CHARACTERISTICS OF THE ELECTRIC LOCOMOTIVE.*

BY

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THE rapid growth of the United States in population and in wealth has been made possible only through its vast network of railways. Our railways, and practically the entire inland transportation system, have grown up around the steam locomotive. To this picturesque personification of power then, we owe our national greatness. However, there have been many evidences in the last few years which indicate that our railways need more power, and a different kind of power, than the steam locomotive can supply.

The rapid growth of the country, stimulated as it was by the railways, has imposed most severe requirements on them. There has been an unceasing demand from the traffic department for more power, for larger and still larger locomotives. The steam locomotive designers have risen to the occasion magnificently, and the modern steam locomotive is so much larger and more efficient than the locomotive of thirty years ago that a comparison between them is scarcely possible. It would seem, however, that the limit to the capacity of the steam locomotive has been closely approached, if it has not already been reached; and where greater capacity is required, another type of motive power must be used. The other type of power, in the shape of the electric locomotive, is in the field prepared to take an increasing share of the load from the boilers and cylinders of the steam locomotive; to take the load where the inherent limitations of the steam locomotive make it unequal to the demands upon it or its use undesirable or impracticable.

The far-seeing railway operator is studying the subject of electrification more seriously than ever before, and he confidently looks to the electric locomotive to help him out of many difficulties. He starts with the desire for more power and with

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the idea that he will substitute the electric locomotive whose power can be made anything that is desired for the steam engine whose power is limited by the boiler it carries. While there is no question as to the ability of the electric locomotive in this respect, he finally realizes that electrification requires practically a revolution in operating methods before all of its advantages can be secured.

Many of the old ideas that have grown up around the steam locomotive will have to be modified or abandoned and new methods introduced. The length of engine divisions, ruling grades, distribution of coal and watering stations, dispatching, the tonnage and speed of trains, the design of stations and terminals, have all hinged around the steam locomotive. This revolution will not have to take place all at once—it will be rather a gradual evolution of new methods that will be worked up by the more progressive operators, as the advantages and possibilities of electrification develop before them.

Among the many features that will become evident to the operating man making a close study of the subject of electrification are the following:

1. The power that can be applied to a train is in no way limited by the size of the individual motive power unit. The electric locomotive derives its power from a central power station which may carry the entire railway load and a large industrial load at the same time. Theoretically, the locomotive can draw the maximum amount of power that can be utilized at one point in the train. Whatever may be the size or capacity of the individual motive power unit, it places no limit on the amount of power that can be controlled from one cab, since two or three, or half a dozen if need be, of these units may be coupled together and operated on the multiple unit system like a train of suburban or subway cars. A locomotive may then be an aggregation of motor trucks with a single engineer's compartment. Practically the only limit to the tractive effort that can be controlled from this one point is the strength of the drawbars. Drawbar pull, however, is not the only way in which the greater power is developed; speed accounts for fully as much, and it will soon appear that the highest economical speed for traffic movement can be met by the electric freight locomotive; this may be two or three times as great as that of the steam locomotive. This is

particularly apparent on the mountain grades where the heaviest freight trains when pulled by steam locomotives make from 7 to 10 miles per hour, while the same trains, or heavier ones pulled by electric locomotives, run from 14 to 20 miles per hour. The electric locomotive makes it possible to operate freight trains at practically any desired speed. From this it can be seen that freight trains can more closely approximate passenger train schedules and thus greatly increase the track capacity.

In passenger service it is probable that it will not be considered economical to operate trains at much higher maximum speeds than are attained with steam locomotives. However, it will be possible to operate at a more uniform speed and with fewer delays. Heavy grades can be covered at as high speed as is safe or economical, so that if desired a higher schedule speed can be maintained with the same maximum speed as at present.

2. The length of the division on the railroad will be no longer limited by the locomotive. Electric locomotives make the run daily over the entire electrified section of the Chicago, Milwaukee & St. Paul Railway, between Avery and Harlowton, a distance of 440 miles, and are repeating this trip over and over until 4000 miles or more have been covered before the locomotive goes to the shop for anything but the casual light inspection it receives at ends of runs. There is no question but that the locomotive division could be much longer than 440 miles if it were convenient or desirable to make it so. If the large ocean liners can keep their engines running for a couple of weeks without stop, and Pullman cars can run thousands of miles, there is no reason why electric locomotives cannot operate equally well, and take equally long runs. Under the conditions of operation on the Chicago, Milwaukee & St. Paul Railway, even with only two passenger trains each way per day, one locomotive has made more than 11,000 miles in a single month. With the schedule arranged to suit, this mileage might easily be from 15,000 to 20,000 miles per month. This, of course, means a great reduction in the number of locomotives required. A record for a continuous 24-hour run of 766 miles has already been reached by the passenger locomotives on this road.

