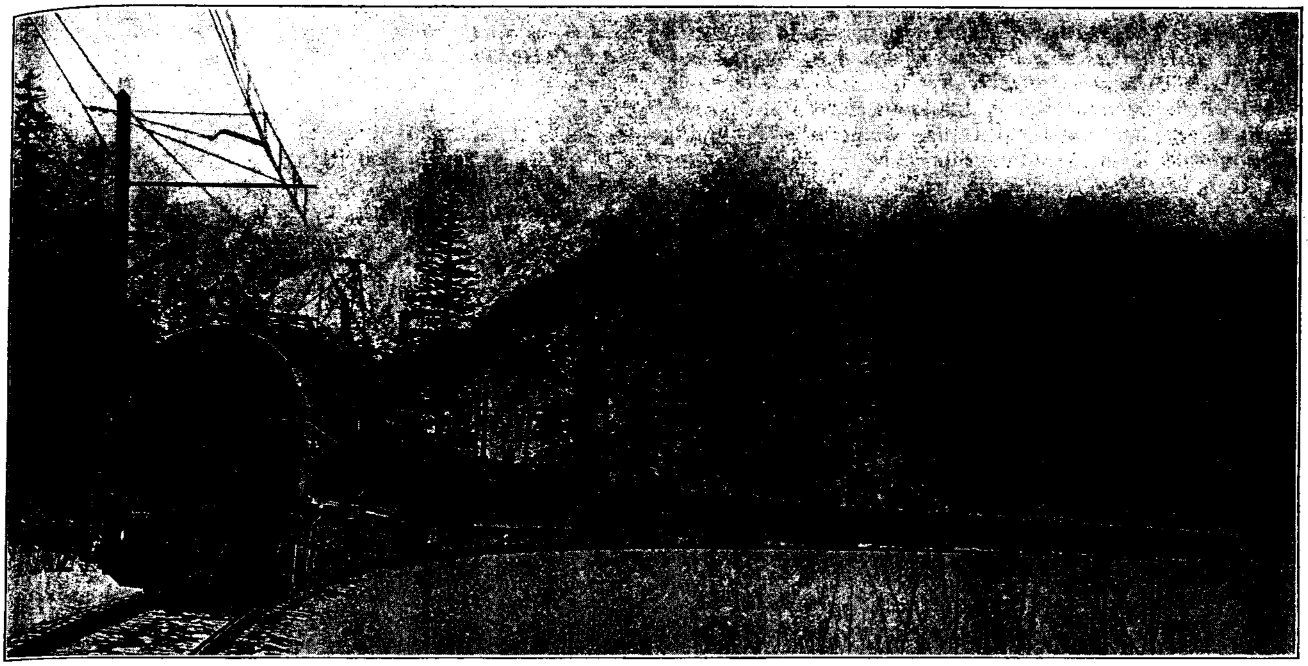


St. Paul Passenger Train on the Western Electrified Section

The St. Paul Electric Passenger Locomotives*

Details of Design Are Described by Representatives of the Manufacturing Companies

THE TWO NEW TYPES of electric passenger locomotives built for the Chicago, Milwaukee & St. Paul were designed for the same class of service by different groups of engineers working independently; from an inspection of the finished locomotives it would appear that the two types could hardly be more different.

Roughly the requirements for both designs were as follows: The locomotives must collect 3,000 volt direct current power from an overhead catenary. They must be able to haul a 12-car passenger train weighing 950 tons over a two per cent grade, compensated for a distance of 20 miles, and over a 2.2 per cent grade compensated for a distance of 17.8 miles. They must maintain speeds of approximately 25 miles an hour up two per cent grades, 35 miles an hour up one per cent grades, 60 miles an hour on level tangent track and must hold trains on down grades by regenerative braking at speeds consistent with safe operation. The sharpest curve on the main line is 10 deg., but the locomotives must negotiate a 16-deg. curve in the yards satisfactorily. The locomotives must also supply current for lighting the trains and charging the train storage batteries at a voltage of from 60 to 85 and must be equipped with an oil-fired boiler, to be supplied by the railway company, to furnish steam for heating the train.

General descriptions of the two locomotives were published in the *Railway Age* of October 24, 1919 (page 819), and January 16, 1920 (page 233).

