Above 90 degrees the factors are the same but in the reverse order.

To use these factors with the curve of any light unit, we take the candle-power at 5 degrees and multiply it by the 0-10 degree factor to obtain lumens in the 0-10 degree zone; we take the candle-power at 15 degrees and multiply it by the 10-20 degree zone factor to obtain the lumens in the 10-20 degree zone, etc. The total lumen for any large zone is the sum of the lumens thus determined in all of the 10-degree sections of the zone.

Another method of determining the flux in any 10-degree zone is as follows: We first measure the horizontal distance between the vertical axis and the point where the candle-power curve crosses the center of the zone under consideration. We then lay off this distance on the candle-power scale to which the curve is plotted. By adding 10 per cent to this figure, we obtain a value which represents the lumens in that zone. Where it is desired to obtain the summation of the lumens in a number of 10-degree zones, for example, from 0 degrees to 60 degrees, it is convenient to mark off these horizontal distances (to the center of each 10-degree zone) successively on the edge of a sheet of paper. The value for the total lumens is then found by simply laying off the total length thus found on the candle-power scale and adding 10 per cent to the result. The results obtained by this method, neglecting possible errors of measurement, are accurate within 0.2 of one per cent.

(*To be continued*)

The 3000-volt D-C. Gearless Locomotive for the Chicago, Milwaukee and St. Paul Railroad*

By A. H. Armstrong

Chairman of the Electrification Committee

The advantage of the gearless locomotive manifests itself chiefly in passenger service on long stretches of level track or easy grades, where high speeds may be maintained for the greater part of the running time. For the low speeds of heavy freight trains there is little difference in efficiency between geared and gearless construction, the advantage, if any, being in favor of the former. The gearless locomotive described in this article will be employed for passenger service on the Seattle extension of the C., M. & St. P. It will be guaranteed capable of hauling a 12-car train weighing 960 tons up a 2 per cent grade at 25 miles per hour, which is very conservative; actually the locomotives will be capable of hauling 13 or 14 cars with practically no sacrifice in schedule speed. The excellent performance of the gearless locomotives on the New York Central Railroad is responsible for the adoption of this type of locomotive by the C., M. & St. P.—Editor.

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 resulted 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 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. The dead weight is approximately 9500 lb. as compared with 17,000 lb. on the driving axles of the present geared locomotive now in operation on the Chicago, Milwaukee & St. Paul. The two fields are carried upon the truck springs and there is full freedom for vertical play 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 is arranged somewhat different. Table I gives the general physical characteristics of the locomotives now under construction.

* Abstract of talk before New York Railroad Club, "Electrical Night," March 15, 1918.

TABLE I

DIMENSIONS AND WEIGHTS

C., M. & St. P. 3000-volt, Direct-current, 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 electrical equipment	235,000 lb.
Weight mechanical equipment	295,000 lb.
Weight complete locomotive	530,000 lb.
Weight on drivers	458,000 lb.
Weight on guiding axle	36,000 lb.
Weight on each driving axle	38,166 lb.
Dead or non-springborne weight per axle	9,500 lb.

With twelve motors per locomotive available for different control combinations, there is an unusual opportunity to secure a wide range of speeds to meet the varying conditions of passenger train operation. Motors are connected three in series or 1000 volts per commutator for full-speed operation, but the control also permits a connection of four, six, or twelve motors in series for fractional-speed operation. Further provisions for variable speed are 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. Table II illustrates the speed possibilities of this locomotive.

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 2 per cent at a speed of 25 miles per hour. Under these conditions there is a demand for 55,200 lb. tractive effort at the rim of the drivers, equivalent to 12 per cent coefficient of adhesion of the weight upon the drivers. There is, therefore, ample margin, both in weight upon drivers and capacity of 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 2 per cent grade with a coefficient of adhesion of only 20 per cent and the accelerating of the train at 0.3 miles per hour per second. These general statements are itemized in Table II.

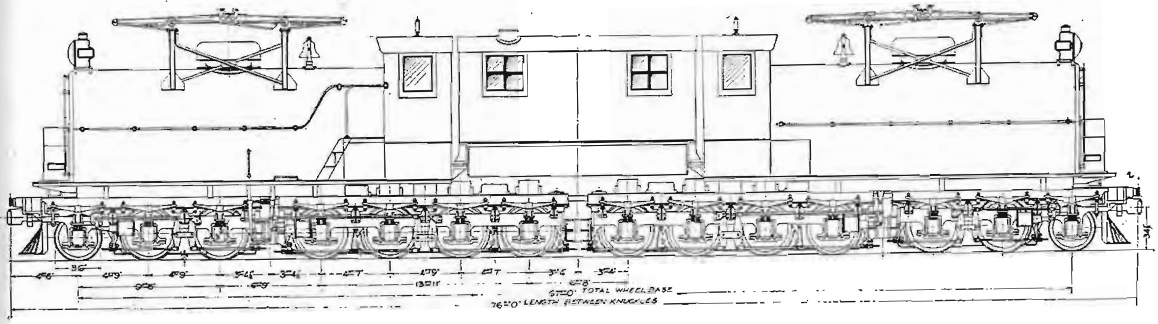

Fig. 1. Outline of Chicago, Milwaukee & St. Paul Gearless Passenger Locomotive

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 indicate that

TABLE II

SPEED CHARACTERISTICS

C., M. & St. P. 3000-volt, Direct-current, Gearless Locomotive 960 Tons Trailing Load

