Technical Paper No. 204.

Possibilities of Steam Railway Electrification

Price Four Annas.

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SIMLA:
June 1920.

F. G. ROYAL-DAWSON,
Chief Engineer with the Railway Board.

PREFACE.

The first part of this paper is a reprint of Part I of Messrs. Merz and McLellan's report of 1914 on the feasibility of electrifying the suburban area of the Eastern Bengal Railway.

The second part is a reprint, with the kind permission of the management of the "Railway Gazette and Railway News," of an article on the "Possibilities of Steam Railway Electrification" by Mr. Calvert Townley, which was published in the issue of 11th July 1919 of that magazine.

The third part is a report by Mr. A. R. Gundry, A.M.I.E.E., A.M.I.M.E., Electrical Engineer, Eastern Bengal Railway, on the electrification of various railways in England together with an account of certain electrical works also visited by him when in England.

In view of the growing importance of the subject to railway men the above three papers are worthy of careful study.

SIMLA,
June 1920.

F. G. ROYAL DAWSON,
Chief Engineer with the Railway Board.

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Technical paper No. 204.

First Paper

General remarks on Electrification,

By

Messrs. MERZ AND McLELLAN.

SECTION "A."

Introduction.

Historical Outline.

At the present day over 2,000 miles of railway have been converted from steam to electric working, the whole of this change having taken place during the past 20 years and by far the greater part of it during the past 10 years.

Although the first electric locomotive was exhibited at Berlin in 1879, the earliest important electric railway was the City and South London Railway. This was the first of the deep level "tube" railways, and was constructed in 1890, at a time when the application of electric traction even to tramways was by no means general. The first railway actually changed from steam to electric working was probably the Nantasket Branch of the New York-New Haven System in 1895. The earliest conversions to electric traction in Europe were those of the Paris-Lyons-Mediterranean Railway in 1900, while the first to take place in England was that of the Mersey Tunnel Railway in 1903.

It was not, however, until 1904 that the Lancashire and Yorkshire and North Eastern Railway Companies in England, and the Long Island Railway Company in America, converted really important sections of steam railway carrying a dense and varied traffic over considerable distances. Table I gives a list of some of the more important schemes carried out since 1900.

There are to-day in progress many other large schemes, those at New York, Paris, Berlin, Buenos Ayres, Melbourne and London, alone involving the conversion of considerably over 1,000 miles of suburban track.

Reasons for Electrification.—Several reasons have led to the adoption of electric traction for Railway work. Perhaps two of the most important are the ease with which a greatly improved train service can be given and the question of ventilation.

Numerous instances where the use of electric traction was decided upon for one or both of these reasons can be given. In the case of the underground and "tube" lines in London, the Mersey Railway and the underground lines in Paris, Berlin, Hamburg, and New York, it was financially necessary to run a very heavy and fast service of trains, while the importance of the question of ventilation is obvious from the nature of the lines. In the case of the Tyneside lines of the North Eastern Railway and the London, Brighton and South Coast Railway, the neighbouring tramway competition necessitated that frequent service of fast trains which electric traction is peculiarly fitted to give, and which did, in fact, arrest the loss of traffic—changing a decreasing traffic into an increasing one. In the case of the suburban railways in New York, Berlin, Melbourne, and Buenos Ayres, a rapidly increasing traffic necessitated greatly improved services which could best be given by electric traction.

Electric Locomotives and Motor Coaches.—The earlier lines, whether equipped electrically from the outset or converted from steam working, were suburban. This can be seen from Table I. On these earlier lines electric locomotives were usually employed. There is, however, a serious drawback attaching to the use of locomotives (whether steam or electric) for this class of traffic in that heavy weights are required on the driving wheels in order to obtain the high accelerations necessary. This adds so much dead weight which has to be hauled.

The question therefore arose—could not the weight of the carriages be used for adhesion, thus rendering unnecessary the use of the dead weight on the locomotive? The result has been to produce what is now known as the

Historical Outline *contd.*

"multiple-unit system" of train working. With this arrangement power is provided on every second or third coach. The coach provided with electric motors,—a "motor coach"—when coupled to one or two additional trailer coaches, as the case may be, constitutes what is known as a "train-unit." The train-unit so formed can be driven from either end as required. Trains of a greater number of coaches can be made up by coupling two, three, or four such train-units together, the whole multiple-unit train being driven equally well from either end.

TABLE I.

Railways converted from steam to electric working (1900—1911).

Date.	Name of Line.	Electrical System.	Nature of duty.
1900	Paris-Lyons-Mediterranean Railway Terminus.	Direct-current .	Terminal working.
1901	Les Invalides (Versailles Railway) . .	Direct-current .	Suburban.
1901	Milan Varese (Porto Ceresio Railway) .	Direct-current .	Suburban.
1902	Valtellina Railway (Italy)	Three-phase .	Passenger and Goods traffic.
1903	Manhattan Elevated Railway (U. S. A.) .	Direct-current .	Dense Urban.
1904	Lancashire and Yorkshire Railway (Liverpool-Southport Section).	Direct-current .	Fast Suburban.
1904	North Eastern Railway (Tyneside Section) .	Direct-current .	Suburban.
1904	Long Island Railway (U. S. A.) . .	Direct-current .	Suburban and interurban.
1904	London Metropolitan District Railway .	Direct-current .	Dense Urban and Suburban.
1905	London Metropolitan Railway . .	Direct-current .	Dense Urban and Suburban.
1906	West Jersey Railway (U. S. A.) . .	Direct-current .	Suburban and interurban.
1907	New York, New Haven and Hartford Railway.	Single-phase .	Interurban.
1907	New York Central Railway . . .	Direct-current .	Terminal and interurban.
1907	West Shore Railway (U. S. A.) . .	Direct-current .	Suburban and interurban.
1909	London, Brighton and South Coast Railway (South London Section).	Single-phase .	Suburban.
1909	Midi Railway (France)	Single-phase .	Heavy Gradients.
1909	Giovi Line (Italy)	Three-phase .	Tunnels and Heavy Gradients.
1911	Kiruna Railway (Sweden) . . .	Single-phase .	Goods Haulage chiefly.

