locomotives be built for a power supply at 3,000 volts direct current. The load specified was a train of twelve steel coaches, making a total weight of 950 tons. The limiting grades are 2 per cent, compensated, for a distance of 20 miles from Piedmont to Donald on the east slope of the Rocky Mountains, and 2.2 per cent, compensated, for 17.8 miles from Beverly Junction to Boylston on the western division. The curvature of sharpest curve on the main line is 10 deg., but the locomotive must negotiate a 16-deg. curve in the yards satisfactorily. Speed requirements were set at approximately 25 m.p.h. up a 2-per cent grade, and approximately 35 m.p.h. up a 1-per cent grade, with a maximum speed of 65 m.p.h. for safety. Trains on down grades were to be held at speeds consistent with safe operation by means of regenerative braking.

CHICAGO, MILWAUKEE & ST. PAUL PASSENGER LOCOMOTIVE, GENERAL ELECTRIC CO.

It was further provided that the locomotive be equipped with an oil-fired boiler to be supplied by the railway, to furnish steam for heating the train. Storage capacity was required for 30,000 lb. of water and 750 gal. of fuel oil. Apparatus was also required in the locomotive for lighting the train and charging the train storage batteries at a voltage of from 60 to 85.

With these general statements as an introduction, the abstracts will now be given:

The General Electric Locomotive

BY A. F. BATCHELDER AND S. T. DODD

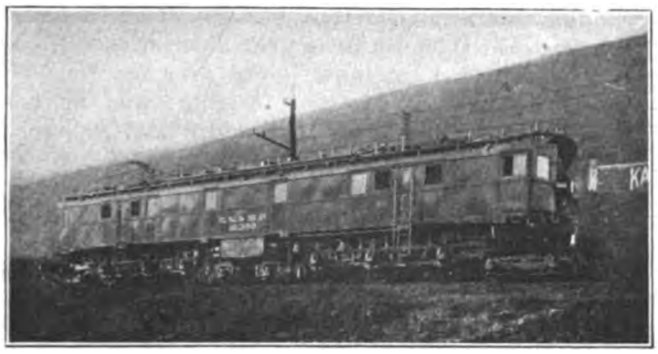
THE locomotive as completed and delivered by the General Electric Company is shown in an accompanying illustration, while another shows an outline drawing of the side elevation, giving some general dimensions. It will be seen that the running gear is composed of four individual trucks, the two end trucks having three axles each and the two center trucks having four axles each. These trucks are connected by special articulation joints. The motor armatures are mounted on the axles and the motor fields are carried on the truck frames.

*Abstracts of papers presented before the Pittsburgh Meeting of the American Institute of Electrical Engineers, March 12, 1920.

†See issues for March 23, 1918, pp. 559 and 561; Nov. 1, 1919, p. 827, and Jan. 3, 1920, p. 36.

The superstructure is made in two sections of similar design, with a third section between them. The third or central section contains the train-heating equipment, which consists of an oil-fired steam generator, together with water and oil tanks. This unit is complete in itself and is carried over supports attached to the middle two trucks. It can be readily removed for repairs without interfering with any other part of the locomotive. It is placed between the two operating cabs in order to be easy of access to the engineer's helper or fireman, from either location.

The end sections are similar in appearance. The operator's cab in either section is on the inner end next to the heater cab above described, having been so placed in order that the operator can be convenient to the heater and to allow a maximum space for apparatus in the apparatus cab or outer end section. Another advantage of this arrangement of cabs is that the operator can have access to any section of the locomotive requiring his presence without passing through a section containing high-tension apparatus. The engineer's or operating cab contains a main or master controller, the air-brake valves and handles and an instrument panel with air gages, ammeters and speed indicator. The engineer uses either of the two operating cabs, according to the direction in which he is running.



CHICAGO, MILWAUKEE & ST. PAUL PASSENGER LOCOMOTIVE, WESTINGHOUSE ELECTRIC & MANUFACTURING CO.