3. Electrification permits radical changes in terminals, due partly to the absence of smoke, dirt and noise, and very greatly

to the use of multiple unit car equipments for the suburban traffic. The absence of the smoke and dirt results in a change in the entire character of the neighborhood surrounding the railroad and its station. The railway is free to take full advantage of its aerial rights in the construction of hotels, office buildings, warehouses, etc., over the tracks, which, with steam locomotives, must be left open. What this one feature alone means in a congested centre like the Chicago district, for instance, where there are 4500 miles of steam railroad track in operation, it needs no words to tell. Wherever the value of real estate is high, the land covered by the railroad is very valuable and its use for building purposes can be made a source of revenue to the railway, which will go far towards paying the cost of the electrification.

The absence of smoke and dirt makes it safe and desirable to enter the city in a subway, and to have the tracks on two or more levels with a corresponding increase in capacity of the station site. This in the future may, in fact, be the only possible answer for the increase in needed capacity.

The use of multiple unit equipments makes large increase in the terminal capacity, especially where it is a stub-end terminal like that at Broad Street, Philadelphia, by decreasing the number of idle movements in the terminal which are necessary with the steam locomotive but are not required at all for the electric. All of these advantages are familiar to everyone who is interested in the subject.

A considerable improvement in terminals will also be made in the handling of freight. The electric switcher lends itself to any desired arrangement of terminal and yards. It has proven its value in the great Harlem River yards of the New York, New Haven & Hartford Railway where the switchers remain in continuous service a month or more at a time with no more attention than the crew can give them.

4. The advantage in the use of the electric locomotive for long tunnels is obvious. This has been recognized for many years, and many long tunnels that were objectionable with steam locomotives have been electrified with the best of results. The Simplon Tunnel, constructed under the great mountain range between Switzerland and Italy was based wholly upon electrical operation. In fact, it would probably be impossible to operate

a tunnel 12 miles long in any other way at this time. This characteristic of the electric locomotive will undoubtedly be taken advantage of hereafter in eliminating many long and expensive mountain grades by tunnelling through the mountains. There seems to be no reason why tunnels of much greater length should not be used.

5. Electrification obviously means conservation in fuel. Just how great this conservation will be is a mooted question. Some enthusiastic electrical exponents claim it will save two-thirds of the fuel that is now used by the steam locomotive. Some steam locomotive enthusiasts, on the other hand, deny that anything approaching this saving can be effected, basing their statements on a comparison with engines of the latest design and the best practice. Undoubtedly neither is wholly right, but it cannot be disputed that the consumption of fuel is attended with every refinement continuously in a modern power house, and that this can never be hoped for when this responsibility rests upon the performance of each of the thousands of locomotive firemen on steam locomotives. Bearing this in mind, it seems certain that, on the average, an electrified railway with modern steam power houses would not use more than one-half of the fuel that would be required for the railway under steam operation.

6. Another thing electrification means which is of vastly more importance to the management is the greater effectiveness of labor. This follows from the greater capacity which can be secured from the railroad machine.

It would seem that, just as it is possible for the housewife to save herself an enormous amount of drudgery in the everyday duties of keeping house by the adoption of the innumerable electrical devices which are now offered on every hand, so it will be possible for the railway operator to improve labor conditions by the proper use of the most efficient and reliable of all modern servants—electricity.

7. Last but not least among the things which are to be mentioned as following electrification of a railroad is increased reliability of the motive power. In every case where electric power has supplanted steam, this has been inevitably attended with improvement in regularity and reliability of train movement.

What are the characteristics of the electric locomotive that make it so desirable; that fit it so admirably for railway service?