It will be seen that this arrangement eliminates the necessity of carrying about a heavy dead weight for adhesion. The chief difficulty in its adoption was the question of the control of all the motors scattered throughout the train, by one driver, but this was overcome, and the "multiple-unit" system is found to-day upon most important electric suburban railways. The system is discussed later in the Report in greater detail.

Main Line Electrification.—In the instances of conversion from steam to electric working already mentioned, electric traction was adopted more or less of necessity on suburban sections. In those early cases, it was not expected that electric traction could effect sufficient reduction in working expenses to justify

Historical Outline concld.

the necessary capital outlay unless some compensating increase of traffic or saving of new capital expenditure was obtained. But actual experience of electric traction, albeit under suburban conditions, showed those responsible for the operation of railways that the haulage of trains by electricity—quite apart from its effects upon the development of passenger traffic—possessed certain distinct operating and financial advantages over steam haulage.

For the haulage of goods and non-suburban passenger trains, the electric locomotive has several advantages. It has been fully established that electric locomotives can be, and are being, built which are far more powerful and which run at higher speeds than is the case with steam. For instance, the electric locomotives used on the Pennsylvania Railroad can develop over 4,000 H. P., while those adopted on the New York Central haul 1,000-ton trains at over 60 miles per hour.

Railway managements are in many cases being faced with the problem of quadruplicating their main lines, hence there is to-day a definite movement in the direction of replacing steam locomotives by electric locomotives, for main line working.

Systems of Electric Traction.—The question of whether or not electric traction shall be adopted in preference to steam, is to-day a financial rather than an engineering one. Most of the advantages of electric traction can be obtained whatever electrical system of working be adopted. At the same time, each of the various systems has special advantages making it suitable for different conditions.

Prior to 1900, direct-current alone was used for traction work at a pressure which had gradually been increased up to 600-800 volts at that date. A number of important schemes were carried out about this time at these pressures, the current being conveyed to the trains by means of a "third rail" carried along the side of the permanent way. The number of railways which were electrified or considering electrification about this period,* led engineers to devise other electrical systems. The three-phase system made its appearance about this time. The technical differences between this and the direct-current system are considerable, the most important being perhaps that alternating three-phase current is used for the motors in one case and the direct-current in the other, while two wires are used for track at different electrical pressures, in the case of the three-phase system. The system possesses certain features peculiarly fitting it for use upon heavy gradients, and it has been largely adopted for mountain traction, specially in Switzerland and Italy. Well-known examples are the Valtellina Railway, equipped in 1902, and the Giovi Line, 1909, both in Italy, besides numerous smaller lines in Switzerland and the North of Italy. The system had not been much used outside these countries and not at all in Great Britain, although its merits were carefully considered by the Board of Trade in connection with the Underground lines in London. In America the only important instance is the Cascade Tunnel on the Great Northern Railway, United States of America.

The single-phase system with commutating motors using single-phase current, was introduced about 1904-05. Single-phase current was the earliest form of current used for electric lighting, for which it was adopted on a large scale. It has been adopted for electric traction in several important cases, notably in Berlin and in New York, as well as on a section of the London, Brighton and South Coast Railway on the South side of London.

A recent development of the direct-current system has been in the use of higher voltages for the track conductor.

Fundamental difference between Steam and Electric Traction

The fundamental difference between steam and electric traction is that, in the case of steam traction, the fuel necessary to supply the mechanical energy for running the train is consumed on the locomotive, whereas, in the case of electric traction, it is consumed in stationary apparatus at a central power station. In the latter case, owing to the fact that the energy required is developed in large amounts, a much larger and more efficient type of steam and electric generating plant can be used, space not being confined as on a steam

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* No less than fifteen railways in Europe began the conversion of the suburban lines between 1900 and 1905.

locomotive. In the case of electric traction, the energy often has to be transmitted over long lengths of transmission line, transformed in sub-stations and delivered to the trains where it is used by electric motors. In all these processes, losses of energy occur, but in spite of this, the economies which can be introduced in the fuel consumption are usually sufficient to reduce considerably the annual cost of coal and water. In cases where the traffic is sufficiently dense the saving which can thus be made is more than sufficient to pay the capital and operation charges of the power station.

In cases where the energy for electric traction can be obtained from a source which is also used for general supply purposes, a further reduction often results, due to the combined generation and distribution of the electrical energy, in virtue of the economies which can be effected in the amount of plant required, apart altogether from its efficiency.

In Calcutta, the economies which can be effected in coal consumption are not of the usual importance since coal is cheap and hence the financial value of savings in the amount used, correspondingly small. The power station standing charges are, however, normal, and hence while the annual value of the savings is abnormally small (coal being cheap), the standing charges to be paid are as high as usual, and hence in this case the economies which can be effected in coal consumption are not sufficient alone to show a net saving after paying these charges. As will be seen later, however, there are other important economies resulting from the use of electric traction which, even in this case, make its adoption advantageous.

SECTION "B."

Suburban Electrification.

Classes of Electrification.

The electrification of steam railways which has, up to the present, been carried out in different parts of the world, can be divided into four classes :—

(*a*) Suburban electrification.
(*b*) Terminal electrification.
(*c*) Electrification of lines including heavy gradients.
(*d*) Main Line electrification.

This order corresponds approximately with the chronological development of electrification. In this section we consider suburban electrification, and in the next section we deal with the remaining three classes.

Suburban Electrification.