A door gives access from the operating cab to the apparatus section, which extends with a curved top to the extreme end of the locomotive. This construction adapts itself naturally to the protection of the apparatus included and, in addition, allows a clear view for the operator from his normal operating position. Contained in this apparatus section are the resistors and contactors for control of the power circuits of the locomotive. The starting resistors are placed in two rows on each side of the central passage just above the floor of the superstructure. They are covered at the sides by removable covers, which when opened allow the separate resistor boxes to be slid out upon the longitudinal running board outside the apparatus cab. The air compressor for the air brakes, the motor-generator set for the train lighting and the storage battery for marker lights and emergency control stand upon the same level as the resistors and can be removed or replaced in a similar manner. Above the resistors are located the contactors with their arc chutes facing a central aisle 2 ft. wide. This allows ample arcing space and room for inspection of contactors. Above the contactors is the curved roof of the locomotive with trap doors for inspection of the back connections and insulation and for removing the contactors in case replacement is necessary. The whole design and arrangement of this apparatus cab lends itself to economy of cost and material, as well as to convenience of inspection and repair of apparatus.

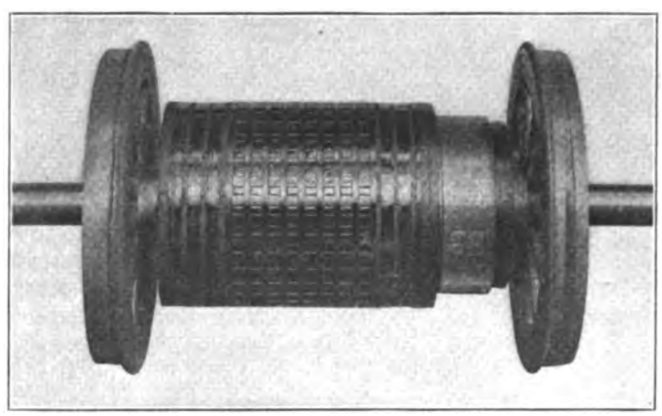
THE GEARLESS MOTORS ARE OF THE BI-POLAR TYPE

The motors are of the bi-polar gearless design which was adopted for the New York Central Railroad locomotives. To insure light weight per axle, flexibility in control and good truck arrangement for curving as well as for high-speed running, twelve motors were used, each of relatively small capacity. They are especially designed to withstand high temperature, being insulated with mica and asbestos.

The motor armature complete was built directly on the axle with the wheels pressed and keyed in place. The continuous rating of each motor at 1,000 volts and with 120 deg. rise, measured by increase in resistance, is 266 hp., corresponding to 3,500 lb. tractive effort at the rim of the drivers at a speed of 28.4 m.p.h. Forced ventilation is employed for cooling, and the armature core is provided with holes for the passage of ventilating air. Ventilating blowers are located above the motor armature. Air is delivered at the commutator end of the motor where it divides, a part passing through the armature and a part back through and around the field coils where it escapes upward and is afterward used for ventilating the starting resistors.

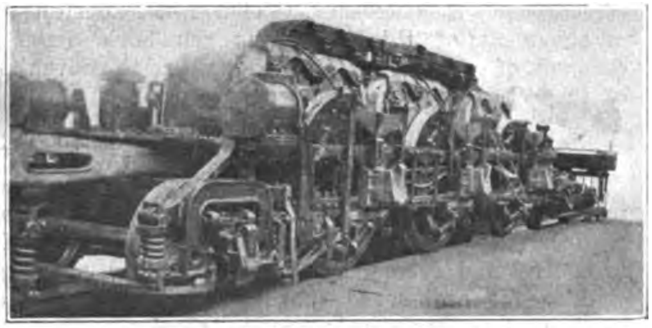
Besides having no journal bearings or gearing, this type of motor has the advantage of simplifying and making compact the locomotive design, as use is made of the frame to furnish the return path for the magnetic flux. With this construction the magnetic flux passes horizontally in series through all twelve motors, having a return path through the locomotive frame. Large surfaces in contact are provided in the articulation joints, thus giving an easy path for the flux. The polepieces are made flat to prevent them from coming in contact with the armature during its movements.

In the control equipment electro-magnetic control is used for single independently-operated switches, but electro-pneumatic cam control is used for operating banks of switches.



GEARLESS MOTOR ARMATURE AND DRIVING WHEELS, GENERAL ELECTRIC LOCOMOTIVE

Four combinations of motors are provided for motoring. The first is with twelve motors in series, the second with six motors in series and two sets in multiple, the third with four motors in series and three sets in multiple, and the fourth with three motors in



ONE-HALF OF RUNNING GEAR, WITH MOTORS MOUNTED. WESTINGHOUSE LOCOMOTIVE

series and four sets in multiple. In each combination there is one tapped-field step in addition to the rheostatic steps, thus giving eight operating speeds exclusive of the thirty-one resistance steps.