The General Electric Locomotive

By A. F. Batchelder and S. T. Dodd.

The running gear of the General Electric locomotive is composed of four individual trucks, two end trucks having three axles each, and two center trucks having four axles each. These trucks are connected together by special articulation joints. The motor armatures are mounted on the axles and the motor fields are carried on the truck frames.

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 two middle 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 two end sections are similar to each other in appearance. The operator's cab in either section is on the inner end next to the heater cab above described, in order that the operator can be convenient to the heater and in order 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, containing air gages, ammeters, and speed indicator. The engineer uses either of the two operating cabs according to the direction in which he is running.

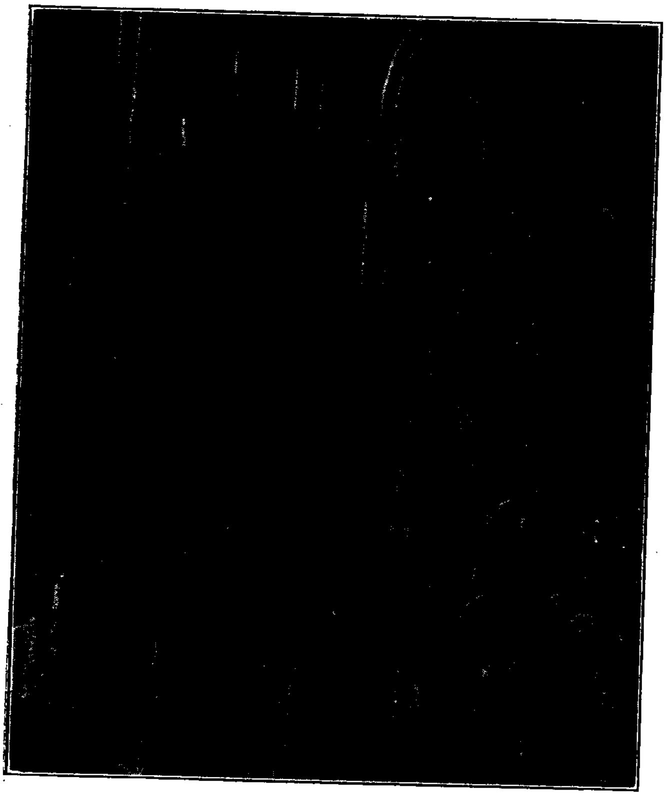
A door gives access from the operating cab to the apparatus section which extends with a cylindrical top to the extreme end of the locomotive. The cylindrical construction naturally adapts itself to the protection of the apparatus included and in addition to this it has the advantage of allowing a clear vision for the operator from his normal operating position. Contained in this apparatus section are the resistors and contactors to control the power circuits of the

*Abstracts of papers presented before the 358th meeting of the American Institute of Electrical Engineers at Pittsburgh, Pa., March 12, 1920.

locomotive. The starting resistors are placed in two rows on each side of the central passage just above the floor of the superstructure and are covered at the sides by removable covers which when opened will allow the separate resistor boxes to be slid out upon the longitudinal running board outside of the apparatus cab. The air compressor for the air brakes, the motor-generator set for 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 two feet wide. This allows ample arching space and room for inspection of contactors. Above the contactors is the cylindrical roof of the locomotive with trap doors for removing the contactors in case replacement is necessary.

Motors

The motors are of the bi-polar gearless design which were adopted by the New York Central 14 years ago for operating heavy passenger trains between Grand Central Station and Harmon, N. Y. To insure light weight per axle, flexibility in control, good truck arrangement for curving as well as for high-speed running, twelve motors are chosen, each of relatively small capacity. They are especially designed to withstand high temperature, being insulated with mica and asbestos. The continuous rating of each motor at 1,000 volts and with 120 deg. rise by resistance is 266 hp., corresponding to 3,500 tractive effort at the rim of the drivers at a speed of 28.4 mi. per hr. Forced ventilation is employed for cooling. The armature core is provided with holes for the passage of ventilating air. Ventilating blowers are located above each motor armature and deliver air 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 upwards and is afterwards used for ventilating the starting resistors.



