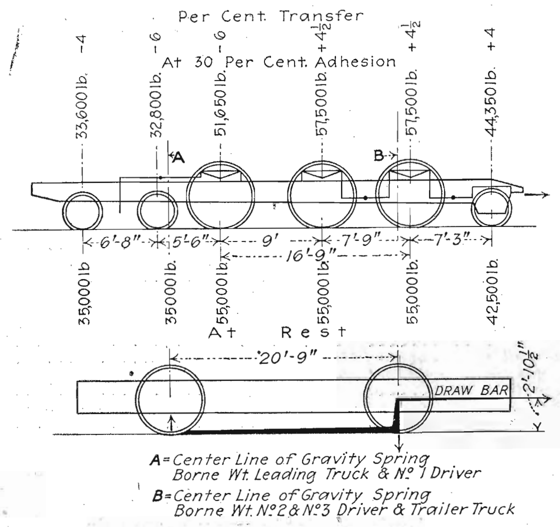
of service data which may be directly comparable the reasons may be classed as somewhat theoretical. In the first place it was understood that the weight on driving axles, both as to amount and disposition, in the present engines would not be accepted for additional engines for passenger service. A departure from the design of the locomotive at present in passenger service was therefore necessary. This could have been accomplished by the use of more driving wheels with smaller and lighter motors, or of very large motors with side rods. The service conditions require a minimum of six driving axles, with a weight of 55,000 lb. on each. This requirement can be very reasonably and economically met by twin motors with quill drive.

Among the advantages of this type of construction the following may be noted:

1. The limitation of voltage across any commutator



WEIGHT DISTRIBUTION AT REST AND AS MODIFIED BY DRAWBAR PULL, ON ST. PAUL QUILL-DRIVE LOCOMOTIVES

to 750 volts, thereby obtaining especially stable commutation for both motoring and regenerating.

2. The greater accessibility, lesser restriction in design, and greater freedom from injury to motors, due to their position above the axle remote from the roadbed.

3. The mounting of the motors rigidly upon the locomotive frames, thereby securing great flexibility between the roadbed and the motor mass.

4. The height of center of gravity of the running parts, which is 43½ in. above the rail.

5. The use of a minimum number of gears and the removal of the necessity for spring gears.

6. The very desirable wheel arrangement, weight distribution and equalization.

The utilization of the weight of the locomotives for adhesion is not of the same importance in passenger locomotives as in those designed for freight service. However, the relative value of wheel arrangement is affected by weight transfer, due to the tractive effort being applied at the height of the drawbar, as shown in the accompanying diagrams. Thus with 30 per cent adhesion the weight transfer of this wheel arrangement is no more than 6 per cent, while if the wheelbase were as short as 10 ft. 6 in. the weight transfer under the same condition would be 16.4 per cent. Thus for drag or heavy freight service the use of side rods has a distinct advantage, since all of the drive wheels on the truck are coupled.

The American railroad track is a cushioned, yielding structure, but unfortunately the yield of the rail due to wheel loads varies greatly, depending upon the track joints, special work, condition of ballast and sub-grade. This general condition is exaggerated, of course, by the extreme weather conditions experienced in this country.

A great deal of importance has been attached to such matters as center of gravity, wheel arrangement, size of wheels and equalization on steam locomotives, especially for passenger service. The steam locomotive, of necessity, consists of a large mass, including boiler and cylinders, carried on the locomotive frame, the driving wheels being loosely and flexibly connected thereto. Space limitations also require a relatively high center of gravity. It is a coincidence that this limitation in the design of steam locomotives automatically secures a reaction upon the roadbed which is inherently easy upon the latter. In view of the flexibility of the heavy parts of the locomotive, the individual axles are relatively free from restraint imposed by directly imposed weight. In the electric engine described these advantageous features are all retained. In the use of side rods on electric locomotives the action differs from that of steam locomotives in the entire absence of dynamic augment produced by the lack of counterbalance of reciprocating parts of the steam locomotive for all speeds. The electric locomotive with side rods is perfectly counterbalanced for all speeds, since the motion of the rods is of pure rotation only.