For regeneration, some motors are used to excite the fields of the others, which in turn are used as generators to return power to the line.

As a provision against short circuits or extreme overloads, a quick-acting circuit breaker is provided in the apparatus cab which will protect the circuit in less than 1 of a second.

Mechanical Construction Designed to Provide Flexibility

For flexibility in curving the running gear is made up of four trucks, each of a relatively short wheelbase. The middle two trucks have four driving axles each, and the two end trucks, two driving axles and one guiding axle each, making a total of fourteen axles. The trucks are connected together with articulation joints which allow of no relative lateral movement between them, so that each truck positively leads the following truck. This is for the purpose of reducing flange wear on curves and lateral oscillation on tangent track.

It is felt that with a wheelbase which is as long as the present one (67 ft.), the use of articulated trucks allows the locomotive to accommodate itself most satisfactorily to track curvature, at the same time minimizing lateral oscillations on tangent track.

To care for any lateral blow which might, however, be given against the rail head the leading and trailing axles are allowed a movement of ½ in. relative to the truck frame either way from their central position. This movement takes place against a resistance introduced by wedges above the journal boxes. This wedge construction is shown in an accompanying illustration. Further protection of the track from lateral displacement on the ties is provided by carrying the outer end of the superstructure on rollers, bearing on inclined planes upon the truck frames. By this construction the leading and trailing trucks tend to maintain their central position and the weight of the superstructure is best distributed so as to increase the adhesion of an affected rail to its tie.

The Westinghouse Locomotive

By N. W. Storer

Accompanying reproductions of pictures show views of the completed Westinghouse locomotive, and an outline cut-away drawing shows the general arrangement of the interior, as well as the exterior. The running gear consists essentially of two Pacific-type running gears coupled back to back. One half of the running gear is shown in another illustration. The side frames are steel castings, joined over the four-wheel trucks by a heavy A-frame casting; also by heavy cross-ties between the drivers, which also support the motors and carry the center pin and the coupling between the two running gears. Each half running gear has six spring-supported plungers on which the cab rests. There are two supports at each end and two in line with the center pin. By the use of shims, the distribution of weight between the two ends of each running gear may be adjusted as desired. The coupling between halves consists of a long bar of a box section.

The superstructure consists of one long cab built so strong and rigid that it can be lifted at the ends. It is light but stiff. The cab is divided by cross partitions into compartments, one at each end for the engineer and the others for the several parts of the cab equipment.

In the middle cab, and occupying relatively a large portion of space, are located the steam boiler and the water storage tanks. The fuel oil tank is located beneath the boiler and the two water tanks are placed just fore and aft of the boiler.

Twin Driving Motors Are Used

The six driving motors are of the twin-armature type, that is both armatures are contained in a single frame arranged to secure the maximum economy of weight. The fields are of the standard four-pole type with four salient poles and four inter-poles for each armature. Each armature is wound for 750 volts, but fields and armatures are connected permanently in series so that the rating of the complete motor is based on 1,500 volts.

The one-hour rating is 700 hp., based on the A. I. E. E. rules, and the continuous rating 567 hp., with forced ventilation and 400 hp. without blowers.

Twin motors were adopted to reduce space used by gears, to reduce locomotive weight, to make the most efficient use of available space and to secure the advan-

OUTLINE DRAWING OF GENERAL ELECTRIC LOCOMOTIVE tage of low-voltage armatures. Motor capacity was fixed by the number of axles, six being selected as the smallest number that could be used under the limitation of weight on the drivers. This led to the adoption of the double Pacific type of running gear with its excellent riding characteristics. An illustration shows the pinion end of the twin motor.

Fans mounted on the motors give them a high continuous rating without the use of forced ventilation, and it is expected that the blowers will not have to be used with normal train load except on heaviest grades.

Quill drive, similar to that used on the locomotives of the New York, New Haven & Hartford Railroad was adopted.

