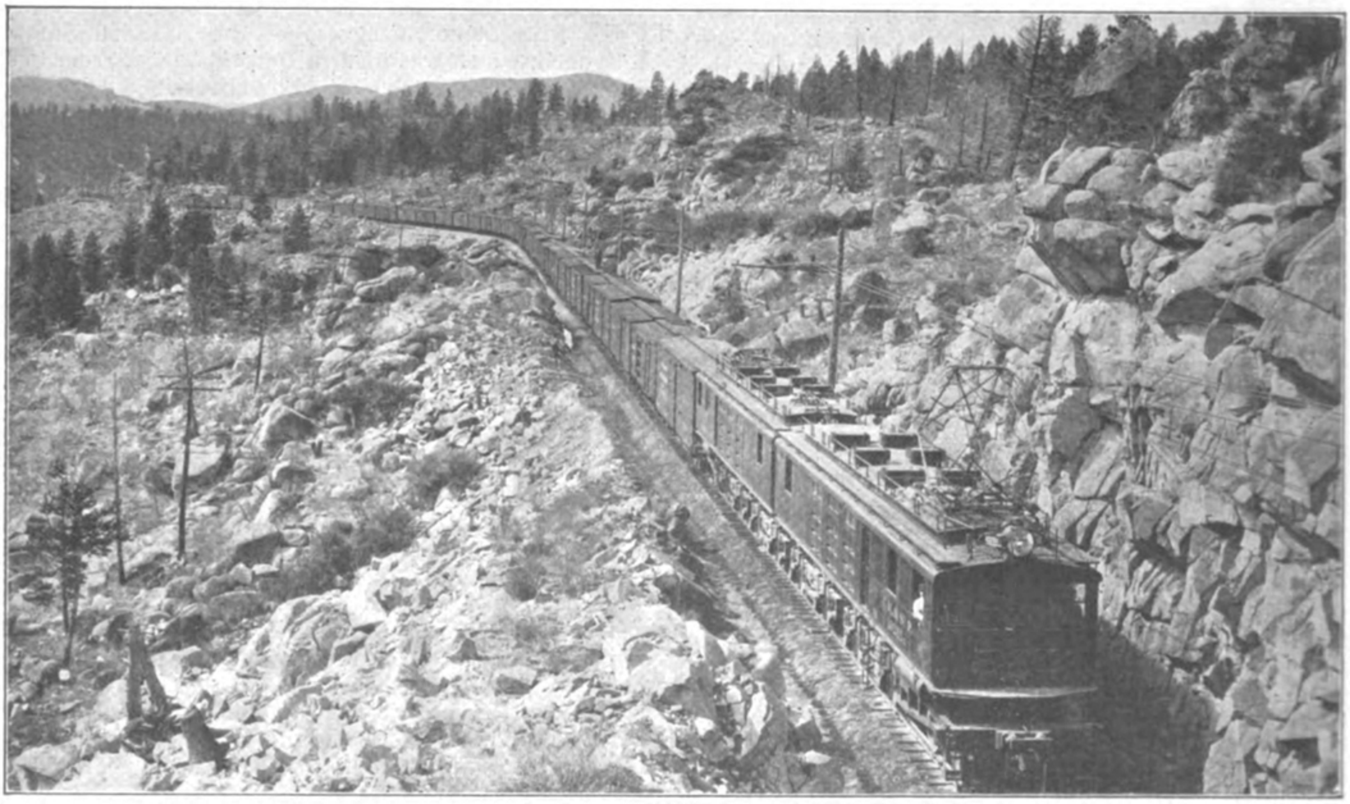
Mechanical and Electrical Features of the C., M. & St. P. Locomotives

Details Are Published for the First Time Regarding the Method of Regenerative Braking with D.C. Motors, Also Regarding the Mechanical Construction of the 288-Ton Locomotives Which Have 450-Hp. Axle-Mounted Motors and Operate Satisfactorily at 65 m. p. h. in Passenger Service



C., M. & ST. P. LOCOMOTIVES—FREIGHT TRAIN DESCENDING 2 PER CENT GRADE ON EASTERN SLOPE OF ROCKY MOUNTAINS

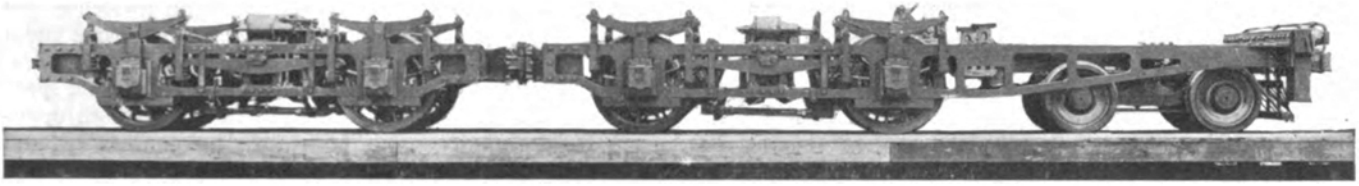
THE locomotives for the Chicago, Milwaukee & St. Paul Railway's electrification, which has been discussed in various past issues of the ELECTRIC RAILWAY JOURNAL,* possess more than ordinary interest through their many novel features, the most notable among these being the use of 3000-volt direct-current and the adoption of direct-current regenerative braking. These locomotives were first placed in regular service in December, 1915, so that some of them have had practically one year's service. During this period the engines have been operating most successfully, permitting an increase in train load on maximum grades from 1700 tons to 2500 tons, and an increase of speed from 8 m.p.h. to 15 m.p.h. At the same time there has been a reduction in the number of helper engines on the grades, and half of the dispatchers originally employed are now able to handle trains on the 226 miles of route that are electrically operated at the present time. Indeed, according to C. A. Goodnow, assistant to the president Chicago, Milwaukee & St. Paul Railway, who is in charge of the electrification, the installation has been such a tremendous success that the fact of the existence of the Continental Divide has been altogether forgotten.