3000-Volt Gearless Locomotive for the St. Paul

By A. H. Armstrong

The excellent operating results obtained during the past ten years with gearless motor locomotives on the New York Central tracks have attracted increasing attention to this form of construction. The extreme simplicity in design offered by mounting the armature directly upon the driving axle, thus eliminating all gears, quills, jack-shafts, side-rods, etc., has been reflected in great reliability and low cost of maintenance. It is, therefore, an achievement of much importance to announce the entry of the gearless locomotive in mountain grade haulage, as it can be reasonably expected that this type of construction holds promise of equally good operation in this heaviest class of railroad service.

The gearless locomotive now under construction in the General Electric shops for the Chicago, Milwaukee & St. Paul extension to Seattle is equipped with fourteen axles, twelve of which are drivers and two guiding axles. The armature is mounted directly upon the axle and, with the wheels, constitutes the only dead or non-springborne weight of the locomotive. This weight is approximately 9,500 lb. as compared with 17,000 lb. dead weight on the driving axles of the present geared locomotives now in operation on this road. The two fields are carried upon the truck springs with full freedom for vertical plan of the armature between them.

The construction of the motors throughout is practically identical with that employed upon the New York Central gearless locomotives, but the capacity of the locomotive is much increased and the wheel arrangement somewhat different. The following table gives the general physical characteristics of the locomotives now under construction:

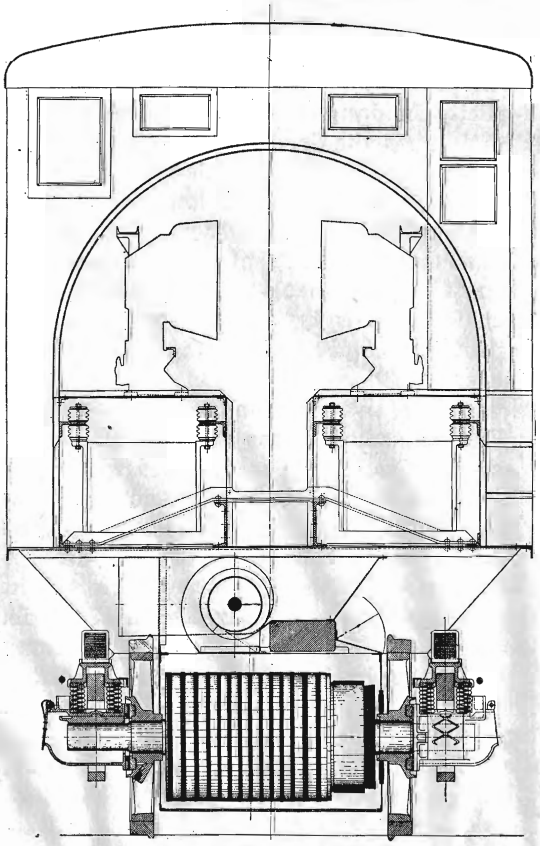
DIMENSIONS AND WEIGHTS—C., M. & ST. P. 3000-VOLT D.C. GEARLESS LOCOMOTIVE

Length inside knuckles	76 ft. 0 in.
Length over cab	68 ft. 0 in.
Total wheel base	67 ft. 0 in.
Rigid wheel base	13 ft. 11 in.
Diameter driving wheels	44 in.
Diameter guiding wheels	36 in.
Approximate height center of gravity	57 in.
Weight of electrical equipment, pounds	235,000
Weight of mechanical equipment, pounds	295,000
Weight of complete locomotive, pounds	530,000
Weight on drivers, pounds	4[illegible]8,000
Weight on guiding axle, pounds	36,000
Weight on each driving axle, pounds	[illegible]
Dead or non-springborne weight per axle, pounds	9,500