When tramways were electrified and interurban electric lines built, it was found that they seriously diverted the traffic from steam railways operating in the same districts, the travelling public preferring to use the electrified line, even if it were a tramway. The reasons for this were chiefly that, in the case of the tramway, passengers were picked up in the streets and deposited almost at their doorsteps, while the travelling was quick, clean and comfortable. With the exception of picking up the passenger wherever he happened to be, and depositing him near his doorstep, railways could offer, by the adoption of electrification, all the advantages which the tramways and the interurban railways could. To offset the advantage of picking up the passenger in the street, they can offer the traveller a higher speed (owing to their private right of way) and additional comfort, thereby regaining traffic which might have been lost through competing tramways. As we stated on page 1, it was chiefly for these reasons that certain railways adopted electrification. There are, however, several other inducements to electrify suburban lines, apart altogether from questions of recovering any lost traffic, and we will now consider them in detail and how electric traction can bring them about.

Since many of the advantages are due to the use of the *multiple unit system* of train operation, we will consider this system in greater detail than on page 1.

Multiple-unit Trains.

Each multiple-unit train, as the name implies, consists of one or more train-units. Such train-units usually consists of two or three coaches which are coupled together and one of which is equipped with electric motors. This motor equipment provides sufficient power to act as the locomotive of the train-unit to which it is attached. The chief advantages of this arrangement are :—

(1) That the train-unit can be operated with equal facility from either end.
(2) That, where the train is made up of one or more train-units, the motive power provided is always proportionate to the weight of the train which it has to operate.
(3) That high accelerations are possible.
(4) That the weight of the motor coaches and passengers in them is utilised for adhesion, thereby reducing the transportation of dead weight.

If a train-unit consists of three coaches, a train of three, six or nine coaches can be made up from such train-units, while a train of any intermediate number of coaches can be run, provided there is a sufficient proportion of motor coaches. The assembled train can be operated from either end; it also travels equally well in either direction. It is clear that, since the motive power is divided into a number of units, a very much larger number of axles is driven than is the case with a train hauled by a steam locomotive, and consequently a much greater percentage of the total weight of the train is available for adhesion. This is one of the main features which renders feasible the high starting accelerations, the use of which is a characteristic of suburban electric train working.

Advantages of Suburban Electrification.

We now consider the advantages which result from suburban electrification using the multiple-unit system of train operation.

A Regular and More Frequent Service Throughout the Day.—Since each train-unit consisting of, say, three coaches can be operated separately, it is clear that it is possible to run trains consisting of one train-unit only, during slack hours; and consisting of two or three train-units at times of heavy traffic. The cost of electrically operating the lighter trains is small, since under electrical conditions, the cost of electrical energy, of cleaning of coaches, and of repairs and renewals both to coaches and electrical equipments, are directly proportional to the coach mileage. This renders it financially possible to give a regular and frequent service of trains throughout the day, the regularity of the service being maintained even during slack hours by trains consisting of one train-unit only. It has been found that such a service greatly stimulates traffic.

Higher Speeds.—It is economically possible with the multiple-unit system of train operation to give speeds which are much better than existing steam speeds. We may briefly consider the reasons for this, dealing in the first place with the speed characteristics of a suburban service. It is obvious that the lengths of run and duration of stop have a material effect upon the schedule speed which can be obtained, whatever system of traction is used. In the first place, if the run is very short, the train does not have sufficient distance in which to become fully speeded up—notwithstanding the fact that its acceleration may be very high. In the second place, assuming stop of fixed duration, the time spent at rest obviously forms a large proportion of the total time of the journey when the runs are short. With short runs it may be absolutely impossible to adopt a schedule speed which may be quite practicable with runs of, say, double the length. For instance, with runs of about one-fifth of a mile, a schedule speed of over 17½ miles per hour is physically impossible with stops of 20 seconds, while, with the same length of run, if the stop is increased to 40 seconds, the physical limit to speed is 12 miles per hour.* These figures are sufficient to show that the goodness or badness of a given speed for suburban working depends upon the average length of run and the average length of stop involved—a mere statement that the schedule speed of suburban trains is, say, 20 miles an hour, has no definite meaning.

The use of a high acceleration improves greatly the schedule speeds which can be obtained for given lengths of run and of stop, and if, by the use of electric traction, such an acceleration can be obtained at a reasonable cost, both in installing the tractive power to develop it and in operating it, then the schedule speeds for given lengths of run and stop can be materially improved over the steam speeds. We have seen that the multiple unit system of train operation is peculiarly fitted to the development of high accelerations since, upon this system, the whole weight of the train can be utilised for purposes of adhesion if required. It is usually both unnecessary and undesirable to go so far as this. Practical accelerations are limited (apart from the question of providing motive power upon the trains) by the fact that high accelerations impose unpleasant conditions upon the people occupying the train. With very high practical accelerations (say, 2·0 miles per hour per second) not only does the weight and cost of the motor equipment become excessive, but travelling becomes uncomfortable. Sufficient motive power can be provided and adhesion obtained for accelerations up to, say, 1½ miles per hour per second, if the train-unit consists of one motor coach and one trailer coach, the four axles of the

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* It may be of interest to indicate the nature of the physical limitations of schedule speed. The limitation chosen for illustration is adhesion—a factor which would be one of the last to limit speed and yet it will be seen that speeds as limited by it are not high for short runs when stops are also included. In the case of multiple-unit trains the whole of the weight of the train is rendered available for purposes of adhesion, if the trains consist entirely of motor coaches. The maximum acceleration which it is physically possible to develop (irrespective of the insuperable difficulties of providing the necessary tractive power) is say 7 miles per hour per second. Suppose we consider the run to occupy 20 seconds; then in 10 seconds, while the train is accelerating, the speed would reach 70 miles per hour and the distance travelled would be 515 feet. An equal distance would be run in decelerating. Allowing a stop of 20 seconds, the total time of the run would be 40 seconds. The schedule speed would therefore be slightly over 17½ mile per hour. This, of course, leaves out of consideration altogether the insuperable difficulties of providing the tractive power, and the intolerable conditions which the use of such an acceleration as that taken would impose upon the people occupying the train. The illustration is of interest in showing that there are physical limitations to the speed which can be obtained on railways, in spite of high accelerations. The question of the influence of the length of stop can be shown from the above figures. If the stop is increased to 40 seconds instead of 20 seconds, the schedule speed falls to about 12 miles an hour and this is the maximum which it is physically possible to obtain.