*Among the previous articles on this installation in the ELECTRIC RAILWAY JOURNAL are the following: Nov. 21, 1914, Construction Plans; Dec. 19, 1914, Operating Plans; June 5, 1915, Locomotive Design, Oct. 16, 1915, Substations and Overhead; Dec. 18, 1915, Operating Tests; March 4, 1916, Switching Locomotives; April 1, 1916, Features of Operation; June 17, 1916, Operating Notes.

MECHANICAL DETAILS OF THE LOCOMOTIVE

The decision to use 3000-volt direct current for the Milwaukee locomotives followed a careful study of the relative cost and other features of split-phase and alternating-current systems and of the other practical direct-current voltages. This review showed figures and operating characteristics favorable to direct current with but little difference in the investment between 3000 volts and 5000 volts. However, the investment in copper for the former case was transferred to investment in locomotives for the latter case, and copper was obviously subject to less depreciation and maintenance than in the case of rolling stock. Further, as the investment for substations and copper was sufficient for a material increase in traffic, such locomotives as might be subsequently purchased, if built for 5000 volts, would continually add the burden of a higher cost. As installed. the initial investment for the 440 route-miles of the electrification will be something less than $30,000 per mile, according to figures published by the railway company.

The first of the four engine divisions to be electrified by the Milwaukee extends through a most difficult sec-



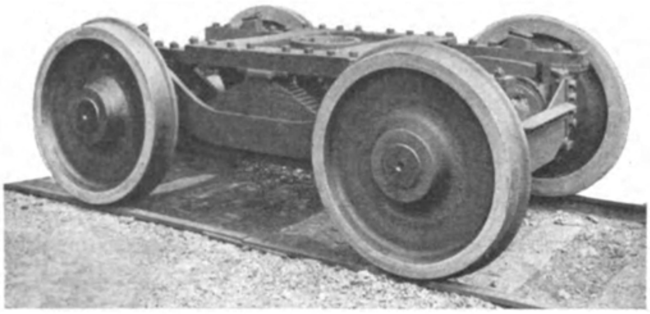
C., M. & ST. P. LOCOMOTIVES—RUNNING GEAR FOR ONE HALF-UNIT

tion of the Rocky Mountains. During the past year, however, this division has been operated by the electric equipment without any apparent difficulty, not only keeping the road clear of congestion, but almost universally making up time that had been lost on adjoining steam-operated portions of the road. From the mechanical standpoint, the electric locomotives that have been making this remarkable record are of unusually large size, the principal dimensions being as follows:

Maximum tractive effort	132,500 lb.
Continuous tractive effort	71,000 lb.
Length overall	112 ft. 0 in.
Total wheel base	102 ft. 8 in.
Width overall	10 ft. 0 in.
Height, pantograph lowered	16 ft. 8 in.
Rigid driving wheel base	10 ft. 6 in.
Rigid guiding wheel base	6 ft. 0 in.
Diameter driving wheel	52 in.
Diameter guiding wheel	36 in.
Size main driving journals	8 in. x 14 in.
Size guiding journals	6½ in. x 12 in.
Total weight	576,000 lb.
Weight on drivers	450,000 lb.
Weight per driving axle	56,250 lb.
Spring borne weight per driving axle	40,000 lb.
Dead weight per driving axle	16,250 lb.
Weight on guiding wheels	126,000 lb.
Weight per guiding axle	31,500 lb.
Spring borne weight per guiding axle	27,274 lb.
Dead weight per guiding axle	4,226 lb.
Maximum tractive effort in per cent of weight on drivers	30 per cent
Continuous tractive effort in per cent of weight on drivers	16 per cent
Normal braking power in per cent of weight on drivers	89 per cent
Normal braking power in per cent of total weight	69 per cent

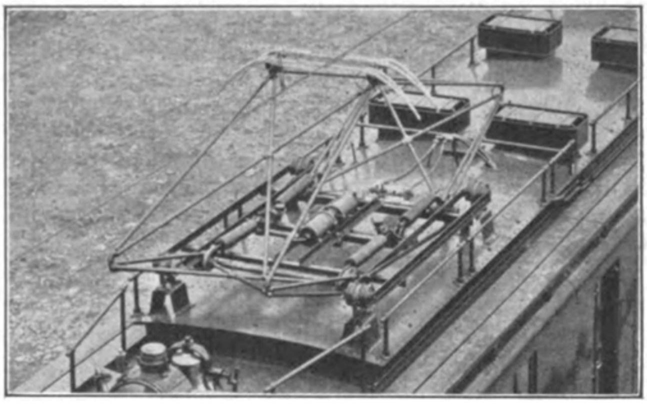
The locomotives, which were built by the General Electric Company, are each made up of two duplicate sections, each section having a cab mounted on two driving trucks, of which one is unsymmetrical in that it has an extended frame to carry the draft rigging and the center pin for the guiding truck. The guiding truck is of the well-known equalized type common to steam locomotives, and it carries the load on a center bearing through a bolster which provides 4 in. of lateral movement each way from the center against a constant pressure. The riding characteristics have been most satisfactory, speeds of 65 m.p.h. being attained in passenger service. There is absolutely no nosing on tangent track.

In the driving trucks the side frame, transoms and other parts taking longitudinal stresses are designed to withstand a 500,000-lb. static pressure with liberal factors of safety. The side frames are of cast steel 4½ in.