1. Its maximum tractive effort is from two to four times its normal continuous running tractive effort. This depends for the most part on the coefficient of adhesion which is used for the normal tractive effort. This may vary anywhere from 5 per cent. to 20 per cent. of the weight on drivers. Of course, where the normal tractive effort is 20 per cent. of the weight on drivers, it would be impossible to secure more than double the normal. Ordinarily a coefficient at normal tractive effort of 16⅔ per cent. will not be able to give more than 100 per cent. above normal as a maximum, but where, as is usually the case, the normal tractive effort requires only from 10 per cent. to 15 per cent. adhesion, it is possible to develop as much as three times the normal. This compares very advantageously with the steam locomotive whose maximum tractive effort or given horsepower rating is comparatively close to the normal running. It means a great deal in the operation of the locomotive; it makes it comparatively easy to start its normal train in the worst position and also to start it very quickly without jerk. Everyone knows who rides on our steam trains that a heavy passenger train is usually started with a jerk. The reason for this is simply that the steam locomotive at the head of the train must jerk it if it is to start at all, because its maximum tractive effort is so close to that required for pulling the train after it is started that it has little margin. The locomotive may be amply large to pull the train at high speeds, but it cannot start it without a heavy jerk. The electric locomotive, on the other hand, can start with a steadily increasing tractive effort until the train begins to move, and the maximum tractive effort can be maintained until full voltage is applied to the motor.

2. The capacity of the electric locomotive is limited by the heating in the motors. The necessity with an electric locomotive is to keep the temperature of the parts down, which is just the reverse of that of the steam locomotive. For this reason, the electric locomotive can easily develop considerably greater power in cold weather than in warm weather. Here, again, it is just the reverse of the steam locomotive.

3. Practically all of the wearing parts of the electric locomotive have normally a long life. Therefore, all that is needed to keep the locomotive on the road is to secure proper lubrication, keep the bolts tight, brakes adjusted, and to give an occasional inspection to insure that nothing abnormal has taken place in

the equipment. This is the secret of the great mileage which is possible with the electric locomotive; it explains why the locomotive is ready for service so large a part of the time; it is the reason that only one-half or one-third as many electric locomotives are required for a given service as would be required for steam operation; it explains why the round-houses and inspection forces can be reduced to such a small limit; why the intermediate division points are eliminated; it gives the reason for the great reliability of the electric locomotive.

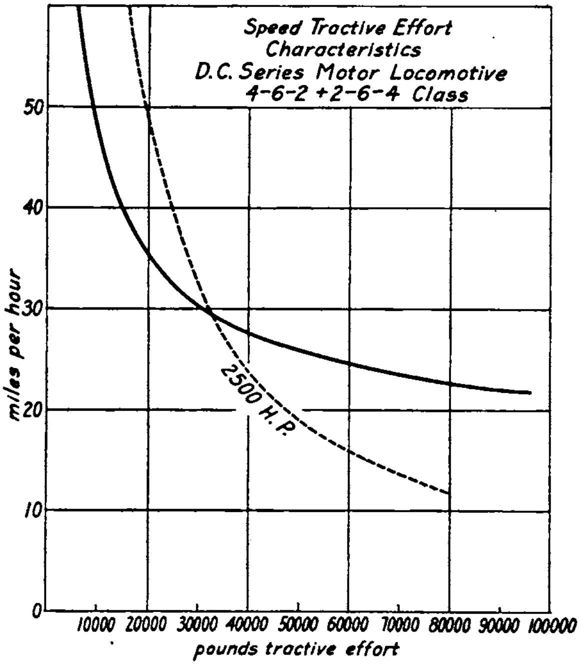
The foregoing are some of the most prominent general characteristics of the electric locomotive. It must be understood, however, that there are many other characteristics, depending on the specific type of locomotive that is under consideration; in other words, on the system which is adopted for the electrification. These characteristics are apparent chiefly in the speed and tractive effort curves. The three types of locomotives which are in use in this country to-day are, first, direct-current with series wound motors; second, single-phase locomotives with commutator type motors having series characteristics; third, constant-speed locomotives fed either from a single-phase trolley by means of phase converters or from double trolleys carrying three-phase current.

DIRECT-CURRENT LOCOMOTIVE.

The series wound motor is the one which is in practically universal service the world over where direct current is used. Its characteristics are especially suited for railway service, since the speed curve falls rapidly as the tractive effort increases, which gives the best characteristic for dividing the load, especially where a considerable number of driving units are operating in the same train. It also permits the motor to handle a much heavier load or a normal load on much heavier grade than would be possible if the speed did not fall with the increase in tractive effort.