Advantages of Suburban Electrification. (*contd.*)

motor coach being each motor driven. The advisability of the use of such a high acceleration depends upon the length of run, length of stop and schedule speed required.

The acceleration of steam trains is much lower than this—it is of the order of 0·3 to 0·5 mile per hour per second with, say, a 6-coach train. Further, the acceleration of the steam train at starting depends upon the weight of the train while, with the multiple-unit system of electric working, the acceleration is independent of the actual number of coaches to the train since the motive power is proportional to the number of coaches.

While there is a wide possibility of improving upon the steam speeds now given by using accelerations ranging from the steam figure of, say, 0·5 to the practical electric figure of, say, 1·5 miles per hour per second, the actual increase of speed adopted must be settled from considerations of economy. With very high accelerations, the cost of the motor equipment becomes high, consequently an acceleration should be adopted for electric working which gives a reasonable and commercial improvement on the steam speeds—the adoption of too high an acceleration not only increases unnecessarily the capital cost of the electrical equipment, but it also increases the operating costs, since the trains are run at a higher speed than is necessary. Just as in the steam case, exceptionally high speeds are costly, since the electrical energy consumption goes up rapidly as the schedule speed is increased, for a given length of run and length of stop. In order to give some idea of the effect of schedule speed upon the energy consumption for given lengths of run, we have prepared the curves given in Figure 1 which shows the energy consumption required at the train for runs of 1 and 2 miles at various schedule speeds. These curves show that the energy consumption rises rapidly as the schedule speed is increased for given lengths of run. It will further be clearly seen that very much higher schedule speeds can be adopted economically for longer runs than for shorter ones. This point is borne out by Table II which shows the schedule speeds and the average distance between stations for various electrified lines.

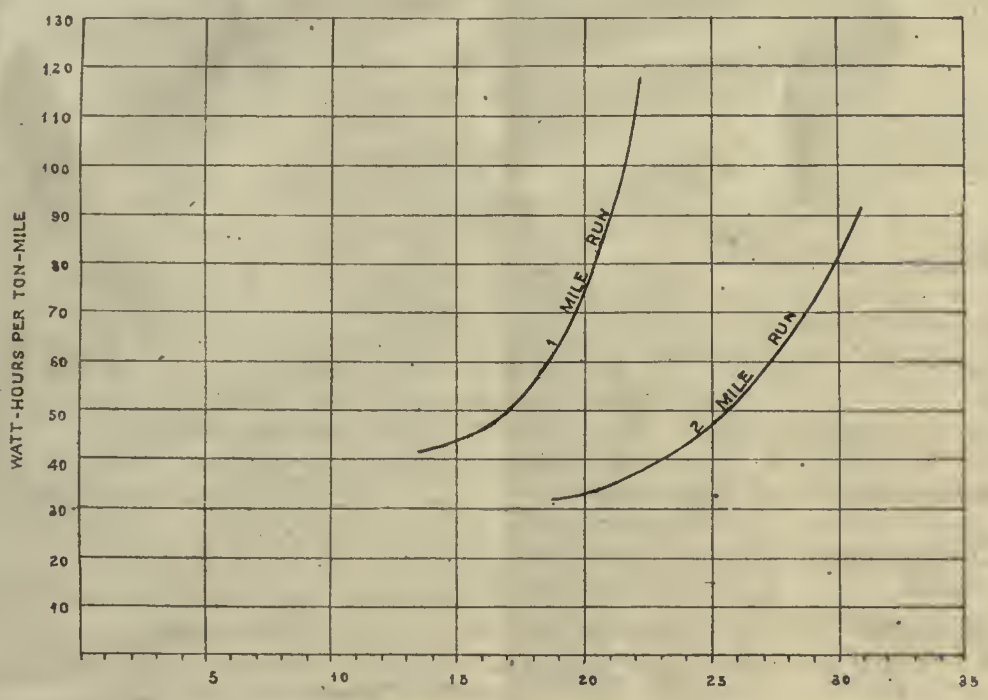


FIG. 1.—CURVE SHEWING RELATION BETWEEN ENERGY CONSUMPTION AND SPEED. FOR MULTIPLE-UNIT TRAINS.

Advantages of Suburban Electrification (contd.)

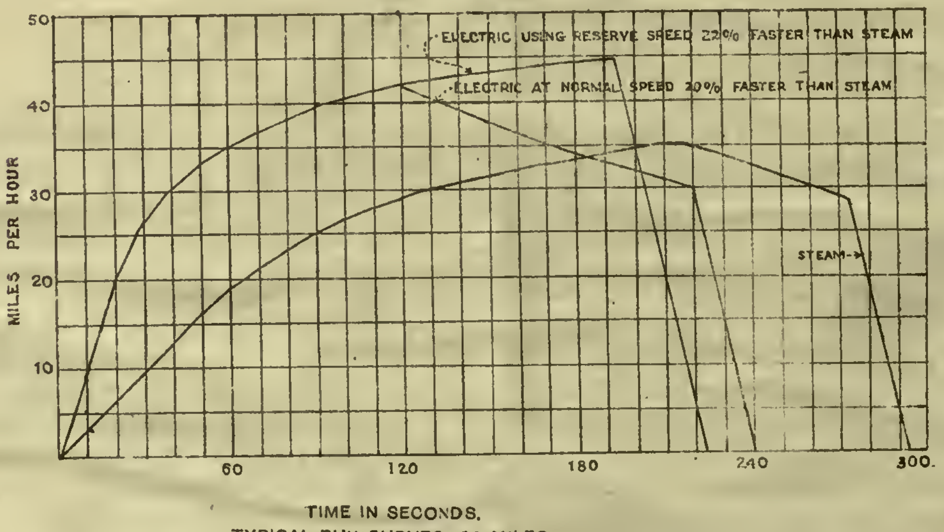
TABLE II.