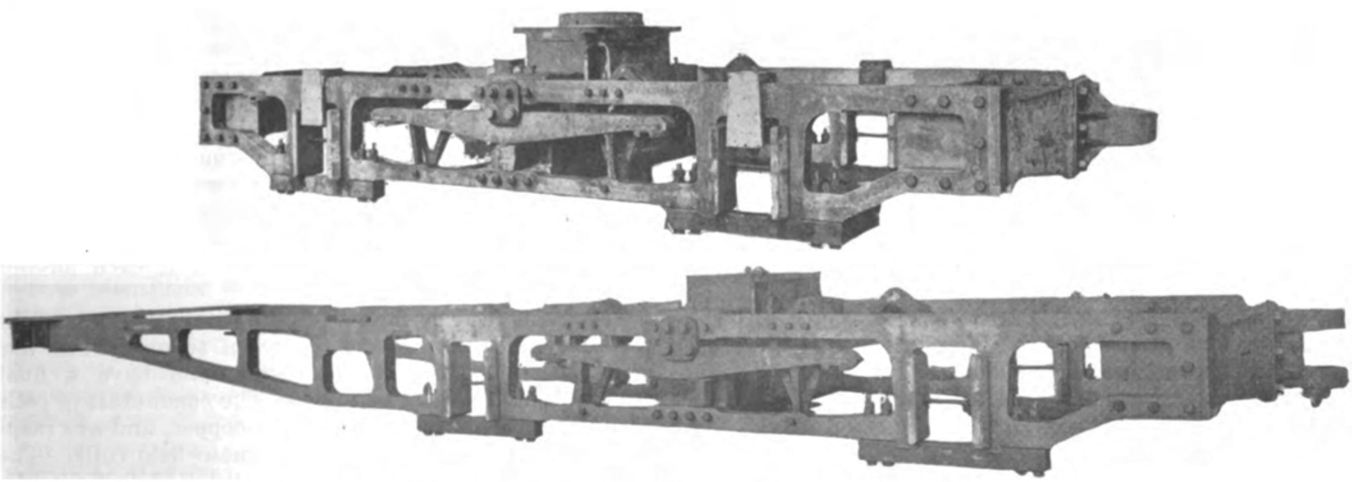
C., M. & ST. P. LOCOMOTIVES—GUIDING TRUCK

thick placed on 80-in. centers. Midway between the wheels on each of the trucks is a hollow cast-steel transom with supporting lugs for the nose of the traction motors, and ventilation from the blower in the cab is



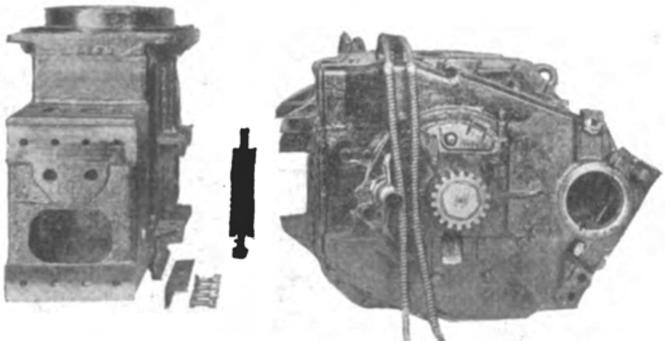
C., M. & ST. P. LOCOMOTIVES—DOUBLE SHOE PANTOGRAPH AND VENTILATORS ON CAB ROOF

transmitted through this direct into the motors. The equalizing arrangement for each driving truck is similar to that used upon steam locomotives. No vertical



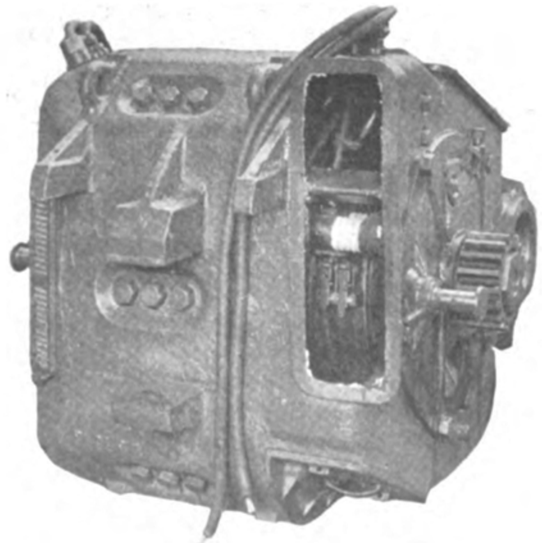
C., M. & ST. P. LOCOMOTIVES—FRAMES OF SYMMETRICAL AND UNSYMMETRICAL TRUCKS play is allowed in the hinge between the trucks for each half unit, but it is provided in the hinge joint between the two half-locomotives.

The frames are provided with pedestal shoes at the journals so that when the shoes are dropped the journal boxes can be removed from place without lifting the frame. This makes it convenient to renew the thrust plates which are provided at the back of each box. The motors are supported in the usual way directly on the axle at one side, and by a nose bracket through double-acting springs to the bolster in the other side. The motors drive through flexible gears that are mounted directly on the axle, one at each end of the motor.



C., M. & ST. P. LOCOMOTIVES—DISSEMBLED VIEW OF NOSE-SUSPENSION OF MOTOR ON TRANSOM

The superstructure of each section of the locomotive is made up with two 12-in. longitudinal center sills placed 31 in. apart, this forming a box girder and providing for an air duct to conduct the ventilating air from the blower to the motors. A secondary floor of 6-in. channels forms ducts for the wiring conduit and serves as a floor for the cab. The cabs are built in the usual way, with ventilating louvres in the sides. Each is divided into two compartments, consisting of the main apparatus cab, 47 ft. long, and the motorman's cab, 5 ft. long. The apparatus cab is arranged with an aisle 23 in. wide that extends for the entire length on each side, with compartments for the control and other apparatus arranged in the middle, hatches being provided in the roof for handling all apparatus with overhead cranes. The motor-generator set, the blower and the compressor are carried directly on the box girder forming the main air duct.

