the problem confronting him, the electric railway engineer nevertheless offers in the modern electric locomotive a type of motive power which can accomplish results in transportation which are not possible to obtain with the steam locomotive both as regards tonnage handled, speed on mountain grades and general flexibility and economy in operation. The first large electric locomotive built was placed in operation on the Baltimore & Ohio Railroad in 1895, and it is worthy of note that this was a gearless locomotive and a forerunner of the highly efficient gearless locomotives now in operation upon the New York Central Railroad to-day. The New York Central locomotive, as developed in the later T type, is capable of hauling the heaviest overland passenger trains over any length of track that may be electrically equipped, and with-all at a cost for upkeep, including all labor and material spent in maintenance, of not exceeding 3½ cents per mile run, as is shown by the records of the New York Central during the operation of the past seven years.

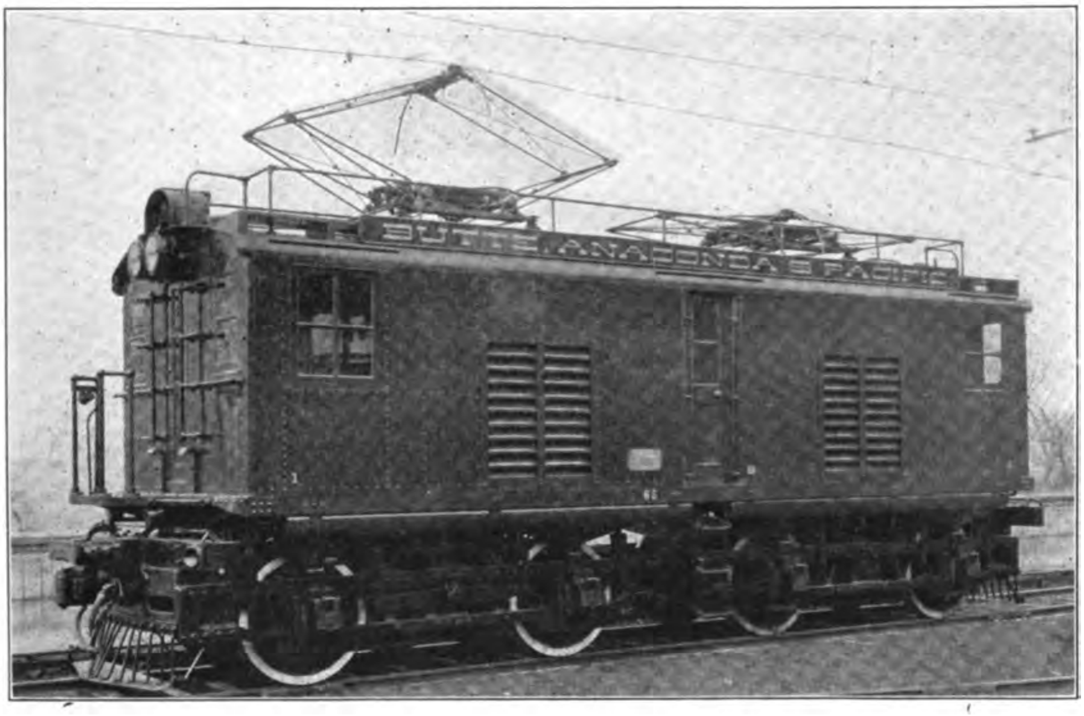

FIG. 1 THE 80-TON LOCOMOTIVE UNIT OF THE BUTTE, ANACONDA & PACIFIC RAILWAY

The first railroad in this country to adopt electric freight locomotives having large sustained output capacity was the Butte, Anaconda & Pacific Railway. Some three years ago the construction of 92 miles of the total of 114 miles of track was commenced, being completed for freight operation in May, 1913, and for complete freight and passenger operation in October, 1913. There are still four or five steam engines in operation on Butte Hill, but these will be replaced in the near future, so that in a short time the entire road, or 114 miles of track, will be in operation electrically. The one motive inspiring this installation was economy in operation, and preliminary reports indicated that the savings in electric over steam operation should be sufficient to pay something like 17½ per cent upon the capital required to electrify. During the first six months operation of this road, careful detail figures were kept on the cost of electric operation, every item of expense being accounted for, with the result that, prorated over the entire fiscal year, there was a saving shown of $240,000 over the cost of steam operation during the previous year with practically the same tonnage handled. The entire first cost of this installation, including all material and labor and contingent expenses as well as interest on money during construction, was approximately $1,200,000, so that the saving above indicated results in a 20 per cent gross return upon the capital required for electrification. This makes no allowance for the scrap value of more than 20 steam locomotives discarded.