SCHEDULE SPEEDS AND AVERAGE LENGTHS OF RUN ON VARIOUS ELECTRIC RAILWAYS.

	Schedule Speed.	Average distance between stations.
	Miles per hour	Miles.
Paris Metropolitan	12·4	0·51
New York Elevated	13·0	0·33
Liverpool Overhead	15·3	0·43
New York Subway, stopping trains	15·0	0·43
Charing Cross and Hampstead Tube (London)	17·3	0·47
Metropolition Railway (Inner Circle Trains, London)	15·6	0·48
Central London Railway	15·3	0·52
Metropolitan District (London)	19·8	0·66
Melbourne Suburban Railways (under construction)	21·0	0·83
London, Brighton and South Coast	22·2	1·06
Prussian State Railways, Hamburg-Altona	18·8	1·03
North Eastern Railway (England)	20·2	1·10
New York, New Haven and Hartford	22·8	1·30
Buenos Ayres Western (under construction) stopping trains	24·2	1·30
Lancashire and Yorkshire (Liverpool-Southport)	30·0	1·32
New York Central	25·4	1·38
Central Argentine (under construction) stopping trains	25·2	1·50
Great Indian Peninsula (proposed stopping trains)	23·1	1·55
New York Subway, expresses	25·0	1·61
Bombay, Baroda and Central India Railway (proposed stopping trains)	24·8	1·75
Pennsylvania Railroad (West Jersey and Seashore)	27·0	2·15
Midland Railway (Heysham and Morecambe) England	28·6	3·25
Buenos Ayres Western (under construction) expresses	33·9	5·65
Central Argentine Railway (under construction) expresses	37·5	6·00

The gist of the whole question of choice of speed with stopping trains for comparatively short runs, is that high speeds can only be secured by accelerating rapidly; the higher the acceleration, the more costly is the electrical equipment of the trains; and the higher the maximum speed, the greater is the energy consumption. Very high speeds for short runs are costly both in capital outlay and operating costs. A considerable improvement can, however, be made over the existing steam speeds for any suburban service, and at the same time the cost of the electrical equipment and the energy consumption can be kept within reasonable and commercial limits.

Figure 2 is a typical speed-time curve for an average run of 2·0 miles. The "electric" acceleration is chosen so as to give an economic improvement in the steam speed with which the "electric" speed is compared. The thick line represents steam, and the thin lines electric conditions.



TYPICAL RUN CURVES—20 MILES.

FIG, 2—SPEED CURVES FOR STEAM AND MULTIPLE UNIT TRAINS.

Advantages of Suburban Electrification (*contd.*)

Improved Punctuality of Trains.—In actual operation, where the runs between stops are sufficiently long to allow it, it is usual to take advantage of the high acceleration possible with electric traction, not only to improve the speed but to accomplish as much as possible of each run by coasting. This reduces the energy consumption. By keeping on the power instead of coasting the distance can be covered in less time when it is necessary to make up for delays thereby improving the punctuality of the trains.

Increased Capacity of Terminal Stations.—The increase in capacity of terminal stations, which is brought about by electrification, is due to the fact that trains can enter and leave the station at a higher speed and—with the multiple-unit system—no shunting is required. Multiple-unit trains are operated equally well from either end. The driver merely walks out of his driving compartment at one end of the train and enters the driving compartment at the other—taking the train out exactly as if, under steam conditions, a locomotive were at his end of it, he changing ends rather than the locomotive. This alone eliminates about one half of the signal, point and train movements and effects a very considerable increase in the capacity of a given amount of platform accommodation.

More Economical Employment of Train Crews.—Train crews can be more economically employed, due partly to the higher speed, by which each crew can perform a higher train mileage daily and partly to the absence of locomotives. When the multiple-unit train reaches its terminus, all that needs to be done is for the carriages to be opened up for ventilation for a few minutes, and the motor man to go to the other end of the train. The ordinary working "lie-over" can, therefore, be considerably reduced. As a matter of interest, upon the Metropolitan District Railway of London, at their Richmond and other western termini, the trains merely run in, empty, refill, and run out again on the return journey, the "lie-over" in many cases not being more than three or four minutes. Of course, at certain times of the day, and after a certain number of runs, a somewhat longer "lie-over" is necessary, but a considerable saving in crew's time can be effected, largely owing to the flexibility of the multiple-unit trains system, apart altogether from the higher speed.

Increase in Earning Capacity of the Line.—The increase in the earning capacity of the lines is due to the higher speeds and the ability of the electric train to run to schedule time. The headway between trains can, therefore, be reduced, and this, in conjunction with the improvement of speed, greatly increases the train mileage which can be run upon a given track.

Development of Residential Areas.—The development of residential areas is facilitated, since a regular service of light trains can be run cheaply at good speeds, and a passenger traffic to and from an attractive residential district can thus be fostered.

Reduced Cost of Repairs and Renewals per Train-mile.—A saving is effected in the cost of repairs and renewals per train-mile, with multiple-unit operation, because—

(*a*) Less rolling stock is required to run a given mileage, owing to the higher speed, and therefore the amount of rolling stock which has to be repaired and renewed per train-mile is less.

(*b*) The ratio of coach mileage to train mileage can be considerably reduced with the multiple-unit system owing to the ease with which the length of train can be varied to suit the requirements at different times of day. Useless movement of rolling stock is thus reduced.

(*c*) The cost of repairing the electrical equipment on a given train is considerably less than the cost of repairs and renewals upon the locomotive which would operate the same train under steam. This is due to the simplicity of the electric motor, which corresponds to the engine on the steam locomotive. The repairs to steam generating plant such as boilers, fire-boxes, etc., on the steam locomotives are absent in the electrical case, since these pieces of apparatus are all at the power station, and there the repairs and renewals are obviously less than for plant operating

Advantages of Suburban Electrification (contd.

upon the road, while the costs for these are included in the price paid for electrical energy.