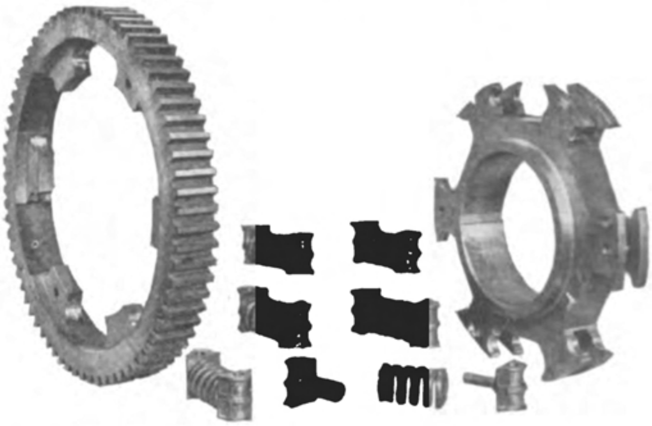


C., M. & ST. P. LOCOMOTIVES—VIEW OF 450-HP. MOTOR SHOWING VENTILATING AIR INTAKE

In the compartment for rheostats and switches the rheostats are supported near the floor, and above them are mounted the contactors. Ventilating flues leading from the rheostat compartment through the roof provide natural ventilation, air being taken through openings in the floor. The front of the contactors and switches is accessible from a center aisle into which all contactors face, thus providing liberal arcing space. This arrangement of rheostat and contactor compartment has been found particularly desirable on account of the ease of inspection and removal of parts that need replacement. By this means also all of the high-tension apparatus that might be a source of danger is safely inclosed.

MOTORS

The motors used with these locomotives are the largest of the axle-mounted type that have been used in the electrification of steam railways. They are known as the General Electric type 253. Based on the A.I.E.E. standard method of rating, their one-hour rating is 452 hp., and the continuous rating, based on a temperature rise of 100 deg. C. in the armature and 120 deg. C. in the fields, is 396 hp. These ratings are for a potential of 1500 volts, two motors being coupled permanently in series for operation on 3000 volts from the line. The motor is designed for operation with an external blower and the volume of air at the continuous rating approximates 2500 cu. ft. per minute. The air is blown into the motor through a large opening on the front of the magnet frame at the commutator end, then passes in parallel streams through the armature and over the field coils, and is exhausted through openings in the magnet frame and bearing head at the opposite end.



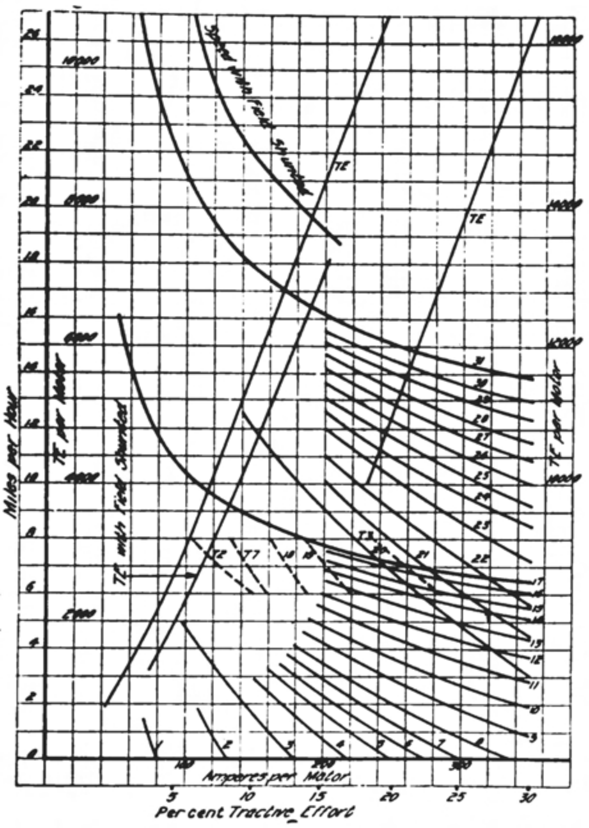
C., M. & ST. P. LOCOMOTIVES—DISSEMBLED PARTS FOR FLEXIBLE GEAR

Each motor complete, including spring gears, pinions, gear case and axle lining, weighs 14,860 lb. It has four main poles and four commutating poles, and is designed for field control, the field being shunted 50 per cent in motoring at full speed. The armature has forty-nine slots with seven coils per slot, and the commutator 343 segments. The armature has a single-turn winding, and the diameter of the armature core is 29½ in., the coils being insulated with mica and asbestos. At the one-hour rating the speed of the armature is 446 r.p.m. There are four brush holders per motor, each having two brushes 11/16 in. x 1¾ in.

The main field coils are wound with strip copper in two sections with asbestos between turns. They are insulated with mica and asbestos, and have a final wrapping of strong cotton tape. The commutating coils are made of edgewise-wound strip copper, and are insulated in a similar manner to the main field coils. The main exciting field coils are not subjected to full voltage, since the armatures of two motors are connected in series with the fields of both motors on the ground side. The clips connecting the top and bottom bars at the back end of the armature are electrically brazed to the bars, thus insuring a reliable connection at any abnormally high temperature which might occur at excessive overload. The magnet frame is made of cast steel, and except in size differs but little in general appearance from standard box frame railway motors.

The commutating characteristics of the motor are excellent, and it has been found possible to raise the voltage on a stand test 50 per cent above normal without injurious sparking. When the motors are regenerating at voltages materially higher than 3000, the fields can be shunted to a surprising extent without appreciable sparking.