With twelve motors per locomotive available for different control combinations, there is a possibility of securing a wide range of speeds to meet the varying conditions of passenger train operation. Motors are connected three in series, giving 1000 volts per commutator for full-speed operation, but the control also permits a connection of four, six and twelve motors in series for fractional speed operation. Further provision for variable speed is made by shunting the motor fields in all combinations of motors, but it is probable that the greatest value of field shunt will be obtained with the full-speed connection of three motors in series. The following table illustrates the speed possibilities of this locomotive:

SPEED CHARACTERISTICS—C., M. & ST. P. 3000-VOLT GEARLESS LOCOMOTIVES, 960 TONS TRAILING LOAD

	Speed in m.p.h.			
	On Level	On ½ per Cent Grade	On 1 per Cent Grade	On 2 per Cent Grade
Three-motor shunt field	63.0	47.2	38.5	30.5
Three-motor full field	49.5	36.0	30.0	25.0
Four-motor full field	40.5	27.0	22.0	18.0
Six-motor full field	29.0	17.8	14.2	11.0
Twelve-motor full field	15.0	8.0	6.0	4.0



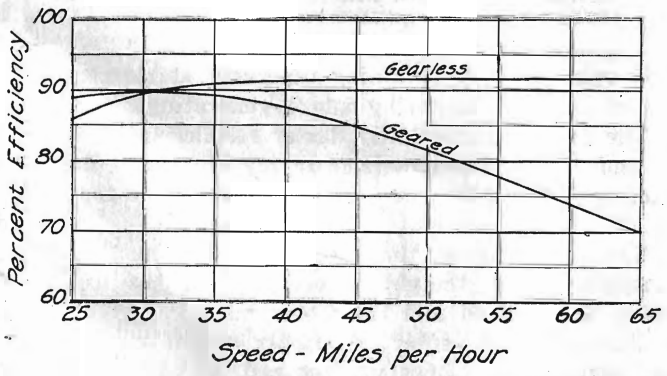
CROSS-SECTION OF NEW GEARLESS LOCOMOTIVE FOR THE ST. PAUL

It is especially desirable that a passenger locomotive shall have sufficient weight on the drivers and reserve motor power to haul additional train weight on occasion, and in this respect the gearless locomotive under construction presents some attractive possibilities. The manufacturer's guarantees cover the operation of a twelve-car train weighing 960 tons against an adverse grade of two per cent at a speed of twenty-five m. p. h. Under these conditions there is a demand for 55,200 lb. tractive effort at the rim of the drivers and equivalent to twelve per cent coefficient of adhesion of the weight upon the drivers. There is, therefore, ample margin both in weight upon drivers and capacity of the motors to haul not only twelve cars but on occasion thirteen or fourteen cars, with practically no sacrifice in schedule speed and without overloading the motors or exceeding known and conservative practice as regards loading of driving wheels. For example, the gearless locomotive being built will permit the starting of a twelve-car train on a two per cent grade with a coefficient of adhesion of only twenty per cent and accelerate the train at 0.3 m. p. h. per second. The above general statements are tabulated below:

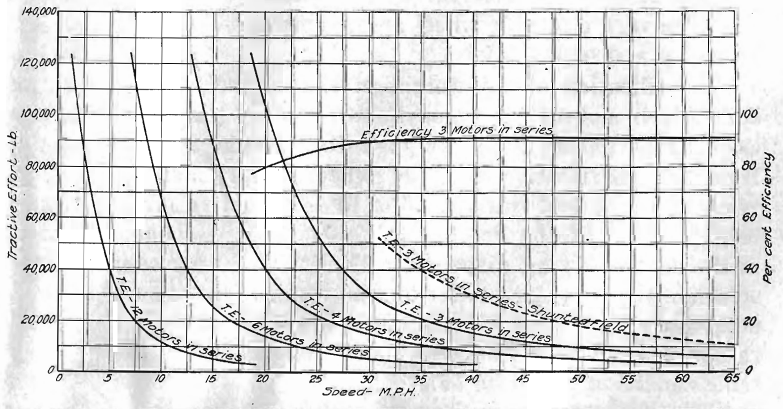
HAULING CAPACITY—C., M. & ST. P. 3000-VOLT D.C. GEARLESS LOCOMOTIVE