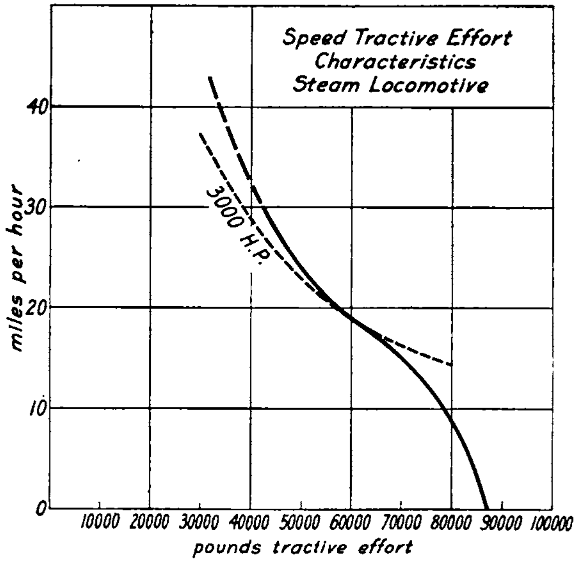
It gives, in a way, the same effect as the shifting of gears on an automobile enables it to exert an unusual amount of effort with a relatively small engine. The method is not the same, but the result obtained is similar. The solid curve on Fig. 1 shows the performance of the direct-current series motor. Thus, it can be seen that this slowing down of the speed with increased effort relieves, to a certain extent, the whole electrical supply system—the trolley, the transmission lines, and the generating units—from the peak loads caused by starting heavy trains or by hauling over heavy grades. When lighter grades or level track is reached, the characteristics of the series motor cause it to speed up very rapidly, as shown by the shape of the curve, so that full advantage is taken of the falling off of the load by increasing the speed. While running over a varying profile, it can be seen that the speed of the motor will vary much the same as that obtained with a steam locomotive. Speeds will be considerably reduced on heavy upgrades, but may be quite high on level track, and as high as the roadbed will permit on downgrades. A train running behind time may be pushed to the limit at every opportunity, and the time made up.

FIG. 1.



On all of the figures in dotted lines are plotted a series of constant horsepower curves. That is, the speed and tractive effort read from any point on a given curve will produce a constant horsepower. The direct-current motor curves at the higher speeds resemble these constant horsepower curves, and run very nearly parallel to them. On Fig. 2 is plotted a curve showing the speed-tractive-effort characteristics of a modern steam locomotive. This curve has the desirable faculty of following the shape of the constant horsepower curves very closely. On the other hand, however, it does not have the same desirable characteristic at the heavier tractive efforts which is evident on the electric motor curve, namely, that of rapidly increasing its pulling power as the load increases. The torque of a steam locomotive is limited definitely by the ability of the boiler to supply steam and the cylinders to utilize the steam. This is shown by the rapid falling off of the curve when this point is reached.

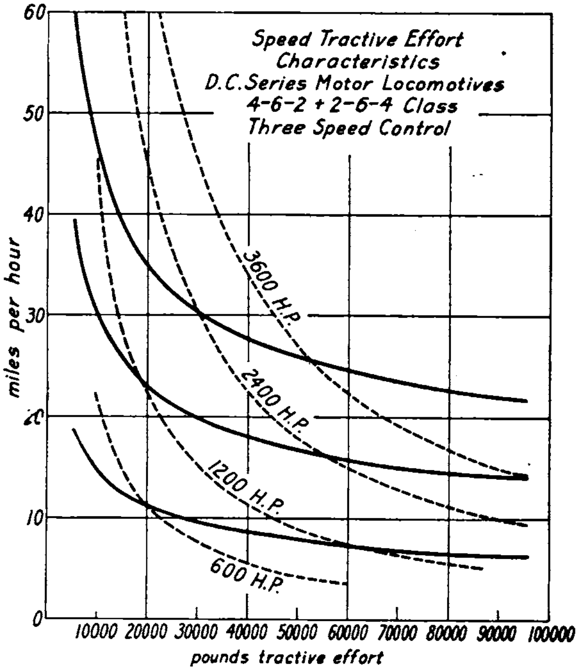
FIG. 2.



These curves then illustrate the advantage of the series motor characteristics which approach the constant horsepower curve over a certain portion, and at the same time permit of exerting very high tractive efforts when necessary.