Control Apparatus in Engineer's Cab of the General Electric Locomotive

This type of motor lends itself nicely to simple and compact locomotive design as the frame is made use of to furnish the entire path for the magnetic flux. The pole pieces and field coils are fastened to the cross transoms of the trucks and the magnetic flux passes horizontally in series through all twelve motors, finding a return path through the locomotive frame. The articulation joints between the trucks are made in such a manner that large surfaces are in contact to provide an easy path for the flux. The pole pieces are made flat in order to prevent the pole pieces from coming in contact with the armature during the vertical movement of the truck frame on its springs or when removing or assembling the armatures. A minimum clearance of ⅛-in. on each side is allowed between the armature and the pole piece tips. The brushholders are bolted to the transom allowing the brushes to move up and down with the fields as the frame rides on the truck springs.

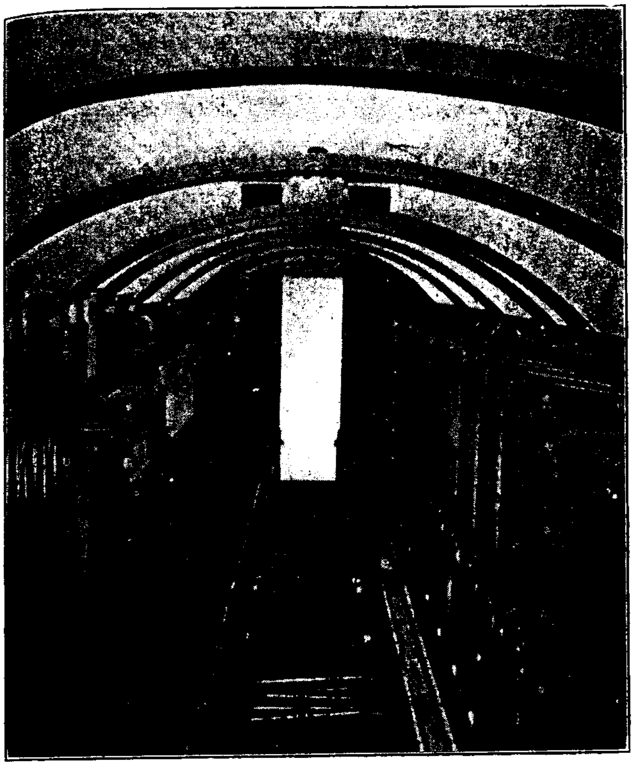
View from Engineer's Position on General Electric Locomotive

Control

In choosing the control apparatus special care has been taken to use individual pieces of apparatus best suited to the particular requirements. Where single independently operating switches are necessary as on the resistance notches, electro-magnetic control is used. Where several switches are required to operate at one time as in changing from series to parallel motor connections, banks of switches with electro-pneumatic cam control are used, thus insuring positive operation, eliminating interlocks, and simplifying the wiring.

The control for motoring is arranged for four motor combinations. The first combination has nine rheostatic steps, one full field step, and one tapped field step, with twelve motors in series across 3,000 volts. The second combination has six rheostatic steps, one full field step, and one tapped field step, with six motors in series and two sets in multiple. The third combination has eight rheostatic steps, one full field step, and one tapped field step, with four motors in series, and three sets in multiple. The fourth combination has eight rheostatic steps, one full field step, and one tapped field step, with three motors in series, and four sets in multiple. This results in a total of 39 control steps with a choice of eight operating speeds, exclusive of the resistance steps.

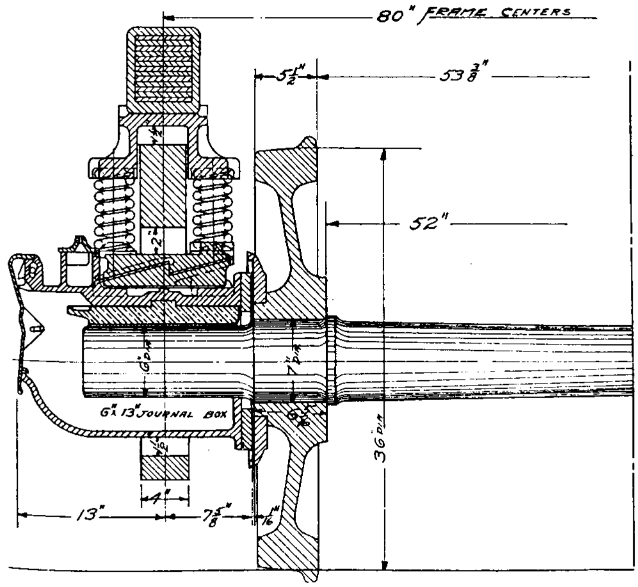
The regeneration of power for braking is accomplished