Number of motors	12
One-hour rating, horse-power	3240
Continuous rating, horse-power	2760
Tractive effort, one-hour rating, pounds	46,000
Tractive effort, continuous rating, pounds	42,000
Tractive effort, 2 per cent ruling grade with 960-ton train, pounds	55,200
Coefficient of adhesion ruling grade, per cent	12
Starting tractive effort, 20 per cent coefficient of adhesion, pounds	91,600
Rate of acceleration, starting, 2 per cent ruling grade, miles per hour per second	0.3

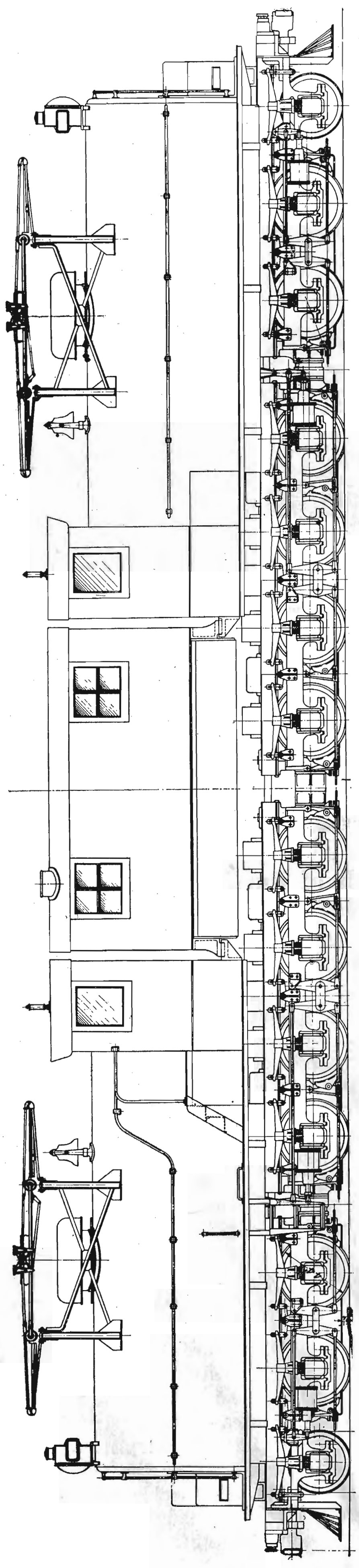
While the manufacturing guarantees are limited to 42,000 lb. tractive effort as a continuous output of this locomotive, preliminary tests upon a sample motor built



EFFICIENCY CURVES OF PRESENT GEARED AND FUTURE GEARLESS ST. PAUL LOCOMOTIVES



CURVES OF TRACTIVE EFFORT AND EFFICIENCY PLOTTED AGAINST SPEED, ST. PAUL GEARLESS LOCOMOTIVES



ELEVATION OF GEARLESS LOCOMOTIVE FOR THE CHICAGO, MILWAUKEE & ST. PAUL RAILWAY

indicate that this rating is conservative and that the final tests upon a complete locomotive when finished may show values materially higher than the guarantees made. This fact is of the greatest importance and holds out wide visions of radical changes in the operation of trans-continental trains, both passenger and freight.

The total weight upon drivers of 458,000 lb. is practically the same as the driver weight of the freight locomotive now in operation on the Chicago, Milwaukee & St. Paul. If, therefore, the completed locomotive meets the expectations of the builder, it offers the possibility of using the same locomotive interchangeably for both passenger and freight service.