Reduction in Working Costs per Train-mile.—The nett result of the economies is, that the working costs per train-mile under electrical conditions are usually less than the costs for steam operation, in spite of the higher speeds.

Increased Revenue due to Increased Train Mileage.—Since electric traction is an inherently cheaper method of operation, the Traffic Department is justified in running the more frequent and regular service of trains to which we have referred, to attract traffic. This higher train mileage reaps an increased revenue, which is due solely to suburban electrification.

SECTION "C."

Terminal, Heavy Gradient, and Main Line Electrification.

Terminal, Heavy Gradient, and Main Line Electrification.

We shall now consider the three remaining classes of electrification mentioned upon page 5. We have dealt, up to the present, with the question of suburban electrification and it will be remembered that we commenced the discussion by describing a special system of train working—the multiple-unit system—which enables the fullest advantage to be taken of the possibilities of electric traction for such working.

In the case of terminal, heavy gradient and main line electrification, the type of traffic which must be catered for is of a different character. For instance, the working of heavy goods trains has now to be taken into consideration. While the characteristics of a suburban passenger service are a very frequent service of light trains at speeds requiring high accelerations, the characteristic of those traffics which we are about to discuss is a comparatively infrequent service of very heavy trains at speeds which, from the nature of the case, do not require high accelerations. It is a far simpler matter, whatever system of traction is considered, to develop a schedule speed of 60 miles an hour on a 20-mile run than it is to develop a schedule speed of 20 miles an hour on a run of half-a-mile. In the case of a 20-mile run, if the average speed is to be 60 miles an hour the run will, of course, take 20 minutes.* If the acceleration is chosen so that the train attains its full speed in two minutes, the acceleration is, of course, half-a-mile per hour per second. If this were done, the train would be accelerating for one-tenth of the total time. If we were to allow two minutes for breaking at the same retardation, the train would be running at full speed for 16 out of the 20 minutes. In order to perform the run at 60 miles an hour, the maximum speed required for the 16 minutes would be about 67½ miles per hour.

Contrast this with figure 2, page 8, where a speed-time curve for an average suburban run of two miles is given. It will be seen from the figure that an acceleration of 1·0 mile per hour per second is adopted and that the train is accelerating for about 50 per cent. of the total time of the run. Further, even with this acceleration, the multiple-unit train does not have sufficient time in which to attain the maximum speed of which it is capable—the speed is rising even at the instant the current is cut off.

It will be readily understood, therefore, that for traffics other than suburban passenger traffic—

(1) High accelerations are not required, since the train is, in any case, only accelerating for a small proportion of the time that it is in motion.

(2) For the bulk of its time the train is running at full speed, which is only slightly above the average speed of the trains.

Another important point is that, since such trains are heavy, there is not the same objection to carrying about a few tons of dead weight on a locomotive, since the extra weight forms only a small proportion of the total weight of the train, and, since the runs are long, the cost of accelerating and decelerating the weight is not so important. For the same reason there is not the same necessity for avoiding the cost of shunting by a special locomotive, for the expenditure of even a quarter-of-an-hour or so at terminal stations at the end of long journeys, is not a matter of very great importance, except at very busy termini. There is consequently not the same advantage in equipping the trains so that they can be operated from either end, as is the case with suburban trains; in the case of long distance trains, very little would be gained if this were done. It is clear that the conditions which have to be met, are quite different from those of a suburban passenger service, and that the arguments which justify the adoption of the multiple-unit system for the latter are not so paramount for long distance traffic—for infrequent long distance traffic of every description, locomotives are as suitable on most lines as a multiple-unit system would be.

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* Omitting the stop.

Steam Locomotives.

Most of the advantages which electric traction possesses for ordinary passenger and goods traffic, are to be found in the superiority of the electric locomotive as a train hauling appliance. We shall first consider the demands which are being made upon the modern steam locomotive and the manner in which they are being met. As we pointed out on page 3, it is possible that the fact that some of the large railways are approaching the limits of their existing capacity, has been largely instrumental in engaging the attention of the railway authorities to the possibility of electric traction for general haulage purposes.

In recent years, railway companies have been called upon to deal with traffics which are increasing at a high annual rate. The frequency of the trains has, in many cases, been so increased that it is impossible to add materially to the number of trains which are run per hour upon the existing tracks, having in view the high speeds of main line working and the headways which must necessarily be left between trains for purposes of safety. It follows that the tendency is, for the weights of trains to increase very materially, and at the same time the desire has been for higher speeds, in order to increase as much as possible the frequency of trains.

The present problem is to provide a sufficiently powerful train hauling appliance. If such an appliance can be used (whereby the heavier trains can be operated at the higher speeds required) the capacity of the existing tracks is materially increased and quadruplication is postponed. The capacity for which the steam locomotive can be built, is limited by the loading gauge, and the problem before steam locomotive engineers, is that of increasing the capacity of a steam locomotive in spite of the loading gauge restrictions to which it is subjected. To meet these requirements a large number of improvements have been introduced in steam locomotives. The chief of these are the introduction of superheating, the application of brick arches to the fire-boxes, feed water heating appliances, the use of oil fuel, etc. At the same time, the dimnensions of the boiler and the steam pressure have been increased as much as possible. By these improvements, the efficiency of the steam locomotive has been materially improved, its power and the run capacity increased, while with the use of oil fuel, the smoke nuisance * has been eliminated to a large extent. In spite of these decided improvements the steam locomotive is steadily losing ground with regard to the demands which are being made upon it. If steam traction is retained, the alternatives for the railway authorities whose lines are becoming congested, is quadruplication or increase of the loading gauge. Either of these is, of course, an extremely costly proceeding. This is perhaps the main reason (apart from that of direct financial gain in the shape of lower locomotive costs) that railway authorities are becoming interested in the question of the possibilities of electric locomotives which we now consider.

Electric Locomotives.