On this road, the heaviest class of freight trains are operated electrically, regular operation calling for the movement of from 3,500 to 4,000 tons behind the locomotives from the Butte Yards to Anaconda, and record has been made of train weights as high as 4,500 tons trailing against a gradient of 0.3 per cent. Each locomotive (Fig. 1) weighs 80 tons, all on drivers, and two such units are coupled together, operated by one engineer and comprise a complete locomotive hauling the above tonnage. At the Butte end, there is a gradient of 2½ per cent against the returning empty cars, and at Anaconda 1.1 per cent grade against which one of the above locomotives hauls 25 cars or approximately 2,000 tons.

This leads up to the subject of the rating of an electric locomotive. The Butte locomotive (Fig. 1), weighing 80 tons, all on drivers, will give a continuous tractive effort of 26,000 lb. at a speed of approximately 16½ miles per hour at full substation line voltage; this corresponds to 16¼ per cent of the weight upon the drivers. Investigation of the locomotive loading regulations on many steam roads operating over ruling grades indicates that it is almost universal practice to assign to a locomotive a trailing load so that the tractive effort at the rim of the drivers, as required on ruling grade, will be equivalent to approximately 18 to 19 per cent of the weight upon the drivers. In other words, from 18 to 19 per cent coefficient of adhesion between driver and rail is now considered good steam practice, and the electric locomotive rating is closely following this same steam practice. The electric motor, of course, gives a perfectly uniform rotation to the driving wheels, and should thus give something like 10 per cent more tractive effort than the steam locomotive with its reciprocating parts. Continued operation will develop whether this additional 10 per cent tractive effort can be utilized or not. In the meantime, steam practice is being followed in the loading of electric locomotives.

In adopting a coefficient of adhesion of 18 or 19 per cent as the basis of determining the tractive effort required on ruling grades, it is evident that there is left for starting purposes the difference between the above coefficient of adhesion and the slipping point of the wheels, whatever that may be, as determined by the condition of the track. Tests on electric locomotives have shown a coefficient of adhesion as high as 35 per cent, or even more under specially favorable conditions, but it is fair to assume a maximum of 30 per cent as available in operation and even 25 per cent may be nearer the average. There is therefore, not much difference between the tractive effort required on ruling grades and that required for starting, and in order to be "fool proof" and capable of meeting the exacting demands of the heaviest kind of service, the electric locomotive should be capable of delivering continuously a tractive effort equal to from 16 to 18 per cent coefficient of adhesion of the weight upon its drivers. The Butte locomotive is therefore rated at 26,000 lb. or 16.25 coefficient of adhesion as its continuous output, and this capacity is sufficient to meet all demands of operation on the Butte, Anaconda & Pacific Railway.