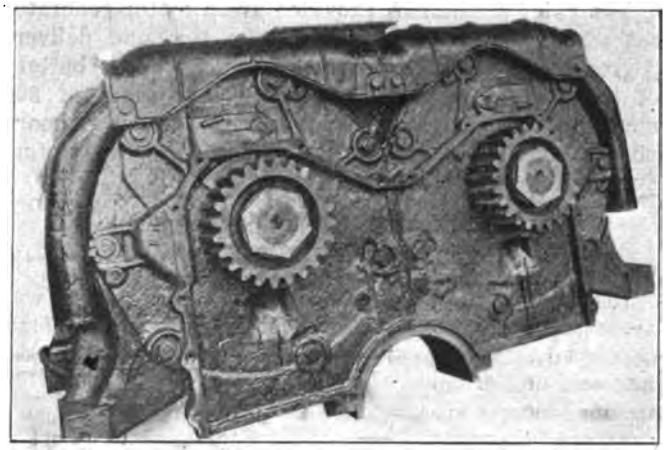
Some Facts Regarding the Control System

An accompanying illustration shows a schematic diagram of the main motor circuits and another diagram gives the details of a single motor with its exciter and resistance. Three combinations of motors are possible; first, six motors in series; second, three in series, two sets in parallel, and third, two in series, three sets in parallel. By the use of inductive shunts on the fields of all three of these positions nine running speeds are possible, in addition to the thirty-three resistance steps available. One feature of the resistance arrangement is that the same resistance groups and switches are used for all of the three combinations. All switches are electro-pneumatically operated, some individually and some in cam groups.

Illustrations are given, also, to show the master controller open and the top view with the control levers. An interlock in the controller prevents the line switches from closing when the motor connection is in the second or third position, unless the engineman knowingly pushes a button in the top of the master controller. When applying current with the locomotive at speed this button must be pressed when it is desired to go immediately into the second or third combination.

For regeneration, the motors are separately excited from two axle-driven generators carried on the inside axles of the two four-wheel trucks and geared to them like ordinary interurban railway motors. These generators are separately excited and the field strength of the main motors is controlled by varying the fields of the exciters.

The scheme used for regeneration includes the use of stabilizing resistance, which is connected in series with the exciter armature, with the main motor field

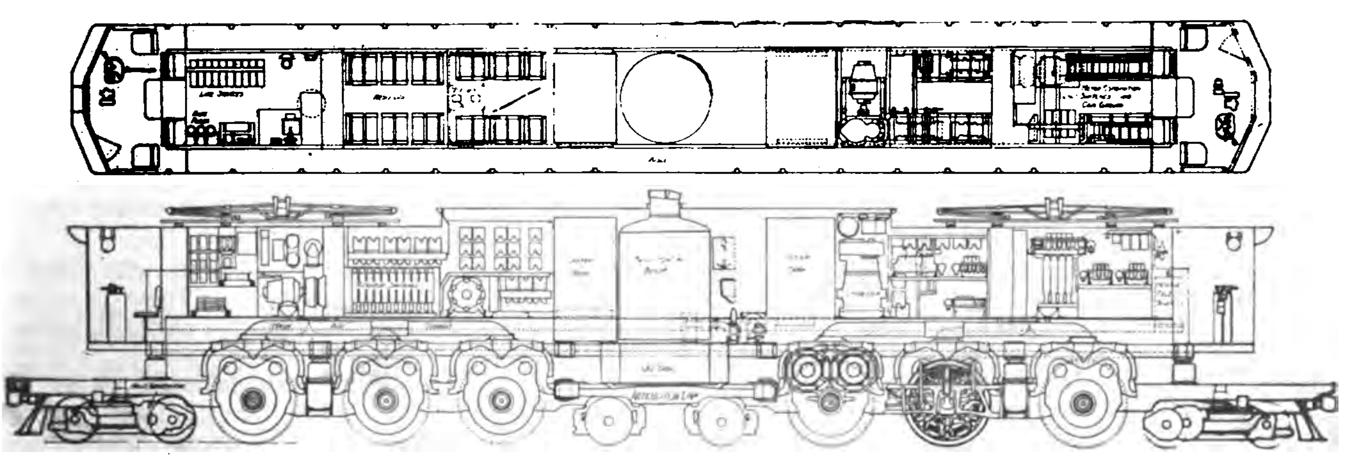


TWIN MOTOR FOR WESTINGHOUSE LOCOMOTIVE

circuit and also with the main motor armature circuit, so that the field excitation is dependent, to a certain extent, on the armature current.