Interior of No. 2 Apparatus Cab of the General Electric Locomotive with Roof Removed

by using some of the motors for exciting 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,

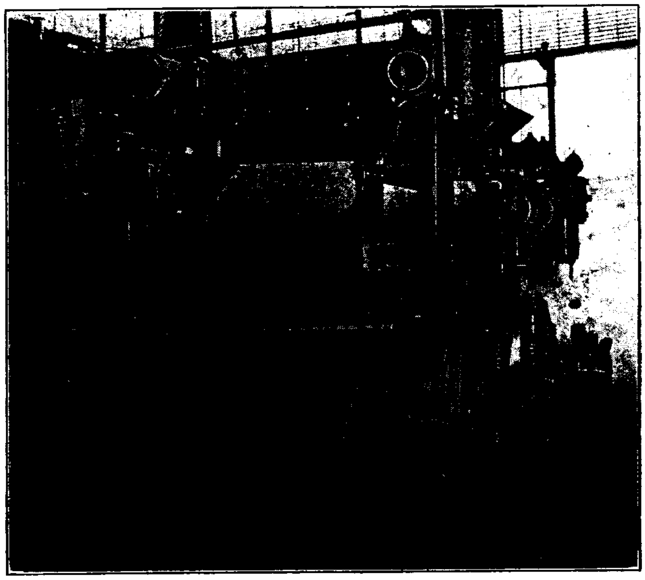


Cross Section of Journal Box, Showing Wedges Used to Give Resistance to Lateral Movement

a quick acting circuit breaker is provided in the apparatus cab which will protect the circuit in less than 1/100 of a second.

Mechanical Construction

For flexibility in curving, the running gear is made up of four trucks, each of a relatively short wheel base. The two middle trucks have four driving axles each; and the two end trucks, two driving axles and one guiding axle each, making a total of 14 axles. The trucks are connected together with articulated joints which allow of no relative



Leading Truck Partly Assembled, Showing Wedges in Place on Journal of Guiding Axle

lateral movement between them, so that each truck positively leads the following truck.

To soften any lateral blow that may be given against the rail head, the leading and trailing axles are allowed a movement of one-half inch 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 which tend to hold the box in its central position and to give a dead beat action opposing the motion. To further protect the track from lateral displacement on the ties, the outer end of the superstructure is carried on rollers, bearing

Platform and Rollers Which Constitute Upper Half of Centering Device

on inclined planes upon the truck frames, while the inner end of the superstructure is rigidly bolted to one of the middle trucks. This construction tends to hold the leading and trailing trucks in their central position. When a blow is delivered by the leading or trailing truck against the rail head, the superstructure, which is rigidly bolted to the middle truck, is displaced laterally across the outer truck very much as a boiler of a Mallet locomotive swings across its leading truck. In such a sideways displacement, the weight of the superstructure rolls up on the inclined plane on that side, and thus transfers weight to the rail that is affected, thereby increasing the adhesion of the rail to the tie. This action really has two results. It not only increases the holding power between rail and tie at that point, but it introduces a time lag and increases the time and distance during which the pressure is delivered to the rail head.

The Baldwin-Westinghouse Locomotive

By N. W. Storer.

The locomotive is built in a single unit, having one long cab, carried on running gear of the 4-6-2-2-6-4 type. The running gear consists essentially of two Pacific type running gears, coupled back to back.

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, carry the center pin and carry 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 equalization is of the standard three-point type; the leading bogie being cross equalized with the leading pair of drivers and the pony axle being equalized with the two adjacent driving axles on the sides. Extra points are provided in the equalizing levers so that practically any distribution of weight that is desired can be attained.

The driving wheels are 68 in. in diameter; the journals 8½ in. by 14½ in., located outside of the wheels. The drawbars, with Miner friction draft gears, are carried in the "A" frame casting, previously mentioned.

The coupling between halves of the running gear consists of a long bar of a box section. The coupling pins are 10 in. in diameter and are located well inside the pony axles. The pins are hollow, filled with oil-soaked waste and have oil holes provided that keep the pins well lubricated.