The motor has twin gears with a 4-in. face and two-pitch. For the freight locomotive the gear ratio is 18:82, and for the passenger locomotive 29:71. Both gears and pinions are made of high-carbon, oil-treated stock, having an elastic limit of 85,000 lb. per square



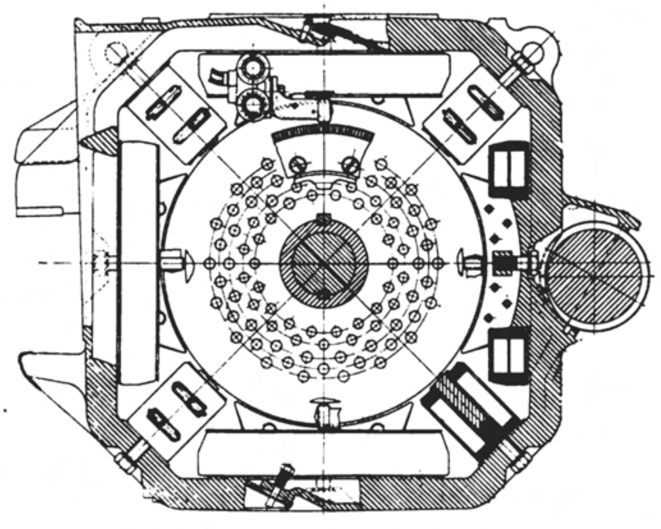
C., M. & ST. P. LOCOMOTIVES—CHARACTERISTIC CURVES FOR VARIOUS CONTROL POINTS, AND SERIES-PARALLEL TRANSFER STEPS FOR 1500-VOLT FREIGHT-SERVICE MOTOR WITH GEAR RATIO OF 18 : 82 AND 52-IN. WHEELS

inch. In service the motors have operated with excellent results, and there is no noticeable gear noise or vibration while the locomotives are in motion. At present the motors run at a comparatively low temperature because their capacity is sufficient to handle heavier trains than originally contemplated.

CURRENT COLLECTION AND CONTROL

As mentioned in previous articles the locomotive has two pantographs, one mounted on each half unit of the locomotive. Each pantograph has two sliding contacts or shoes, which are provided with copper wearing strips, and further provision for increased contact area is obtained by the use of double-contact wires of copper for the overhead catenary system. With the four points of contact at the pantograph it becomes easy to collect the heavy currents that obtain in the service. Sparking is entirely eliminated, although the current required for a single locomotive at continuous rating is 840 amp., and in passenger service speeds up to 60 m.p.h. are attained.

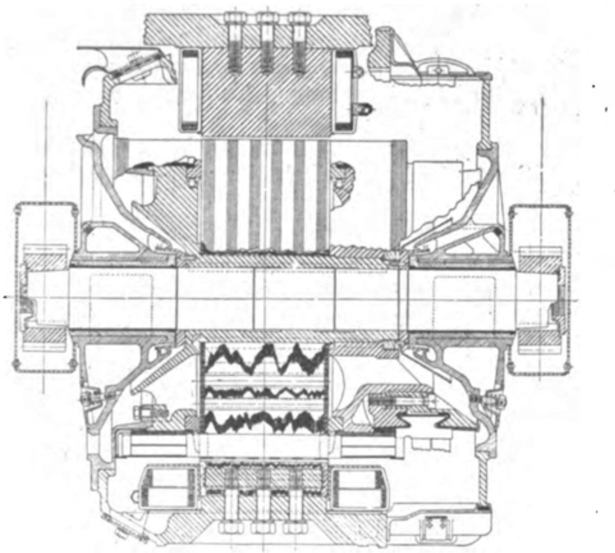
The motorman controls the operation of his pantograph by means of an air valve, which admits air to a pair of cylinders energizing powerful springs, the latter in turn raising the pantograph and at the same time



C., M. & ST. P. LOCOMOTIVES—TRANSVERSE CROSS-SECTION OF MOTOR

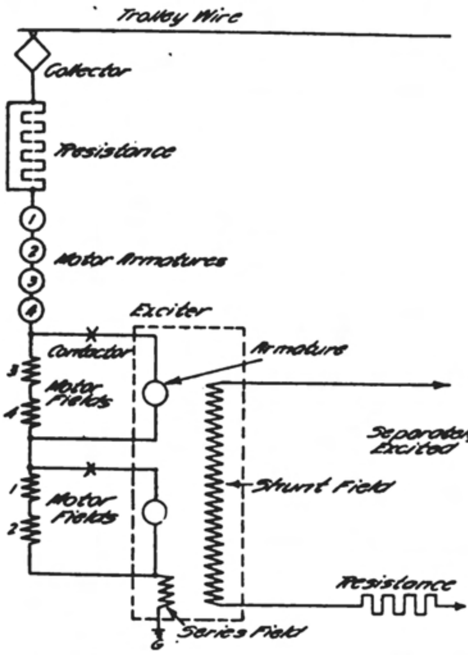
regulating the pressure against the trolley wire. The range of action of the shoe is between 17 ft. and 25 ft. above the rail. An auxiliary trolley pole with a swivel base is supplied to collect current for the air compressor when the locomotive is first put into service. The two pantographs on each complete locomotive are connected by a bus line so that the duplex electrical equipment can be supplied from either one.