With the series motor, the only means of controlling the speed is by varying the voltage on the motor. This may be accomplished by inserting resistance in series with the motor, but this is very inefficient, and cannot be used for other than acceleration. The common method used for obtaining this speed control with direct-current motors is to connect the motors in different series and series-parallel combinations. Fig. 3 shows three speeds obtained by connecting the motors: First, all in series so as to give one-third voltage and speed; second, in series-parallel to give two-thirds voltage and speed; and third, in parallel to give full voltage and speed. This method covers the speed range fairly completely. Fig. 4 shows the addition of six more running speeds, making nine in all. These additional speed curves are obtained by varying the effective turns on the motor field. With the use of these "field control" points, the range in speed is very effectively covered. This set of curves shows the characteristics obtained on the new 3000-volt, direct-current passenger locomotives built for the Chicago, Milwaukee & St. Paul Railway.

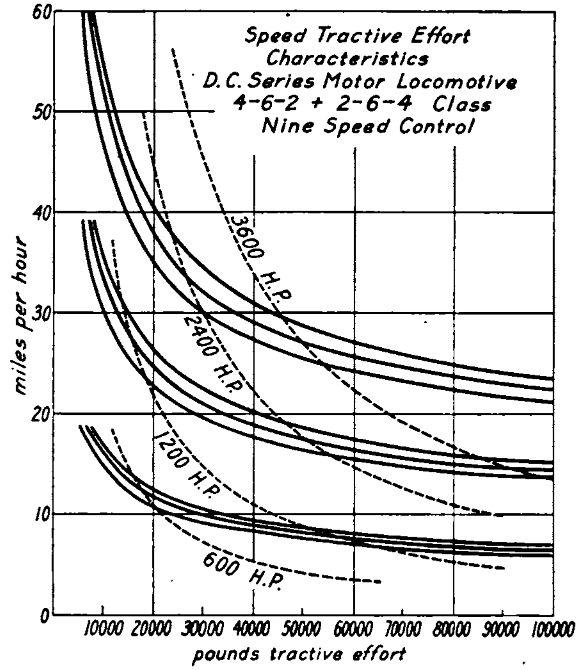
FIG. 3.



ALTERNATING-CURRENT LOCOMOTIVES.

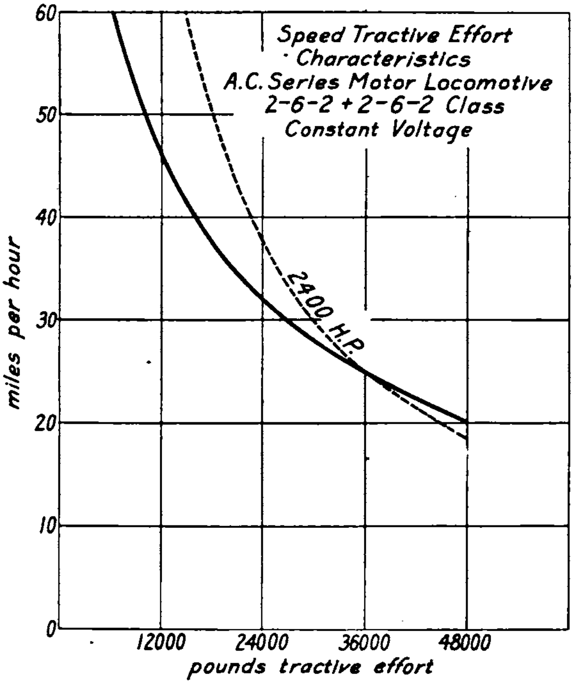
Fig. 5 shows the speed torque characteristics of an alternating-current series motor locomotive. This curve is somewhat more steep than a direct-current series motor curve, and more nearly approaches the constant horsepower curve shown by the dotted lines on the same figure. This type of motor does not, however, have the ability to produce the very high starting torques which it is possible to obtain from the direct-current motor, because of certain commutator limitations when drawing heavy currents. On the other hand, the speed control on this motor is very easily and efficiently obtained by varying the voltage applied to the motors. Power is furnished from different taps on the transformer, and the different speeds obtained as shown on Fig. 6, without in any way altering the grouping of the motors. These curves show the speed control obtained on the latest type passenger locomotive built for the New York, New Haven & Hartford Railroad.

FIG. 4.