The considerable speed variation permitted with four motor combinations insures a means of operating the locomotive at any speed demanded by the character of service to which it is assigned. Furthermore, when operating a freight train at lower speeds it can reasonably be expected that the tractive effort rating of the locomotive will be increased, due to the lower core loss at the lower armature speeds. While not primarily designed as an interchangeable locomotive, nevertheless it is quite possible that the flexibility of this new Chicago, Milwaukee & St. Paul gearless locomotive will become increasingly apparent when it is put into operation and its fitness for freight service will be fully recognized. It is needless to forecast the operating benefits that would result from having only one class of locomotive assigned to the road movement of either passenger or freight trains. Just as the Chicago, Milwaukee & St. Paul Railway was the pioneer road in long distance electrification, utilized for the first time 3000-volt direct current and employed regenerative electric braking on down grades, so also this road may introduce radical changes in the road movement of passenger and freight trains, by reason of the great flexibility offered in the gearless motor locomotive, which will be put into operation within the year.

Motor-Generators Will Not Be Used for Excitation in Regeneration

The control of the gearless locomotive will in many respects be a duplicate of that now in successful operation on the geared motor locomotive previously installed. Provision will be made for regenerative electric braking on down grades as the success and operating value of this method of holding trains on down grades has been fully established during the past two years of electrical operation on the Chicago, Milwaukee & St. Paul Railway. The geared locomotives now operating utilize a motor-generator set for the purpose of motor field excitation while regenerating, and the results with this combination have been excellent. Careful experiments made during the past two years have demonstrated that motor-generator field excitation is not essential and, taking advantage of the advance of the art, the control for the new gearless locomotive will dispense with this feature. This simplification of the control and reduction in weight and cost constitutes a marked improvement.

It is estimated that approximately twenty-five per cent of the 550,000,000 tons of coal mined in the United States during 1917 was consumed under the boilers of steam engines hauling our railway tonnage. One of the greatest arguments for electrification is the saving of fuel effected and therefore it is very essential that the efficiency of electric locomotives be raised as high as possible, in order to fulfill one of the claims for their introduction. In this respect the gearless locomotive under construction offers a marked improvement as compared with the geared-motor locomotive.

Gearless Drive Is Most Efficient at High Speed

The original installation of the Chicago, Milwaukee & St. Paul was undertaken with a single type of road locomotive for both passenger and freight service, the locomotives differing only in the ratio of the gearing between the motors and drivers. The locomotives were therefore interchangeable, except as to gears, with consequent simplification of shop repair practice. The geared locomotive operates at a high efficiency in heavy freight service where pushers are used on up grades, but accumulative gear losses result in a low all-day efficiency of a geared locomotive in passenger service, when the profile is broken and contains long stretches of practically level track. On the other hand the gearless motor operates at highest efficiency on level track or lesser grades and it is this class of service that constitutes the bulk of the all-day duty of a passenger locomotive.

A comparison of the efficiencies of the present geared locomotive of the St. Paul road and the gearless locomotive under construction is presented in the curves shown on page 562 which are plotted with speed as abscissae, instead of the usual method of plotting efficiency to ampere input. A comparison of the two curves is most instructive. The average operating speed at about 50 m.p.h. shows a gain of 10 per cent in efficiency of the gearless locomotive as compared with the geared type and in fact throughout the entire range of speed from 30 m.p.h. up the gearless locomotive will operate at over 90 per cent efficiency, as compared with drooping characteristic of the geared-motor locomotive.

Electrical apparatus is inherently so efficient in its conversion of electrical into mechanical power that there is usually little gain in going from one type of motor to the other. It is therefore proper to note that the considerable gain in efficiency resulting from the adoption of the gearless motor is due almost entirely to the elimination of the mechanical losses inherent with geared motor drive. The exclusion of mechanical parts, such as gears, quills, jack-shafts, side rods, etc., utilized to transmit the power from the motors to the drivers with some forms of locomotive construction not only results in a marked improvement in the all-day efficiency of the locomotive, but is followed by an equally attractive increase in reliability and a marked reduction in maintenance expense. It is felt, therefore, that the introduction of the gearless locomotive upon the Chicago, Milwaukee & St. Paul marks a distinct advance in electric railroading and that this type of construction now for the first time made possible for mountain service will result in a marked improvement in the method of handling both passenger and freight trains in this most difficult class of railroad service.

