THE OPERATION AND RATING OF THE ELECTRIC LOCOMOTIVE

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The rating of electric locomotives is a subject on which we need much education. The author who has done so much work in giving rational ratings to electric railway motors in general gives some most useful data in discussing the momentary, one hour and continuous capacity of some notable electric locomotives. Many details of design including those of the locomotives for the Chicago, Milwaukee & St. Paul Railway are discussed. This article is prepared from the author's discussion at the recent meeting of the Institute of Mechanical Engineers in Chicago.—Editor.

The present article touches upon the subject of electric locomotive operation, what excuse it has for existence, and draws some few comparisons with the steam locomotive as to its selection and rating.

Commencing with the New York Central locomotive, we have a distinctive type admirably adapted to high speed passenger service. It is designed to deliver a moderate tractive effort at a high speed, the first 47 locomotives of the "S" type giving a tractive effort of 7100 lb. continuously at a speed of 56 miles per hour and a one-hour rating of 20,600 lb. The driving motors, four in number, are thus able to give an output of 2200 h.p. for a period of one hour without overheating. The later "T" type of locomotive, weighing approximately 130 tons, has a capacity of 14,000 lb. tractive effort at a speed of 53½ miles per hour or a continuous motor capacity of approximately 2000 h.p. For the one-hour period the output is 2600 h.p.

Electric railway engineers talk about continuous and one-hour capacities and also about starting tractive effort, and that brings up one point that needs explanation to the steam railroad man; that is, the time element plays a very important part in the determination of the rating of an electric motor. In a steam locomotive the tractive effort or pulling power is determined by the diameter of the piston and the steam pressure behind it, and the locomotive can deliver this tractive effort continuously provided it has sufficient boiler capacity to supply the quantity of steam demanded and the fireman is sufficiently industrious to keep the grate covered which is supposed to have sufficient surface. With the electric locomotive, on the contrary, allowance must be made for the fact that the insulation used deteriorates if heated continuously above a certain amount. It takes a considerable time for the motor to heat up to this dangerous point, thus giving rise to a momentary rating or starting effort, a one-hour rating and a continuous rating, the latter being the output which the motors can give continuously without injurious heating. In other words, the steam locomotive engineer is concerned in keeping his boiler hot, while the effort of the designer of electric locomotives is to keep his machine cool.

In the early electric locomotive design there was no such thing as continuous rating. The service which it was called upon to perform was of an intermittent character, the runs between stops were short and the designing engineers were concerned mostly with the question of starting or accelerating, tractive effort and commutation. Therefore, the continuous rating of the early motors did not affect its design. With the extension of electrified lines and more especially with the introduction of the electric locomotive on main steam trunk lines, it was found that the motive power was called upon to deliver a continuous output for long periods at a time, and it became necessary to introduce air blown or ventilated motors as well as fire-proof insulation in order to secure the large output required without exceeding the limitations of space and weight imposed by standard gauge and reasonable diameter of wheels, wheel-base and weight per driving wheel. We are therefore designing electric locomotives today suitable for the heaviest class of freight and passenger service. Such locomotives are entering into competition with the steam locomotive with a full appreciation of the phenomenal growth and possibilities of the latter as developed during the past few years, as well as a knowledge of the growth in the demands placed upon the motive power to take care of modern high speed passenger and freight train service.

In designing such electric locomotives the electrical engineer is fully alive to the fact that a steam locomotive has been built weighing 750,000 lb. on drivers and having a total weight of 850,000 lb., and that nearly 90 per cent of the total weight of the locomotive and tender is now rendered available for tractive purposes by the development of the Mallet principle to include cylinders placed upon the tender itself. It is also known that the tractive effort of these locomotives has increased from the 40,000 lb., of the early "Consolidation" engines weighing 200,000 lb. on the drivers, to values as high as 160,000 lb. for the latest type of Mallet. It is also known that the introduction of the steel passenger car with the need of high sustained speeds of between 60 and 70 miles per hour, calls for the hauling of passenger trains weighing over 1000 tons, and that provision is made in the latest New York Central electric locomotive to take care of 1200 tons at 60 miles an hour. Due appreciation is also paid to the results secured with the combination of superheating and simple engine which has so largely replaced the compound. Also the increased capacity afforded by the use of mechanical pushers, and fire door openings with hand firing, have increased the efficiency of the fireman so that it is now possible for him to throw between 5000 and 6000 lb. of coal per hour where previously 4000 lb. might be considered good performance. Finally it is fully understood that the modern steam locomotive has been so improved as to fuel economy by the introduction of superheating, fire arch and other developments that it is possible to get an indicated horse-power with a consumption of 15 lb. of steam and less than 2 lb. of coal under the best conditions of operation, and that with the use of mechanical stokers or with oil fired boilers, locomotives are in operation giving 3000 indicated horse-power or more.

Fully appreciating the above facts and the magnitude of 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 as regards tonnage handled, speed on mountain grades and general flexibility and economy in operation. The first large locomotive built was placed in operation on the Baltimore & Ohio Railway 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 road today. 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 withal 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.

The first railroad in this country to adopt electric freight locomotives having large sustained output capacity is 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 of 1913 and for complete freight and passenger operation in October of 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 18½ per cent upon the capital required to electrify. During the first six months of 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 3500 to 4000 tons behind the locomotives from the Butte Yards to Anaconda, and record has been made of train weights as high as 4500 tons trailing against a gradient of 0.3 per cent. Each locomotive 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 a 1.1 per cent grade against which one of the above locomotives hauls 25 cars, or approximately 2000 tons.

This leads up to the subject of the rating of an electric locomotive. The Butte locomotive, 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 a 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.

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, this is a 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 400 h.p., making the sustained continuous output of the complete locomotive 3200 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 3600 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 with the Mallet engine of approximately the same weight now in operation on the St. Paul road and we find that the Mallet 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 beast of burden 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 70 tons, has a capacity to haul a 2500 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 one per cent against which one locomotive will haul a trailing load of 2500 tons without assistance. Between Piedmont and Donald, a distance of 22 miles to the summit of the Rocky Mountains, there exists a two per cent grade against which two locomotives will haul 2500 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 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 its introduction being 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 service 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 effecting a great reduction in the cost of maintaining the locomotives of the four engine divisions electrified.

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 locomotive being equipped 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 would require 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 grades and return the energy of the descending train back into the trolley. The efficiency of the locomotive, both electrical and mechanical, is nearly 90 per cent as a 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 conclusion it is well to comment on the suitability of the New York Central gearless type of locomotive for passenger service. This is seen very plainly when the entire absence of mechanical losses in the motor other than the brush friction on the commutator is considered. 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 miles per hour. In other words, the motor has a drooping efficiency curve, being highest at free running and lowest at overloads or during acceleration, and in this respect being just the reverse of the efficiency curve of geared motors which reach their highest point at practically the one hour load capacity of the motors. The gearless locomotive is therefore particularly adapted to operate on fairly level profiles and could not be utilized to such great advantage on roads like the St. Paul which contains many heavy grades sustained over a long distance. It is very difficult to combine in one structure motors capable of hauling 800 tons trailing over heavy sustained grades, and also have the characteristics required for good operation on level track at 60 miles per hour, and in the St. Paul locomotives recourse to gearing between motor and driving axle appears necessary to secure the greatest all round advantages at the lowest first cost.