In many cases, the economies which can be made by the introduction of electric traction are sufficient to justify it *for itself,* apart altogether from the question of the quadruplication which its use postpones indefinitely. The problem is, of course, one which is influenced in each particular case by the local conditions; but we shall point out some of the ways in which electric locomotives are more economical than steam, and at the same time can relieve congestion.

The Capacity of Electric Locomotives.—The power of the electric locomotive to relieve congestion is due to the fact that it is possible to build a much more powerful locomotive within the loading gauge than is the case with steam. The power which can be placed upon an electric locomotive is, in fact, unlimited by the loading gauge restriction, since electric motors only are placed upon it and it possesses no parts corresponding to the steam boiler on a steam locomotive. It is, of course, well known that the special limitation of the steam locomotive is the size of its boiler. This restriction obviously disappears in the case of the electric locomotive. Apart altogether from this an electric locomotive of a given continuous capacity can develop a greatly

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* The nuisance caused by steam vapour and noise from exhaust and blow-off valves has not been reduced, but rather be reverse.

increased power for short periods of time. For instance, if the continuous capacity of a locomotive were 1,000 H. P., it would be quite practicable to develop with it 3,000 H. P. for short periods of time. This is impossible with the steam locomotive

Higher Speeds and Higher Accelerations.—The possibility of developing large amounts of power for short periods of time, taken in conjunction with the higher capacity for which electric locomotives can be built, enables them to operate the heavier trains with which it is now necessary to deal, at higher accelerations and higher speeds than steam locomotives can. This results in a marked speeding up of train handling, just as in the case of suburban working, and consequently relieves congestion. The electric locomotive can easily be built sufficiently powerful to maintain a high speed with the heaviest trains. For instance, as already mentioned, the electric locomotives used on the New York Central Railroad are capable of hauling a 1,000-ton passenger trailing load at 60 miles an hour continuously. The higher acceleration possible with electric locomotives is a point of considerable importance in the case of terminal and shunting yard electrification, since in these cases it is "acceleration" which is important. Electric locomotives can give these higher accelerations and speeds with very heavy trailing loads simply because they can be built of much greater capacity, and can develop for short periods of time very much greater powers than the normal.

Improved Punctuality.—For the same reasons, punctuality tends to be improved. This is, of course, important to the general travelling public and is also of importance at termini, since it shortens the time that each passenger is waiting about on the platforms and therefore passenger congestion on platforms and assembly halls at busy periods is lessened.

Heavy Gradient Working.—The high capacity for which electric locomotives can be designed, is a feature of particular importance in the case of heavy gradient working. In the haulage of trains, tractive effort is required for three purposes :—

(*a*) For the production of the required acceleration at starting.

(*b*) For overcoming the resistance due to windage, bearing friction, track resistance, and so on.

(*c*) For overcoming the opposing force of gravity, which comes into action if the train is ascending any gradient.

For operation on the level or light gradients, by far the greatest proportion of the maximum tractive effort which is exerted by the locomotive is that required for producing the acceleration of the train. When the train has been accelerated, the tractive effort required to overcome the train resistance and to maintain a given speed, is very small compared with the tractive effort at the time of accelerating. Operation upon a heavy gradient is quite different. The opposing force of gravity comes powerfully into action. The tractive effort required to overcome the force of gravity is constant on a given gradient. The heavy gradient, therefore, constitutes an additional constant demand for a large tractive effort from the locomotive.

Since *horse-power* is proportional to the product of speed by tractive effort, it follows that the maintenance of *this* tractive effort constitutes a demand for horse-power which is directly proportional to the speed of the train. To take an example, a train weighing 500 tons when on a gradient of 1 : 30 requires a constant tractive effort to be applied to it merely to overcome gravity, of about 37,400 lbs. At a speed of ten miles per hour, the horse-power corresponding to this is 1,000 H. P. while at 15 miles per hour it would be 1,500 H. P. The locomotive is called upon to develop this horse-power continuously *in addition* to the horse-power which it would have to develop to haul the same train at the same speed upon the level. Any system of traction which can provide very powerful propelling machines is obviously peculiarly fitted for such duty—electric traction is such a system. Electric traction also possesses other marked advantages for heavy gradient working which are of equal or greater importance (see pages 14 and 15).

Economies—Coal and Water.—We have pointed out that the problem with which steam locomotive engineers are faced, is that of designing sufficiently

Electric Locomotives (*contd.*)

powerful steam locomotives within the limits of the loading gauge. In order to economise space they are precluded from adopting the more efficient means of steam raising and power generation. In the first place, the grate area which can be used is comparatively small and in order to burn the large amount of coal per hour which is required to maintain full steam pressure in the boiler a very powerful forced draught must be adopted. This has the well-known tendency to carry out through the locomotive uptake, a large quantity of half-burned coal and cinders. The amount of coal which is lost in this way alone is considerable, amounting to something like 12 per cent. of the total amount of coal used when the steam locomotive is developing its full amount of power. Another important feature, tending towards economy, but which cannot be adopted on the steam locomotive, is the condenser—in fact, its thermal efficiency still remains very low.*

A very important point affecting the coal economy of the steam locomotive is that of stand-by coal losses. The fires have to be lighted up, periodically cleaned and, of course, banked so as to maintain the boiler steam pressure all the time that the locomotive is standing about doing nothing. An exhaustive investigation was recently made by the United States Government into this question of the stand-by losses of steam locomotives and it was ascertained that, in the United States, something of the order of 20 per cent. of the total coal used per annum by locomotives in the United States is wasted in stand-by losses. These stand-by losses are practically entirely eliminated in the case of electric locomotives, owing to the fact that the electric locomotive consumes power only when it is actually performing useful work.