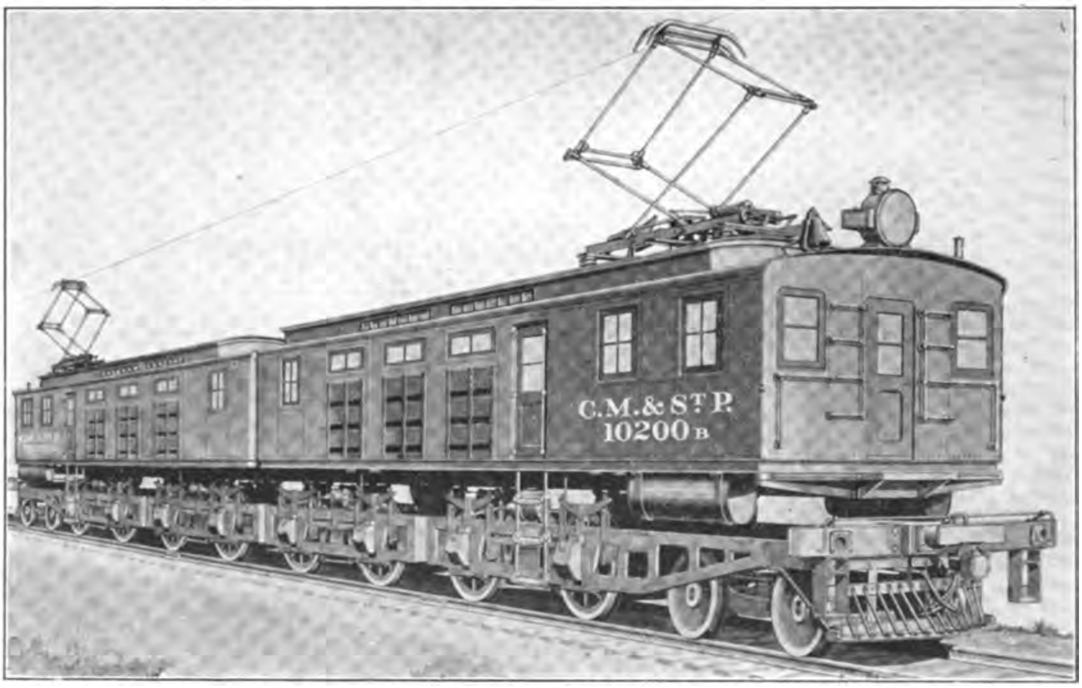

FIG. 2 THE DOUBLE UNIT 260-TON LOCOMOTIVE OF THE CHICAGO, MILWAUKEE & ST. PAUL RY.

Coming now to the latest type of trunk line electric locomotive, the one designed by the General Electric Company for the Chicago, Milwaukee & St. Paul Railway (Fig. 2) is direct development of the Butte, Anaconda & Pacific both as to type of locomotive and general system of electrification installed. The weight of the locomotive is 260 tons, of which 400,000 lb. are on the drivers. Each of the eight driving motors has a continuous rating of approximately 375 h.p., making the sustained continuous output of the complete locomotive, 3,000 h.p. at the rim of the drivers. This locomotive, however, will give a considerably larger output for short periods. For example, it has a capacity of 3,440 h.p. for one hour and even greater than this for short periods. The sustained tractive effort is 72,000 lb. at a speed of 15¾ miles per hour at full substation line potential.

Compare this electric locomotive with the Mallet engine of approximately the same weight now in operation on the St. Paul road, as shown in Fig. 3, and we find that the Mallet engine has 76,200 lb. tractive effort corresponding to 23.5 per cent coefficient of adhesion, but those of you familiar with the performance of this particular engine know that it toils painfully at speeds seldom exceeding 7 to 10 miles per hour when operating at its full hauling capacity. It is in this matter of higher speed for the same tractive power that the electric locomotive excels. In fact the question of speed is simply one of cost and expediency, as the horse-power output of the electric locomotive can be raised to any value desired without exceeding the limits of track loading.

The St. Paul locomotive, weighing 260 tons, has capacity to haul a 2,500 ton trailing load behind the locomotive on a 1.0 per cent grade at nearly 16 miles per hour without any assisting locomotive. The St. Paul road in Montana and Idaho crosses three mountain ranges, the Belt Mountains, the Rocky Mountains and the Bitter Root Mountains. From Lombard to Summit, in the Belt Mountains, a distance of 49 miles, there is an average gradient of 0.71 per cent and a ruling grade of 1 per cent against which one locomotive will haul a trailing load of 2,500 tons without assistance. Between Pidemont and Donald, a distance of 22 miles to the summit of the Rocky Mountains, there exists a 2 per cent grade against which two locomotives will haul 2,500 tons trailing, the second locomotive being used at the rear of the train as a pusher. A second pusher division exists in crossing the Bitter Root Mountains of Idaho, making only two pusher divisions in the 440 miles of electrified road from Avery, Idaho, to Harlowton, Montana.

The general design of the St. Paul locomotive, as shown in Fig. 3, comprises a locomotive divided in halves for facility in shop repairs, each half being identical and equipped with four driving axles and two guiding axles. The design is identical with the Butte locomotive except for the addition of the four-wheel guiding truck at each end of the locomotive. One of the reasons for the introduction of the truck is that the same locomotive is thus made available for both passenger and freight service. This does not mean that any locomotive can be used interchangeably at will in both freight and passenger service, but it does mean that all parts of the locomotive are identical whether used for freight or passenger with the single exception of the gearing between motors and driving axles which has a ratio of 4.56 for freight service and 2.45 for passenger service. This adoption of a uniform type of motive power for all classes of service should result in affecting a great reduction in the cost of maintaining the locomotives of the four engine divisions electrified.