	Level	½ Per Cent Grade	1 Per Cent Grade	2 Per Cent Grade
3 motors in series, shunted field	63.0	47.2	38.5	30.5
3 motors in series, full field	49.5	36.0	30.0	25.0
4 motors in series, full field	40.5	27.0	22.0	18.0
6 motors in series, full field	29.0	17.8	14.2	11.0
12 motors in series, full field	15.0	8.0	6.0	4.0

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 present freight locomotive now in operation on the Chicago, Milwaukee & St. Paul.

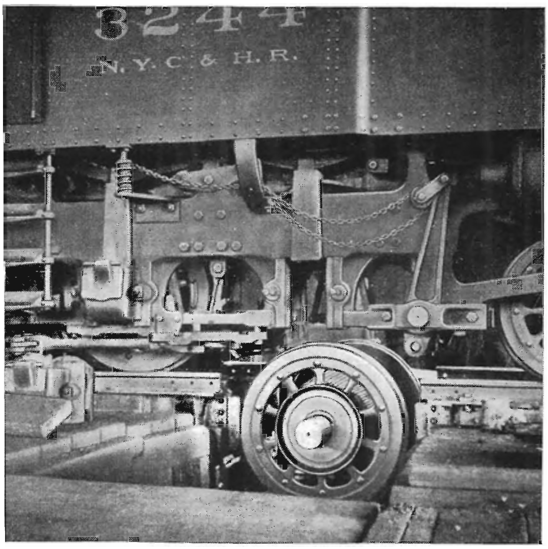

Fig. 3. New York Central Locomotive Showing Method of Removing Wheels and Motor Armature

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, 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, the pioneer road in long distance electrification, utilized for the first time 3000-volt direct current, and employed regenerative electric braking

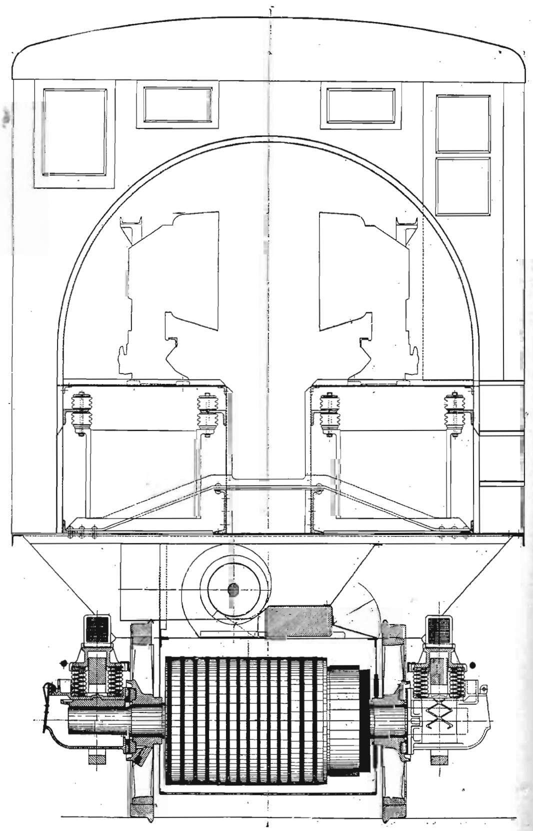

Fig. 2. End Elevation of Chicago, Milwaukee & St. Paul Locomotive Showing Location of Armature and Control Equipment

TABLE III

HAULING CAPACITY

C., M. & St. P. 3000-volt, Direct-current, Gearless Locomotive

Number of motors	12
One hour rating	3240 h.p.
Continuous rating	2760 h.p.
Tractive effort 1 hour rating	46,000 lb.
Tractive effort continuous rating	42,000 lb.
Tractive effort 2 per cent ruling grade with 960-ton train	55,200 lb.
Coefficient of adhesion ruling grade	12 per cent
Starting tractive effort 20 per cent coefficient of adhesion	91,600 lb.
Rate of acceleration starting 2 per cent ruling grade	0.3 m.p.h.p.s.

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 locomotive which will be put into operation within the year.