Great importance has been accorded to the design of the main emergency switches and fuses, and accordingly



C., M. & ST. P. LOCOMOTIVES—LONGITUDINAL CROSS-SECTION OF MOTOR

these devices are mounted in a separate high-tension compartment. The trolley lead, starting from the pantograph, first enters this high-tension compartment and is divided into main and auxiliary circuits therein. From the main switch and fuse the main power lead goes directly to the controlling apparatus of the traction motors. The auxiliary lead passes to three disconnecting switches from which separate circuits run to the motor-generator set, the air compressor and the cab heater. For each lead the switch and fuse are mounted on a cradle that disconnects the fuse when the switch is open. A 3000-volt aluminum-cell lightning

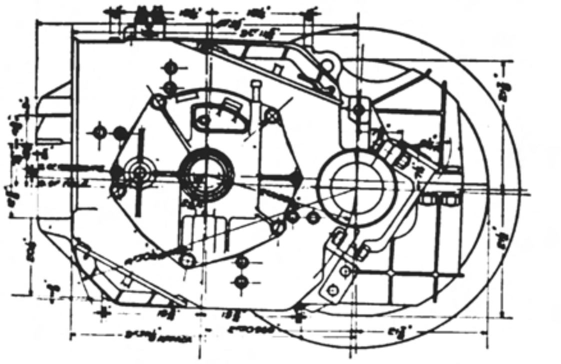


C., M. & ST. P. LOCOMOTIVES—SIMPLIFIED ARRANGEMENT OF CONNECTIONS FOR ELECTRIC BRAKING

arrestor is tapped into the main lead and is mounted on the back of the high tension compartment.

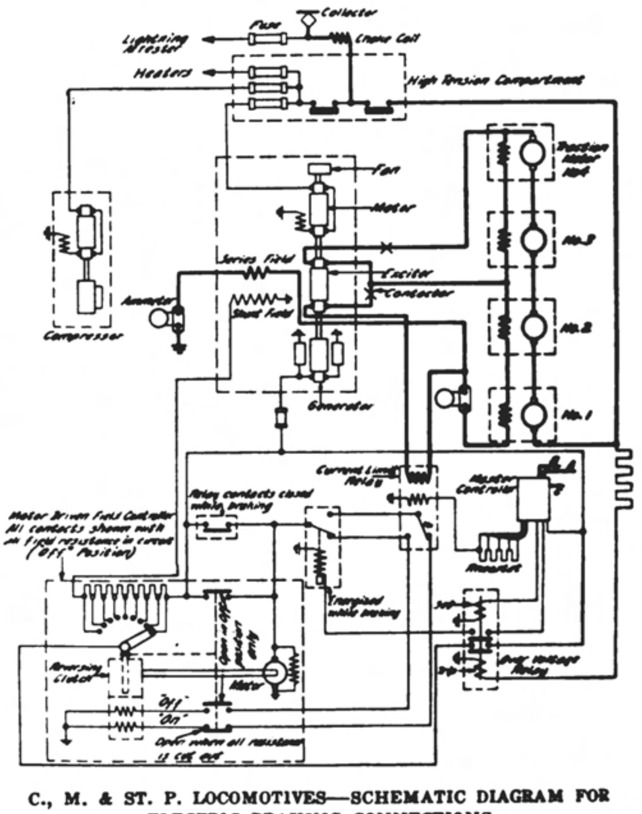
The controlling apparatus which, in general, is of the well-known Sprague-General Electric type "M," is grouped in a sheet-iron compartment located near the center of the cab. At the bottom of this compartment are assembled the starting rheostats, which are of the cast-iron grid type and mounted upon 3000-volt insulators. The rheostats are separated from the equipment groups above them by a horizontal partition, and the bottom of the rheostat compartment is open, ventilation being obtained by six chimneys leading up to ventilators in the cab.

Between the chimneys four control groups are installed, the first of these including the high-voltage disconnecting switches and starting sets for the motor generator set and compressor, as well as the heater disconnecting switch, a portion of the rheostat and tap field contactors and the translating relays between the motor connections for running and regenerative braking. The second group contains the rheostat contactors, and the third group contains the overload relay and a set of line contactors governed by it. The latter apparatus protects automatically against careless operation on the part of the engineer, the fuse in the high-tension compartment serving as a final protection against short circuit. In the fourth group are contactors that are assembled along and actuated by a compressed-air-driven camshaft, their functions being to series-parallel the traction motors in order to obtain two efficient continuous running speeds. Two handles at the end of this group provide for cutting out either of the two series pairs of motors on each half locomotive, permitting the other pair to be controlled either direct or in multiple unit locomotive operation.



C., M. & ST. P. LOCOMOTIVES—ELEVATION OF MOTOR

The master controller provides for operating the permanently connected pairs of traction motors in series through sixteen rheostat points, with a seventeenth full series running point, then through eleven rheostat points in parallel and a twelfth full-parallel point. An additional parallel point with the field of the traction



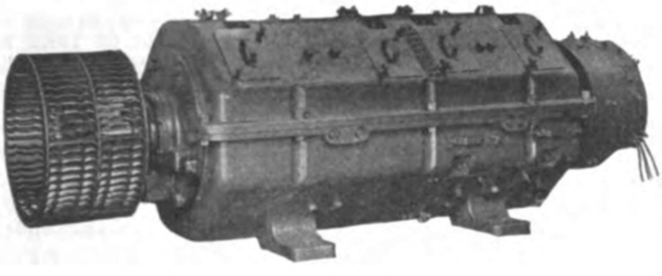
C., M. & ST. P. LOCOMOTIVES—SCHEMATIC DIAGRAM FOR ELECTRIC BRAKING CONNECTIONS

motors shunted is provided on both the freight and passenger locomotives for efficient running at higher speed.

The circuits related to the master control are designed for voltages of 125 or less. This applies also to the circuits for the reverser, since the motor fields are always on the grounded side of the armature, the reverser being operated by an air motor similarly to the series-parallel switch. The shunts and similar apparatus associated with the motor fields are also designed for low voltage. This current at reduced voltage is obtained from a motor-generator set directly connected to the 3000-volt trolley supply. The set consists of a 3000-volt driving motor, a direct-connected fan for ventilating the traction motors, an exciter and a small 125-volt generator. The exciter is used during electric braking to super-excite the traction motor fields, and while not thus employed to recharge storage batteries for lighting in passenger service. The 125-volt generator supplies power for the master control circuits, cab lights, headlight and other low-voltage auxiliary circuits.