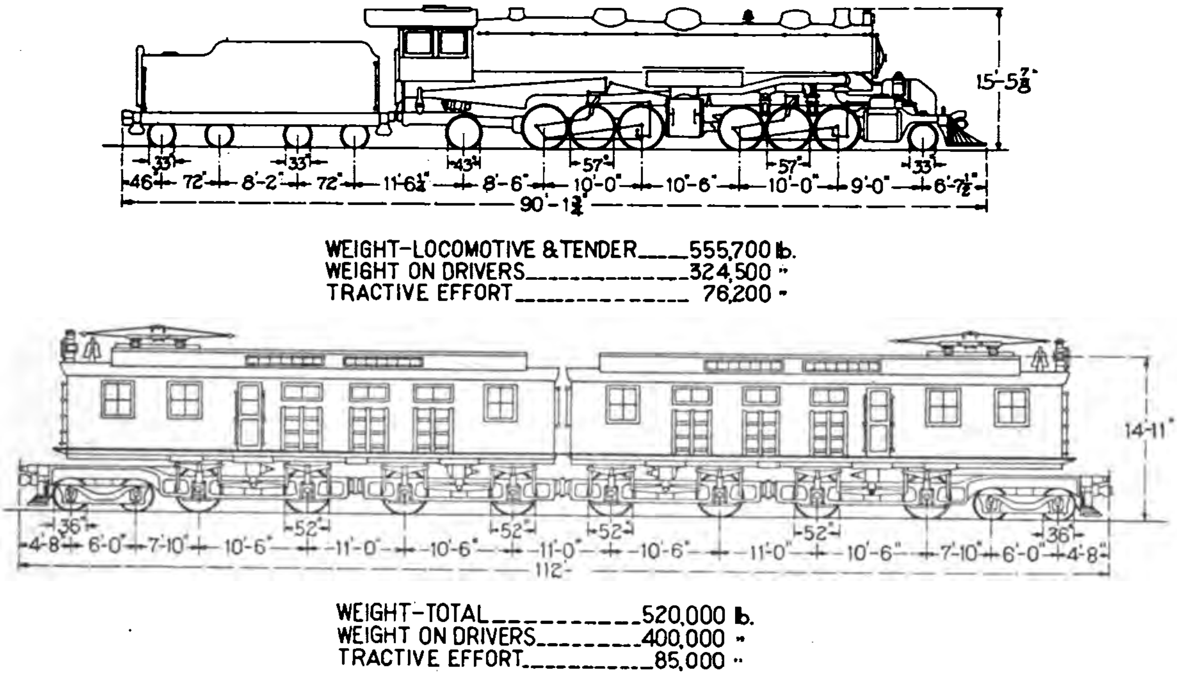

FIG. 3 COMPARATIVE DATA ON THE ST. PAUL MALLET STEAM AND DOUBLE UNIT ELECTRIC LOCOMOTIVES

A second type of light locomotive for shifting service may be introduced later, although in this connection arrangements are being made to operate independently one-half of the through locomotive by equipping it with draft gear in place of the articulated joint joining the two halves. This will provide a locomotive weighing 130 tons having 200,000 lb. on the drivers and capable of doing one-half the work stated above as the capacity of the combined locomotive, this half locomotive requiring turning if used in passenger service, as it has guiding axles at one end only.

The installation on the St. Paul road will use for the first time on such a large scale a principle which should be of the greatest advantage in the operation of mountain grade divisions, that is, the utilization of the motors on the locomotives to brake the train on down grade and return the energy of the descending train back into the line. The efficiency of the locomotive, both electrical and mechanical, is nearly 90 per cent maximum, not taking into account the minor losses in driving ventilating fans and air compressors. When descending heavy grades, therefore, the reversible feature of the locomotive, permitting it to transform mechanical power received into electrical energy, suggests by this means a considerable reduction in the amount of power required to operate the road. It is probable, however, that a power saving of less than 10 per cent will result from the regenerative braking feature of the electric locomotives, and the principal advantage resulting from the introduction of the electric brakes will be to relieve brake shoes and wheels from the dangers attending overheating. To those of you who are familiar with the handling of trains on long and heavy down grades this argument will appeal in full force, as it is not an uncommon sight to see brake shoes red hot as a result of sustained application on down grades of long extent.

In regard to the suitability of the New York Central gearless type of locomotive for passenger service, it has been pointed out the entire absence of mechanical losses in the motor other than the brush friction on the commutator, but the facts are so important as to bear repetition. There are no bearings on the motor of any kind as the armature is mounted directly upon the driving axle and the field structure is part of the frame which is carried upon the journals. The electrical efficiency of the motor and the frictional losses on the commutator due to the brushes are therefore the only losses to be considered, and the efficiency of this locomotive in operation is therefore between 93 and 94 per cent. In other words, of the electrical input received at the third rail shoes, from 93 to 94 per cent appears as useful mechanical output at the rim of the drivers. This in itself is a most remarkable performance, but the value of this high efficiency locomotive is rendered more important when it is explained that the maximum efficiency occurs at approximately the free running speed between 50 and 60