The four-wheel trucks are of the "Woodard" type with outside journals; 36-in. rolled steel wheels and cast steel side frames. The journals are 6½ in. by 14 in. The two-wheel truck is of the well known "Rushton" side-bearing type, also with the outside journals and 36-in. wheels. The journals are 6½ in. by 14 in. Brake shoes are provided on all drivers. A modified form of the 14-EL Westinghouse Air-Brake Company equipment is used.

The cab is 78 ft. 0 in. long, 10 ft. 2 in. wide; is strong and rigid so that it can be lifted at the ends. The main strength lies in the two bridge girders extending from end to end. The heavy cross-braces and the side members and top of the raised deck down the middle of the cab, form a construction that 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 various parts of the cab equipment.

The total motor rating of the locomotive is 4,200 hp. on the one-hour basis. The continuous rating is 3,400 hp.

Driving Motors

The six driving motors are of the twin armature type. 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 interpoles for each armature. There are brush arms on each commutator which are easily accessible. Each armature is wound for 750 volts, but the two armatures and the two sets of field windings are connected permanently in series so that the rating of the complete motor is based on 1,500 volts. The motor is designed for field control by inductive shunts.

Quill Drive

The one hour rating is 700 h. p. The continuous rating is 567 h. p. with forced ventilation and 400 h. p. without blowers. The motors are mounted rigidly on the cross ties of the running gear, one being mounted directly above each driving axle. Each motor is geared to a quill centered in bearings in the motor frame and surrounding the driving axle with a clearance all around when axle and quill are concentric of 1¾ in.

The quill carries the gear and is connected to the drive wheels by long helical springs which are clamped rigidly at the ends in castings which are bolted one to the quill flange and the other to the drive wheel. There are seven springs at each end, worked in compression in one wheel, while those in the other are in tension. All springs with clamps are interchangeable.

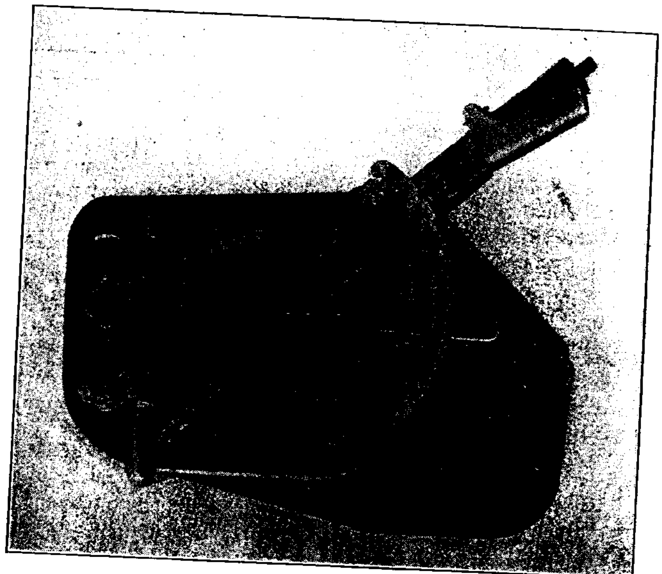
They are easily accessible for inspection, and any spring may be removed without disturbing any other part of the running gear.

Main Motor Control

The six motors are arranged to be connected in three combinations:

1. All in series, giving one-third speed.
2. Three in series, two in parallel, giving two-thirds speed.
3. Two in series, three in parallel, giving full speed.

Inductive shunts are applied to the fields on all three of these positions. Shunt transition is used in passing from one combination to the next. When regenerating, the motors are separately excited from the two axle-driven generators which are 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.



Top View of Westinghouse Master Controller

The scheme that is used for regeneration includes the use of stabilizing resistance, which is connected in series with the exciter armature, main motor field circuit, and also with the main motor armature circuit, so that the field excitation is dependent, to a certain extent, on the armature current.