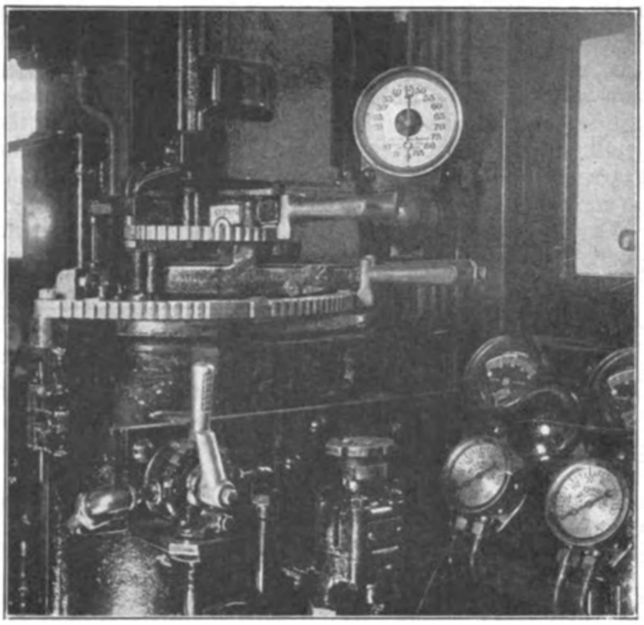
Regenerative Electric Braking

Regenerative electric braking is, doubtless, the most interesting feature of the control equipment. With the simple direct-current motor adopted for the Milwaukee



C., M. & ST. P. LOCOMOTIVES—MOTOR-GENERATOR SET WITH FAN HOUSING REMOVED

locomotives, operation as a motor or a generator depends upon whether the trolley voltage at the locomotive is above or below the voltage at the motor terminals. Hence, when the locomotive descends a grade and is to brake regeneratively, it is necessary only to effect an increase in the voltage across the motor terminals so that power is pumped from the locomotive into the transmission system. The means for thus raising the voltage level of the motor rests in the use of the before-mentioned exciter, which is so connected as to super-excite the traction motor fields. By properly proportioning the design of the exciter for its service, the stable characteristic of the series motor is inherent in the braking connection as in the motor connection. Since the generative function is a reversal of the motor function, the traction motors provide in regeneration that, with an increase in speed, there is an automatic increase in braking effort, and with a decrease in speed there is an automatic decrease in braking effort, a definite torque corresponding always to each particular speed and voltage. The fact that this stable characteristic is closely maintained during regenerative braking is one of the greatest contributing elements to the success of electric braking in this service, because it permits operation down grades at constant speed with but little regulation by the motorman, except as changes in grade or curves produce large variations in the intensity of braking power required.

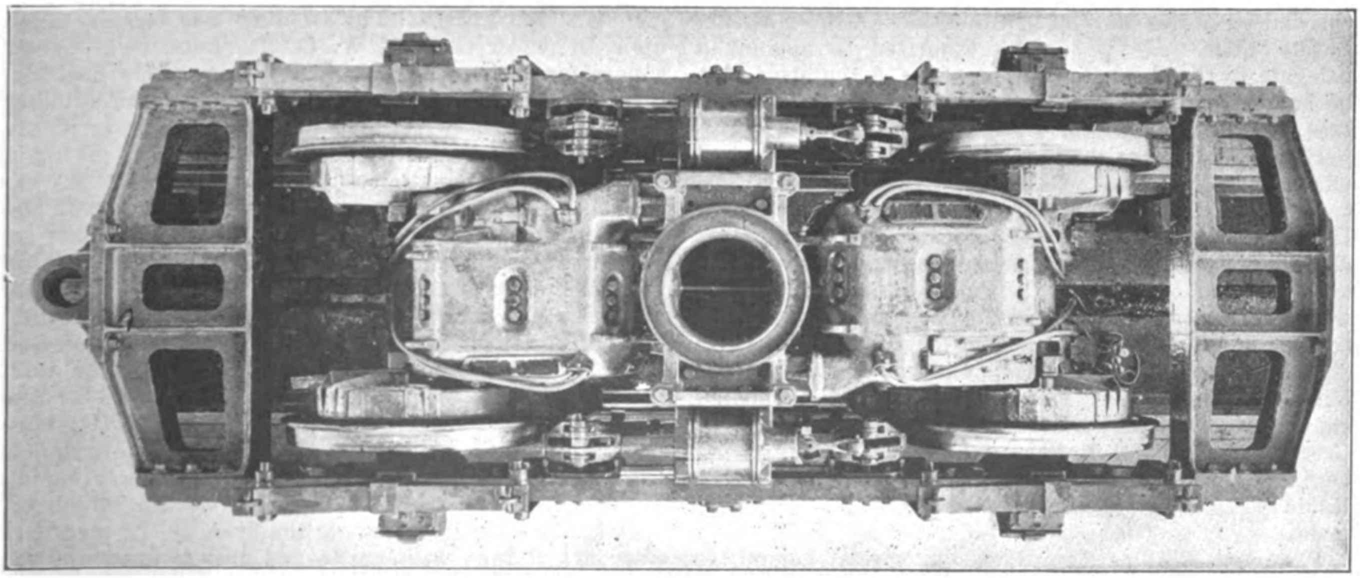


C., M. & ST. P. LOCOMOTIVES—INTERIOR VIEW OF MOTORMAN'S CAB SHOWING CONTROLLER AND ELECTRIC-BRAKING HANDLES AND OPERATING GAGE BOARD

So far as the motorman is concerned the operation is simple. When motoring he varies his tractive effort by changing the resistance in series with his traction motors, thereby limiting the amount of power to be expended in the motors. When braking he merely changes the resistance in the shunt field of his exciter, thereby regulating the increment of voltage above the line, the returned power reacting as a braking effort.