One feature was to provide for beginning regeneration at any speed within the normal running range without having a heavy current in either direction that would produce a surge in the train. This was accomplished by providing that the motors should never be connected to the line without the maximum starting resistance in series between motors and the line. This, of course, is provided for in motoring, but is necessary also in regeneration to prevent undesirable surges. With the 17 ohms resistance provided on the first step, the maximum current that could flow from the line would be less than 200 amp. with no voltage generated in the motors. The resulting torque is negligible, particularly if this current is divided among two or three circuits, as would be the case in the second or third combinations.

The stabilizing resistance protects the motors against sudden changes in line voltage, while the axle generators protect against variations in grade, which would otherwise tend to vary the speed. In case of a sudden reduction in line voltage, which would be followed by a heavy increase in the regenerated current, the increased voltage drop in the stabilizing resistance resulting from this immediately cuts down the field current and the voltage generated by the main motor sufficiently to limit the increase in regenerated current to a safe value. Similarly the axle-generator regulation takes care of the passage of a train from a sharp curve to a tangent.

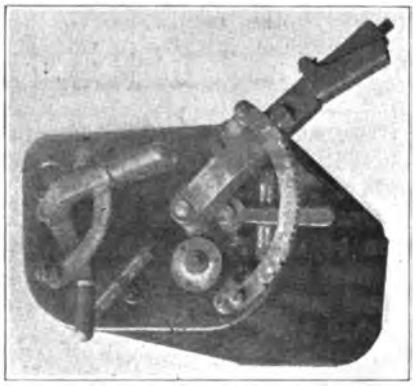


SIMPLIFIED PLAN AND LONGITUDINAL VERTICAL SECTION OF WESTINGHOUSE LOCOMOTIVE

The chief auxiliaries provided are a motor-generator set which draws current from the line and delivers current at a constant voltage of 85; a storage battery of thirty-eight cells with a one-hour capacity of 300 amp., and two axle-driven generators for the primary purpose of furnishing excitation for the main motors during regeneration.

Steam Locomotive Experience Applied in Mechanical Design

In the design of this locomotive the attempt was made to obtain those mechanical features which have developed through years of experience with steam locomotives. The desirable features are location of the mass as close to the center as possible, high center of gravity of that part of the locomotive carried on the running gear, as long a rigid wheelbase as possible, guiding trucks located well outside the mass of the running gear, equalization to secure stability, minimum permissible restriction of free movement of each axle and portion of the running gear and large driver diameter. In the cab it is very advantageous to concentrate heavy equipment between the center pins. In the running gear the closer the weight is concentrated to the center pins the less tendency there is to nose and the easier the duty on the wheel flanges and track.



TOP VIEW OF WESTINGHOUSE MASTER CONTROLLER

This locomotive embodies all the foregoing features to a remarkable degree. Particular attention was given to weight distribution. The cab has the boiler, water and oil tanks, storage batteries, air-compressor, resistors, motor-generator set and the heavier parts of the control equipment concentrated between the center pins. The driving motors are mounted above the axles on the running gear, thus getting the weight well inside the wheelbase, but placing it relatively high. The height of the center of gravity of the complete locomotive is 68 in., a value that compares well with that of a steam locomotive.

The Pacific type of running gear with its long rigid wheelbase and the guiding trucks is a particularly stable design and is especially good with the weight distribution that obtains on this locomotive. The height of the center of gravity of trucks with motors mounted is 43¾ in.

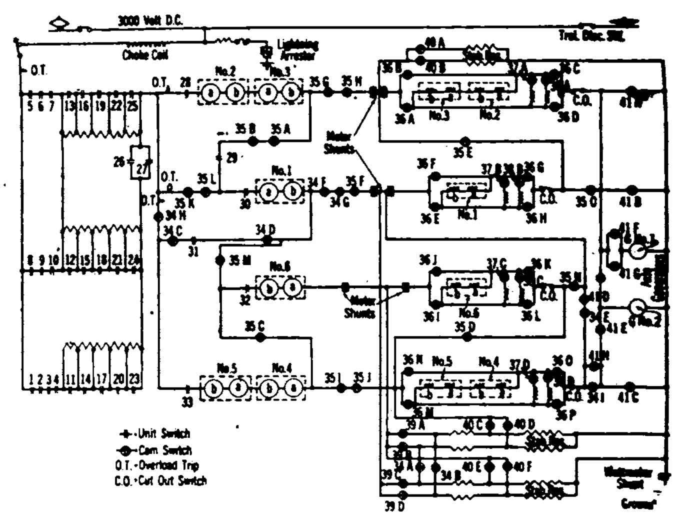
The quill drive, which is a further development of the one used on the New Haven locomotives, gives each driving axle perfect freedom to move vertically the full distance permitted by pedestal jaws without affecting the motors or frames, except through springs. The only "dead" weight carried is the weight of wheels, axles, journal boxes and spring clamps.