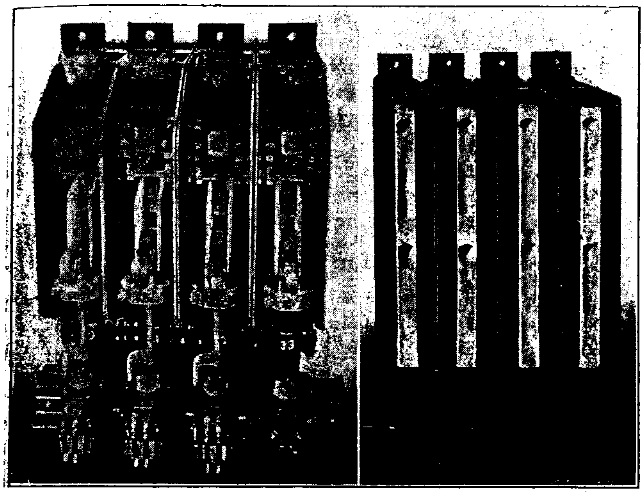
The master controller has four control drums and four operating handles.

1. The speed drum, which controls the resistance switches and line switches; field shunts during motoring and the exciter voltage during regeneration.

2. The reverser drum, which perform the usual function.
3. The motor combination drum, which has three positions, each corresponding to one of the three motor combinations.
4. The regenerative drum, which changes the connections from motoring to regenerating and vice-versa.

The master controller is arranged so that the controller may be thrown from the "off" position to the second or third speed combination, if desired, without passing through the lower combinations.

The engine-man is prevented from accidentally starting the locomotive from rest, in the second or third combination, by an interlock in the controller which prevents the line switches from closing when the motor combination lever is in the second or third position, unless he pushes a button in the top of the master controller. It is, therefore, necessary when applying current with the locomotive at speed, to press the button when it is desired to go immediately into the second or third combination.



Rear and Front Views of Four High Voltage Unit Switches

There are thirteen resistance steps, all of which are available in both first and second speed combinations. On the third combination, there are ten steps that are useful; making a total of thirty-six resistance steps and two field shunting notches in each combination, or a total of forty-two steps in the master controller.

The main resistance is arranged in three groups, each of which has five switches, each short-circuiting a section of resistance. These three groups are connected all in series for the first combination, and three in parallel for the second and third combinations. The sequence of closing the resistance switches is the same on all combinations. The resistances are always connected in series before the master controller reaches the "off" position. The overload trips are arranged to open the resistance switches and insert the entire resistance in series before the line switches are opened.

Switches

The unit switches are numbered from "1" to "33." Each switch is provided with a very powerful magnetic blowout with arc chutes of arc-resisting material, and an arc splitter. It is electro-pneumatically operated and is designed so that it is very thoroughly protected from insulation troubles and for ease of inspection and over-hauling.

The cam switches are designated by numbers and letters. The number corresponds to the group in which the switch is placed and the letter corresponds to the particular switch in the group.

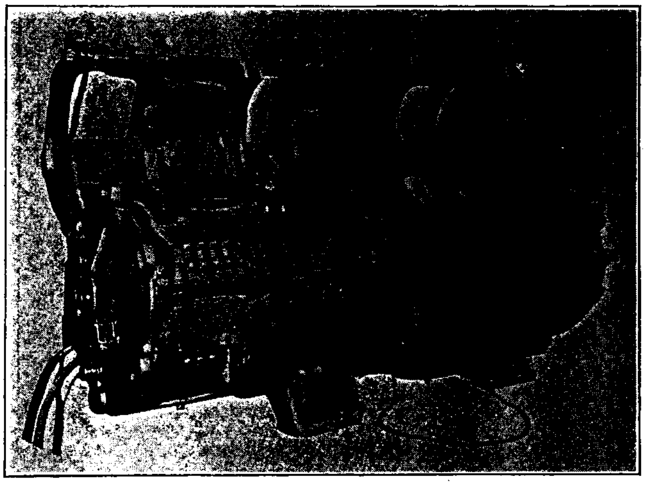
Those of Nos. 37 and 38, which are the groups operating the field shunts, also Nos. 39 and 40 which control the stabilizing resistance during regeneration, are provided with magnetic blowout; but the switches for the reverser, which never close or open the circuit with current on, have no arc chutes or blow-outs. Groups Nos. 34 and 35, which make the different motor combinations, have barriers placed between adjacent switches which have a large difference in potential, but no magnetic blow-out, since these switches are never used for opening the circuit under load. The groups are operated electro-pneumatically.