The other motor used for railway work is the alternating-current induction motor. This motor is essentially a constant-speed motor. Its characteristics are shown on Fig. 7 and are quite different from either of the other two motors discussed. Other running speeds can be obtained with this motor by varying the number of poles, and by cascade connections, but it is rarely practicable to obtain more than two running speeds. The curves shown give two speeds, one at 14 miles per hour, and the other at 28 miles per hour. These speeds are as obtained on the Norfolk & Western freight locomotives. Acceleration is obtained by varying the resistance in the secondary of the motor, but these resistance points cannot be used as running points. This type of motor is capable of producing very heavy starting torques, and of carrying very heavy loads, but on heavy loads, the speed is maintained at practically a constant value, and the power required increases practically with the tractive effort. It is necessary, therefore, to have a motor of greater capacity than with the series motor, in order to take care of the peak loads. Some care is also necessary when operating more than one locomotive of this type in the same train, or even with different motors on the

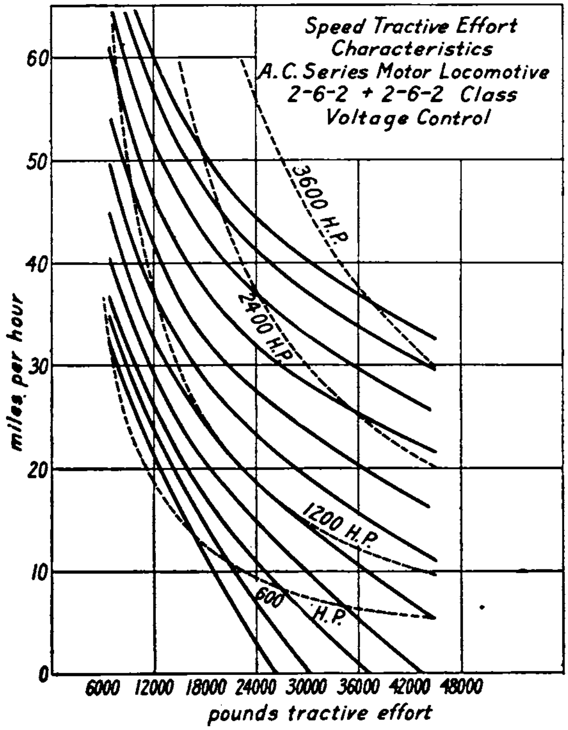
FIG. 5.



same locomotive, to balance the load between them and not overload one motor or one locomotive with more than its proportion of load. A slight difference in wheel diameter may cause considerable overloading, unless special means are used for balancing.

There has been considerable discussion among railroad men as to the advantage and disadvantage of the constant-speed characteristic. The claim is made by some that it is a decided advantage to be able to start a train from one terminal and know that, barring break-down, it will run at the same speed up hill and down, and arrive at the other terminal at a certain definite time. On the other hand, it is claimed that the ability of the series motor to take advantage of every opportunity for making speed is a very desirable characteristic, when it is necessary to make up time. A series-type locomotive of a given rating will always be

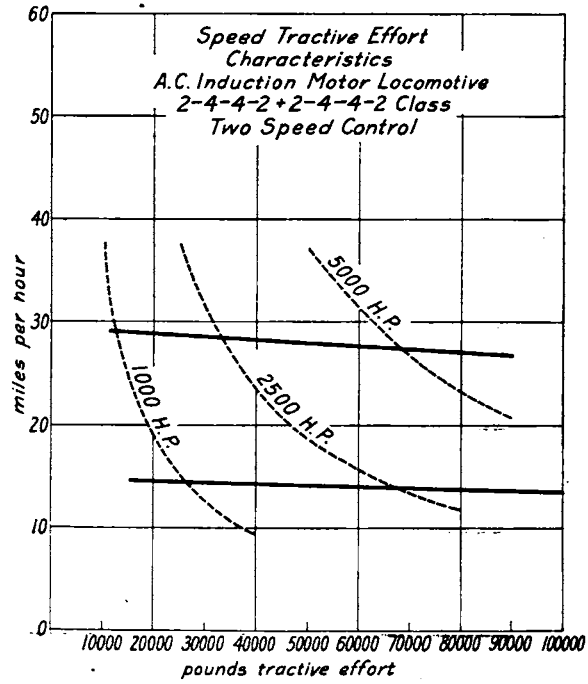
FIG. 6.



able to make a better schedule than a constant-speed locomotive of the same rating.

Fig. 8 gives a set of curves showing the characteristics of the various motors and a steam locomotive. These curves are plotted in percentages so as to be comparative.