New York Central Well Satisfied with Its Bi-polar Motor Locomotives

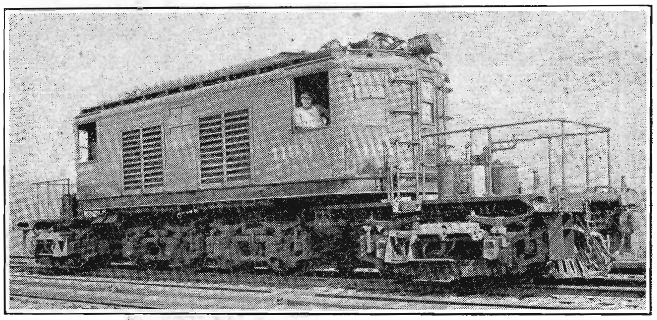
By E. B. Katté

During the past year we have received on the New York Central Railroad nine new electric passenger locomotives of the type known as Class T-2B. The tenth locomotive will be delivered next month. These locomotives are very similar to the earlier Class T locomotives, in fact, when we asked the men in the operating department if they desired to suggest any changes, their representative held up his hands and exclaimed, "For goodness sake, don't make any changes, you will spoil them." As a matter of fact, thirty or forty minor modifications and improvements were made.

These locomotives are driven by eight motors of the bi-polar type, one on each axle. The total weight of the locomotive is 134 tons, and the drawbar pull at 25 per cent adhesion is 66,000 lb. The load is about equally divided on all the wheels. The motors are known as GE-91-A and have a one-hour blown rating of 325 h. p., or a total of 2600 h. p. for the locomotive.

The capacity of the locomotive is the hauling of a 1200-ton train at 60 miles per hour. The maximum speed of the locomotive with lighter trains is 75 miles per hour.

As typical of regular service a Class T locomotive hauls Train No. 71, weighing 1035 tons, between the Grand Central Terminal and Harmon, a distance of 32 miles, making one stop, in 54 minutes running time.



CLASS T GEARLESS LOCOMOTIVE OF NEW YORK CENTRAL LINES

The average maximum speed is 57 m.p.h. and the current consumption has been shown to be equivalent to 21.9 watt-hours per ton-mile.

The cost of inspecting, maintaining and repairing our electric locomotive has averaged 3½ cents per mile during the past year. The locomotives are inspected after traversing an average of 3000 miles, which is equivalent to 33 days between inspections. As a measure of reliability I can say that Class T locomotives average 32,000 miles per locomotive detention.

Some Details of the Boston Elevated Turbine Failure

On Feb. 14 a 35,000-kw. steam turbine in the O Street power station of the Boston Elevated Railway was wrecked, the direct loss due to breakage being estimated at as much as $200,000. This is a horizontal, 20-stage impulse turbine, representing the most advanced practice in single-cylinder machines of large capacity.

The details of the accident were reported briefly in the issue of the Electric Railway Journal for March 2, page 406. Since this was published the editors of *Power* have completed an investigation of the causes of the turbine failure. They conclude that a distorted cast-iron diaphragm in the eighteenth stage probably fouled the eighteenth wheel, breaking off the buckets. The buckets and diaphragms from this stage on to the last or twentieth, and the entire turbine casing, were destroyed.

The accident occurred just before 6 p. m., when the evening peak was coming on. Rubbing sounds from within the casing were heard and the machine was seen to vibrate. Within six minutes after the first indication of trouble the destruction was complete. Fortunately steam was promptly cut off by the tripping of the automatic throttle valve, presumably through the vibration of the turbine. Some comment upon the accident appears in the editorial pages of this issue.