Auxiliaries

Power for the auxiliary motors, control circuits, train lighting, motor excitation, etc., is derived from three sources:

1. *Motor-Generator.* The motor of the set receives current from the line; the generator delivers current at a constant voltage of 85. This is required primarily for train lighting.
2. *Storage Battery.* This consists of MV-25 ironclad Exide type containing 38 cells. The battery has a capacity of 300 amperes for approximately one hour.
3. *Two Axle-driven Generators.* These generators are designed primarily to furnish current for exciting the main motors during regeneration.

The storage battery is always available to supply current for locomotive lights, control circuits, and the air-compressor motor for short periods. When the locomotive is in service, the generator of the motor-generator set is always in parallel with the battery, and from this dual source is always taken the power for lighting the locomotive and train, control circuits, cab floor-warmers, small blower motors for inductive field shunts, boiler blower and exciting current for the axle generators. In addition, the current for the air-compressor motor is supplied from this dual service whenever the locomotive is standing still or regenerating.



Westinghouse 3000-Volt, 85-Volt Motor Generator Set

The axle generators are, as stated, used primarily for exciting the main motors during regeneration. At other times, when the locomotive is in motion, the axle generators are automatically connected to the auxiliary circuits from which the compressor and main blower motors take power. At this time the voltage is automatically maintained at 90.

A two-stage compressor with inter-cooler, having a displacement of 150 cubic feet per minute, is provided. It is a double-acting, upright type, driven by an industrial type motor.

Two blowers are provided to supply forced ventilation to the driving motors. They are driven by motors that are duplicates of the compressor motor.

The axle generator circuits are shifted from one circuit to another by a group of the same type of cam operated switches as are used in the main motor circuits. The field rheostats for the generator of the motor-generator set and the axle generators are operated by small motors. As the fields of the two axle generators are connected in series, only one rheostat is required for them.

The switches for controlling the blower and compressor motors and the high-voltage motor are magnetically operated.

The motor of the motor-generator set is protected from overload or short circuit by a small permanent resistance in series and a set of three expulsion type fuses which blow in series, the first two inserting additional resistance in the circuit, and the last opening only after a relatively high resistance has been inserted and the current consequently limited to a low value.

A Sangamo wattmeter is provided which has separate dials for integrating the motoring watts and regenerating watts. A full set of motor ammeters is provided, and also a voltmeter reading line volts. An ampere-hour meter is provided for the storage battery.

A boiler with a capacity for evaporating 4,000 lb. of water per hour is provided for heating the train and engine-man's cab. The boiler and water storage tanks are located in the middle of the cab and occupy a relatively large proportion of the space. The tank for fuel oil is located directly beneath

Air Compressor Driven Through Gears and Cranks by 30 HP. Motor

the boiler, and the water tanks, two in number, just fore and aft of the boiler.

Two pantagraphs of the double sliding shoe type are provided. These are raised by air and lowered by gravity.

All cable is in steel conduit, and all exposed connections are solid copper bar or strap.

Mechanical Design

This locomotive has been designed to possess certain mechanical features which have developed through years of experience with steam locomotives. 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 wheel base, but placing it relatively high. The height of the center of gravity of the complete locomotive is 68 in., a value that corresponds well with that of a steam 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 the wheels, axles, journal boxes and spring clamps; a total of 7,032 lb. for the wheels, axles and spring clamps which are rigidly fastened together, and 770 lb. for the journal boxes. This weight with the larger diameter of drivers (68 in.), and the total weight of 56,000 lb. per axle, gives a combination that is much better than has been considered very good practise on steam locomotives.

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 practise heretofore with this general type of locomotive to have one center pin rigid in the running gear frame and allow the other one to move freely in a longitudinal direction. It is felt that it is much better to allow a slight relative motion between the two center pins, but to prevent the bumping shocks by spring cushioning.

Comparative Data for the Two Locomotives

	General Electric	Westinghouse
Total weight	521,200 lb.	550,000 lb.
Total weight on drivers	457,680 lb.	336,000 lb.
Non-spring-borne weight per driving axle	9,500 lb.	7,800 lb.
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. 7⅞ in.
Total wheelbase	67 ft. 0 in.	79 ft. 10 in.
Maximum 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, one-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

Photo from International Film Service

The Cog Railway Making Its Way up the Pilatico, an Offset on the Alps on the Borders of the Cantons of Lucerne and Unterwalden