FIG. 7.



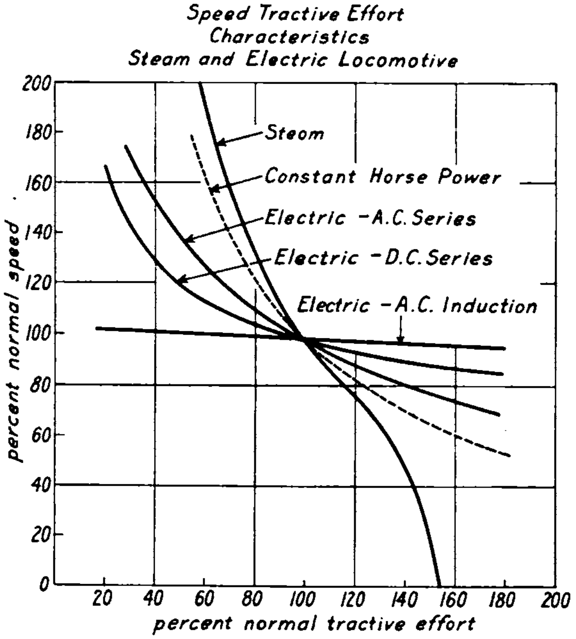
REGENERATION.

Regeneration, or regenerative braking, is another characteristic of the electric locomotive, the advantages of which cannot be overemphasized. While this feature makes it possible to reclaim some of the energy stored in a train when it reaches the top of a heavy grade and starts to go down, this saving in power does not by any means represent the full or most important benefit to be derived from it. Perhaps the most important advantage, and the one which will appeal most forcibly to the railway operating man, is the ease of control and safety provided by this form of braking, as well as the reduction in wear on brake-shoes and tires.

Regenerative braking may be obtained on any of the three classes of locomotives previously mentioned. The methods of providing for this are, of course, different.

In the constant-speed locomotive, with induction motors, regeneration is automatic. When the locomotive, in running down grade, reaches a speed above synchronism, the motors act as generators excited from the line. In this respect the constant-speed locomotive has a great advantage, but the speed is fixed.

FIG. 8.



The series-type of motor, whether alternating-current or direct-current requires excitation from some separate source, and therefore involves some additional apparatus on the locomotive.

Direct-current motors may be excited from a line-driven motor generator set, or an axle-driven generator; or, one or more of the main motors may be used as exciters for the others. Regenerative braking has been thoroughly tried out on the Chicago, Milwaukee & St. Paul Railway and is very successful. It permits operation on the down grades at any desired speed and holds the train without surge or jar. The efficiency of regeneration is about the same as that of motoring.

Alternating-current series motors have been used with regenerative braking to a limited extent and various schemes are proposed for excitation. The taps on the transformer enables the speed to be controlled all the way from maximum to a standstill and in this respect it is superior to all others. Some of the schemes for excitation are very simple, but usually have the disadvantage of either limited braking power or low power factor, or both. To get the most out of regeneration will require excitation from a phase converter or one of the main motors. With that the locomotive can exert a high braking effort and will have a good power factor.

The electric locomotive is so flexible and capable of so many things that it is likely to be overloaded with all kinds of devices that are not at all essential to its operation. These add very greatly to the apparent complication, but after all do not materially affect the reliability. The trend of the times is towards simplification—the reduction of the locomotive to its lowest terms consistent with good operation. This is undoubtedly the way to get the lowest first cost and maintenance charges.

Regenerative braking should be applied on locomotives which are to be operated over heavy grades, but for level or light grade sections the advantage will hardly be worth the complication.

In conclusion, it may be said that the electric locomotive is so flexible that it can be designed to meet practically any reasonable operating conditions, while its unlimited capacity, its great mileage possibilities, its reliability, its low cost for power, and low cost of maintenance, all make it especially attractive to the railway operator.

California's Lofty Mountains. (*U. S. Geological Survey Press Bulletin No. 477*).—At least sixty mountains in California rise more than 13,000 feet above sea level, but they stand amid a wealth of mountain scenery so rich and varied that they are not considered sufficiently noteworthy to be named, according to the Geological Survey. Yet if any one of these unnamed mountain peaks were in the eastern part of the United States it would be visited annually by millions of people. But California has seventy additional mountain peaks more than 13,000 feet high that have been named, or 130 in all, as well as a dozen that rise above 14,000 feet.