Great effort has been made to cushion the locomotive against shock, either while running or from bumping. The apparatus in the cab is especially well protected, since the cab rests on spring-supported plungers which are in series with the main semi-elliptic springs. The cab is protected against bumping strains by floating center pins, which, while held rigidly against lateral motion, are cushioned against longitudinal motion by heavy springs. It has been the practice heretofore with this general type of locomotive to have one center pin rigid in the running-gear frame and to allow the other to move freely in a longitudinal direction. It was considered best in this machine to allow a slight relative motion between the two center pins, but to prevent the bumping shocks by spring cushioning.

Notes on the Electrical Design

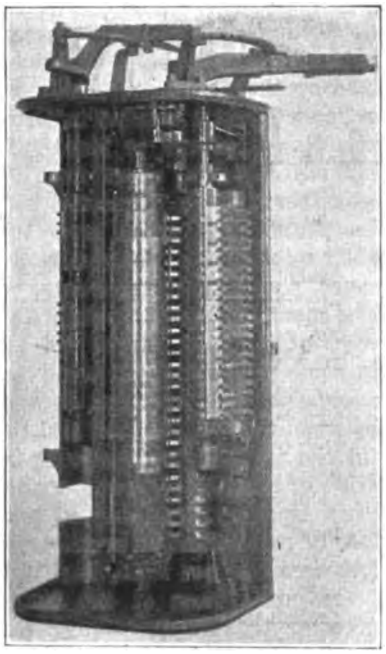
The efficiency of the twin-motor unit with both armatures operating to drive the same gear has been shown by factory tests to be materially higher than that calculated by the A. I. E. E. rules from "no load" losses and the fixed percentage of losses for gears and other load losses. These tests show plainly that those losses assumed for the Institute rules are too high for large motors.

Past practice with direct-current motors has been to use the series-parallel arrangement, or at most, series, series-parallel and parallel, giving one-quarter, one-half and full speed. With six motors and twelve armatures on 3,000 volts the regular series-parallel control could have been obtained in several ways, but the method adopted gives as simple a control as any system for regular series-parallel arrangement and in addition has the great advantage of the three-speed locomotive for handling the service. The one-third and the two-third speed arrangements cover the range so much better than the one-half speed, or than the one-quarter and one-half speeds, that there is scarcely any comparison possible. The one-half speed is too low for a running speed and too high for switching. The one-third speed is an excellent switching speed, and the two-thirds speed is a good running speed, especially good for regenerating on heavy grades. Another advantage lies in the decreased rheostatic losses as compared with those in the ordinary series-parallel control. These losses are further reduced by two field shunting positions on each combination.