The equipment used in producing this result includes a small controller inverted upon the large master controller, the handle for the former being used for varying the intensity of the retarding torque, which may be accomplished when the motors are running either in full series or full parallel. An illuminated ammeter and gage panel is located directly in front of the motorman. This is provided with a center-zero ammeter for the line, and a field ammeter, which measures the current in the traction motor fields when they are being super-excited during regeneration. Red marks are located on the ammeter scales to show when the continuous capacity of the motor is being exceeded.

The exciter current for strengthening the main motor



C., M. & ST. P. LOCOMOTIVES—TOP VIEW OF DRIVING TRUCK SHOWING VENTILATING AIR INLET IN CENTER PLATE fields is controlled by a specially-designed motor-driven controller which is regulated by the braking handle on the master controller. To assist in multiple-unit operation so that the different sets of motors will properly divide the load, a current-limit relay is used in the system of connections between the master controller and the exciter field controller to fix the setting of the latter.

Emphasis may well be laid upon the ease and simplicity of operation of the regenerative system by noting the fact that, during the past year of operation, steam locomotive engineers have been intrusted with the electric locomotives after having but a few days of instruction. In the first days of operation the electric locomotives were even pooled with the steam machines, and an engineer would not know until he was called whether he was to take out an electric locomotive or a steam machine.

Under regeneration the regular operation of the locomotives is not interfered with in any way, electric braking being immediately available at any time. If the speed of the train on any grade reaches a higher point than desired before braking is applied, the electric brake can be put on very slightly and gradually brought up to the point required to slow down the train and hold it at the desired speed. The regenerative control is entirely automatic, and the braking effort is held constant for any definite setting of the braking controller, being entirely independent of changes in trolley voltage, distance from substations or from the nearest locomotive, changing grades, etc. In effect, the locomotive under regeneration acts exactly the same as a portable substation that is moving between the permanent substations but is electrically and physically connected to the substation busbars. The substation generators fix the voltage and the locomotive must generate this voltage plus the voltage drop due to current returning to the substation busbars. If power is fed into another locomotive, the generated voltage is dependent upon the drop in voltage due to the load taken from the substation by the locomotive that is not regenerating. It is possible for one train descending a grade to take a lighter train up the other side of the mountain with all power passing through the substation busbars, but without the delivery of any power from the substation, the generating apparatus merely floating on the line and determining the trolley voltage.

In past years it has always been considered necessary to figure on a larger motor for electric braking than would ordinarily be used, because in this case the motor would be operated continuously, but the internal ventilated type of motor that is installed on the Milwaukee locomotives has such a high continuous capacity that it can be operated continuously at the normal locomotive rating without being overheated. In brief, the advent of the commutating-pole motor, with its greatly increased commutating capacity and its rugged construction, has contributed most largely to the establishment of direct-current regeneration, because the standard commutating-pole motor automatically becomes an excellent generator, when driven by the weight of the locomotive and train on down grades without necessity for adding to the weight of the motor or changing its fields or connections.

American Association News

President Phillips of the Engineering Association Announces the Appointment of Committee Chairmen—Scale of Dues for Manufacturing Members—Meetings of Company Sections in Chicago, New Haven and Milwaukee Were Addressed by Prominent Speakers and Showed Good Attendance

Engineering Association Appoints Committee Chairman

Immediately following the last session of the Engineering Association meeting at Atlantic City, President Phillips called a meeting of the executive committee. Among other items of business the president was authorized to appoint a special committee to confer with the United States Bureau of Standards on the National Safety Code. He was also authorized to appoint a delegate to the Good Roads Congress. A tentative plan of subjects for the consideration of the new committees was also submitted.

President Phillips then announced the appointment of officers of committees as follows: H. H. Adams, Chicago Surface Lines, secretary standards committee; C. H. Clark, Cleveland Railway, chairman way committee; J. W. Welsh, Pittsburgh Railways, chairman power generation committee; C. L. Cadle, New York State Railways, Rochester, N. Y., chairman power distribution committee; E. R. Hill, consulting engineer, New York, chairman committee on heavy electric traction; C. S. Kimball, Washington Railway & Electric Company, chairman committee on buildings and structures; L. P. Crecelius, Cleveland Railway, chairman committee on engineering-accounting, and W. G. Gove, Brooklyn Rapid Transit System, chairman committee on equipment.

President Phillips named as the special committee to confer with the Bureau of Standards: C. L. Cadle, chairman; J. W. Welsh, co-chairman; W. G. Gove, C. S. Kimball and E. R. Hill.

Chicago Elevated Section Inaugurates Educational Talks

The meeting of the Chicago Elevated Railroad Company Section, held recently, was attended by 150 members and guests. The meeting was largely taken up with power matters, W. O. Barnhart, chief power supervisor, being the principal speaker. He first described visits made by the section during the summer to the great Fisk Street and Quarry Street power plants of the Commonwealth Edison Company, later giving a talk on "An Explanation of Electrical Terms." As explained by President H. A. Johnson, the latter was the first of a series of fifteen-minute educational talks on subjects pertaining to the operation of the elevated railroads. These talks are to be followed by general discussions. It was expected that John W. Bunn, Galena Signal Oil Company, would deliver an address on "Signal Oil," but he was obliged to postpone his talk.

Several items of business were disposed of at the meeting, among which were the election of J. H. Mallon, safety engineer, as section delegate to the Atlantic City convention, and the appointment of a nominating committee to prepare a slate for the election which occurs at the meeting. During the evening the members were entertained with music and crayon drawing, the latter to piano accompaniment.