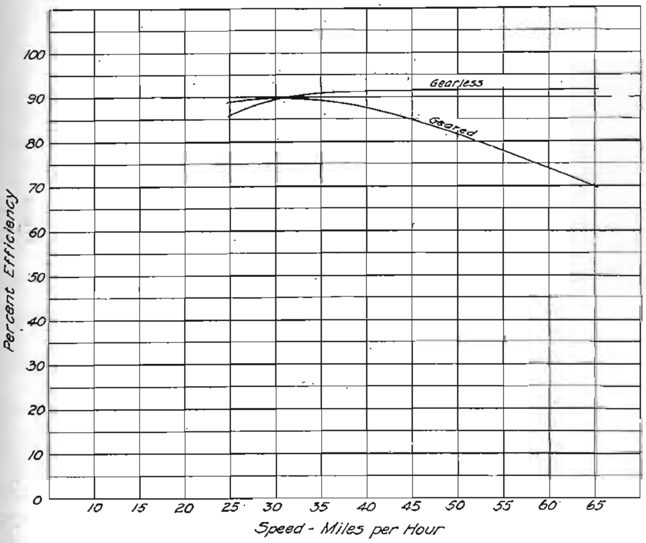

Fig. 4. Efficiency Curves of Present Geared and New Gearless Chicago, Milwaukee & St. Paul Locomotive

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

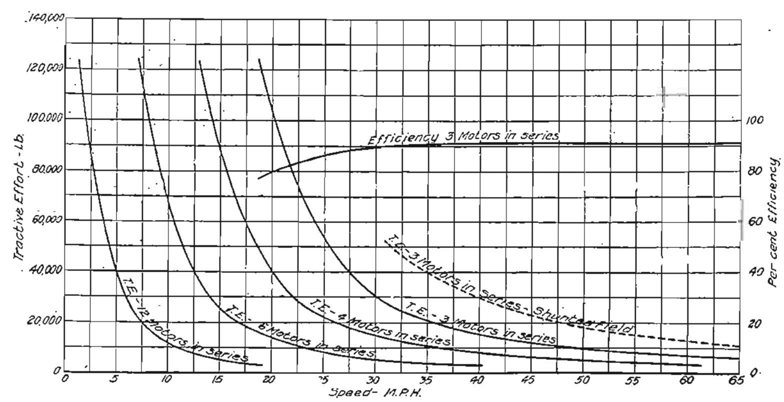

Fig. 5. Characteristic Curves of 3000-volt, Direct-current, Gearless Motor Locomotive for Chicago, Milwaukee & St. Paul Railroad

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 running utilize a motor-generator set for exciting the motor field 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 25 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.

The original installation of the Chicago, Milwaukee & St. Paul was undertaken with a single type of road locomotive for both passenger and freight service, 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 with those of the gearless locomotive under construction is presented in Fig. 4. For convenience the curve is plotted with speed as abscissæ, 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 thirty miles 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.

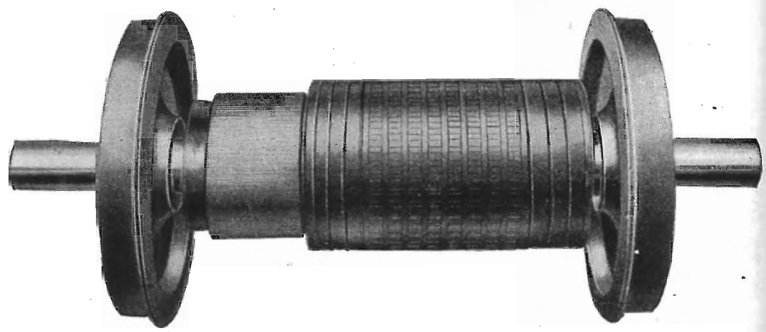

Fig. 6. Wheels and Armature of Bipolar Gearless Motor

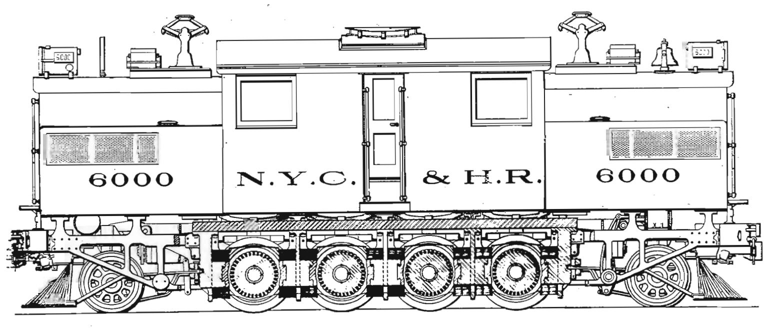

Fig. 7. Latest Type New York Central Locomotive Equipped with Eight Bipolar Gearless Motors