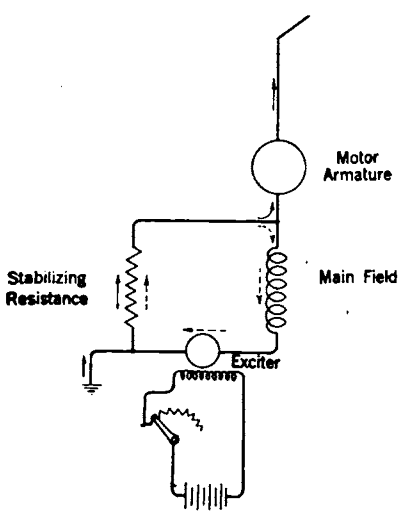


SCHEMATIC DIAGRAM OF MAIN MOTOR CIRCUITS, WITH RESISTANCES AND EXCITERS. WESTINGHOUSE LOCOMOTIVE

One of the fundamental principles on which this locomotive was designed was that the motor circuit should not be opened, either in normal operation or under emergency, until the current had been cut down by the introduction of resistance. This is considered a very valuable, if not an absolutely necessary feature. The effect is not only to divide the arcs among a large number of switches and, therefore, to promote safety, but the generation of high voltages from suddenly rupturing a heavy current is prevented. In order to avoid high-voltage troubles in the auxiliaries it was the policy on this locomotive to limit the high voltage to the minimum possible number of circuits and the minimum amount of apparatus. It was impossible to avoid it altogether on the moving apparatus, due to the fact that the train lighting must be supplied for hours at a time in case of any emergency when the train is held up by a wreck or storms. The motor-generator set, which is designed primarily for this purpose, is the only piece of moving apparatus among the auxiliaries which has the high voltage applied to it. The voltage selected for the auxiliary circuits was primarily determined by the voltage required for train lighting. While 85 volts is lower than would otherwise be selected for the auxiliary motors, it is perfectly safe and is a voltage that is so low that the motors can be forgotten, as far as the questions of insulation and commutation are concerned. The auxiliary motors are, of course, very much smaller than they would be if the high voltage were applied to them. A storage battery, from the standpoint of operation, is, of course, always a desirable thing on a locomotive. The combination of the storage battery and the axle-generators will furnish ample auxiliary power to take a locomotive to the end of a run, if the motor-generator set fails. The same combination will take a train safely down the longest and steepest grade with the air brakes, if power is for any reason cut off the line. If the train is going up a grade and power is cut off the battery will furnish air to hold the train with the brakes for a considerable time, so that it will not be necessary to block the wheels, as is the ordinary practice, unless power is off for a considerable time.



WESTINGHOUSE MASTER CONTROLLER



SCHEMATIC DIAGRAM OF SINGLE MOTOR, EXCITER AND RESISTANCE. WESTINGHOUSE LOCOMOTIVE

In general, wherever possible on the locomotive standard industrial types of motors have been employed for the auxiliaries.

Comparative Characteristics of the Two Locomotives

The following table, which gives a summary of the principal dimensions and characteristics of the two locomotives, is of interest in indicating the manner in which the two manufacturers have met with their individual systems of design the general specifications of the railway for these locomotives:

DATA FOR THE ST. PAUL LOCOMOTIVES

	General Electric	Westinghouse
Total weight	521,200 lb.	550,000 lb.
Total weight on drivers	457,680	336,000
Length over-all	76 ft. 0 in.	88 ft. 7 in.
Height over cabs	14 ft. 11⅝ in.	14 ft. 6 in.
Height over pantograph, locked down	16 ft. 8 in.	16 ft. 7¼ in.
Total wheelbase	67 ft. 0 in.	79 ft. 10 in.
Max. rigid wheelbase	13 ft. 9 in.	16 ft. 9 in.
Diameter of driving wheels	44 in.	68 in.
Diameter of idle wheels	36 in.	36 in.
Heater capacity	4,000 lb. steam per hr.	4,000 lb.
Water capacity	30,000 lb.	25,500 lb.
Oil capacity	6,000 lb.	750 gal.
Compressor capacity	150 cu.ft. per min.	150 cu.ft. per min.
Number of motors	12	12
Type of motor	(Bi-polar) GE-100	(Twin) 4-pole

Locomotive Rating:	General Electric Tapped Field	General Electric Full Field	Westinghouse
Total horsepower, 1-hour motor rating	3,480	3,380	4,200
Total tractive effort one-hour motor rating	36,000	46,000	66,000
Speed, miles per hour	36.2	27.5	23.8
Total horsepower continuous	3,200	3,200	3,360

Substation Operation for Street Railway Service*

The Author Gives the Results of Practical Experience with Three Types of Transformation Apparatus

BY W. T. BIVINS
Chief Engineer of Electrical Equipment United Railroads of San Francisco

SUBSTATION operation for street railway service should be placed in the heavy-duty class. The design of the building and equipment should be made with a view to economy and simplicity of operation, so as to minimize the necessary number of attendants. Due regard, however, should be given to possible future extensions.

For transforming high-voltage alternating current to direct current for railway work, the choice in converting apparatus usually narrows down to synchronous motor-generators, induction motor-generators and rotary converters. On this system all three kinds are used, the largest stations being equipped with motor-generator sets. Where high efficiency, overload capacity, compactness and low initial costs are of greatest importance, the synchronous converter is apparently the most desirable piece of apparatus available, it being understood that the alternating-current feeder-line conditions are favorable and free from severe surges, rapid fluctuations in frequency, excessive ohmic drops, etc.

*Abstract of paper read at Third Annual Electric Railway Night of Pacific Railway Club.