Including stand-by coal, the thermal efficiency of a modern steam locomotive probably lies between 3 per cent. and 5 per cent. If we contrast this with the thermal efficiency of a modern power station, the reasons for the savings which can be effected in the amounts of coal and water used are apparent. The thermal efficiency of a modern power station of large size and good design should be 16 per cent. or even more, the exact figures depending on the size and the load factor. This figure must not be compared directly with the 4 per cent. of the steam locomotive, since there are losses in delivering the electrical energy from the power station to the wheels of trains. It is impossible to state generally what these losses amount to, since they must be calculated for every particular system of power production and transmission, but if we assume a low figure of, say, 50 per cent. efficiency between the wheels of the trains and the power station, the efficiency to be compared with the 4 per cent, in the case of the steam locomotive is about 8 per cent.—a saving of 50 per cent. apart from the fact that much cheaper coal can be burned. Of course, a considerable amount of capital has to be spent on such a power station. Where coal is costly the saving in coal and water is usually sufficient to pay all the capital and other charges of the power station and yet show a nett saving. In some cases it may be possible to utilise a hydro-electric supply, in which case there may be a further saving.

Economies—Regeneration and Braking on Heavy Gradients.—On page 13 we showed that electric traction is peculiarly fitted to deal with heavy gradient working on account of the high power for which electric locomotives can be built. There are several other advantages in the use of electric locomotives for such work, an important one being what is known as "regenerative control." The electric motor is a reversible machine, that is to say, if it is supplied with electrical energy it will develop mechanical energy; conversely, if it is supplied with mechanical energy it will develop electrical energy. In ascending a gradient a train stores energy which it dissipates when descending. In the case of steam haulage, this energy is dissipated in the form of heat by the wasteful process of braking the train, which also results in greater wear of brake blocks

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* Even with all the latest improvements and economies the coal consumption per I. H. P. hour of a steam locomotive cannot be reduced below 3·0 lbs. When running at full power and with good coal having a calorific value of, say, 14,000 B. Th. U. If we take the mechanical efficiency of the engine to be 85%, then the coal required for 1 horse-power-hour at the draw-bar is 3·5 lbs. One horse-power-hour equals 2.545 B. Th. U. and 3·5 lbs. of coal @ 14,000 B. Th. U. per lb. are equivalent to 49,000 B. Th. U. *i.e.*, the thermal efficiency of the locomotive $= \frac{2,545 \times 100}{49,000} = 5{\cdot}2\%$ about. This does not include any stand-by coal—it represents approximately the best the steam engine can be expected to do at present.

Electric Locomotives (*contd.*)

and wheel tyres. With the electric locomotive, on the other hand, owing to the reversible property of the motor, a considerable proportion of this energy can be converted into electrical energy and returned to the track conductor and used elsewhere. In this way the train is automatically braked, but by electrical instead of mechanical means. Hence, there is a reduction in the nett amount of electrical energy required (and therefore, in the equivalent cost of coal and water) and also a saving in brake blocks and tyres.

Economies—Enginemen's Wages.—The process of preparing a steam locomotive for duty involves a considerable expenditure of time and labour and, in addition to cleaning, lubrication and overhauling at very frequent intervals, the fire-boxes have to be raked out, fire-bars renewed, fires relit, the smoke boxes and tubes cleaned, and the boilers blown down and cleaned periodically. In contrast with this, the electric locomotive is always ready to take the road without preparation, the little attention required being almost entirely done by the crew itself while in charge of the engine. Visits to the running shed are practically only required by electric locomotives for the purpose of cleaning and inspection of brake blocks and the less accessible parts underneath the engine. The motors, if they are kept clean and receive a small amount of attention, are always ready for immediate use.

In the case of the steam locomotive, it is necessary to attend to the fire and the boiler gauge glasses, as well as to give the required attention to the numerous moving parts such as piston rods, connecting rods, crossheads, journals, valve-gear, and so on. The fire alone involves shovelling on to the fire anything up to 1½ tons of coal per hour, which keeps the fireman very fully occupied in the performance of this duty alone. In the case of the electric locomotive, conditions are entirely different. The driver has merely to operate a handle, one or two switches, the air brake valve and the whistle. He is thus in a position to give more attention to looking out and to signals, and the second man on the locomotive is hardly necessary.

If two men are still employed, a reduction in the wages per crew should be justified, but even if no reduction is assumed either in men per locomotive or wages per man, there is still a reduction in the cost of wages per train-mile due to the saving of the crew's time. There is always, of course, a considerable difference between the time during which a locomotive is engaged in actually hauling a train and the time during which the crew is in charge of the engine. This is partly due to the fact that a considerable allowance of time is made to the crew for the purposes of engine preparation and partly because engines are necessarily kept waiting under steam, often for very considerable intervals between one trip and next, and are, of course, at all such times, in charge of the crew. When an electric locomotive is waiting between trips, it is not necessarily in charge of the crew—it may be locked and left in a safe place. There is also no doubt that the intervals between trips and the amount of waiting about with engines would be reduced, more particularly since the whole range of engine duty can be performed with far fewer types of locomotive.

Economies—Running Shed Expenses.—With engine preparation largely reduced and performed almost entirely by the crew during running and ordinary station stops, the remaining shed expenses are confined to—

(*a*) Cleaning, which involves only a fraction of the labour incidental to the cleaning of a steam locomotive.

(*b*) Adjustment and renewals of brakes.

(*c*) Provision of lubricant, and renewal of brushes.

These can be performed at periodical infrequent intervals and very low cost and therefore there is a marked reduction in the comparative running shed expenses.

Economies—Repairs and Renewals.—A considerable reduction is effected in these items. A consideration of the amount of repairs and renewals required upon electric and steam locomotives readily explains it. The repairs required upon an electric locomotive are :—

(1) Repairs to wheels, tyres, frame, brake-gear, axle-boxes, journals, etc. These have analogous parts on the steam locomotives, but neither the tyres of the driving wheels, nor the frames of the electric

locomotives are subject to the same amount of wear and tear as the corresponding parts of steam locomotives, because—

(*a*) Connecting rods, if present, can be balanced, whereas on steam locomotives, the reciprocating parts are always, to some extent, unbalanced.

(*b*) The turning moment is uniform throughout the revolution.

(*c*) The wheels of electric locomotives are unable to slip violently since slipping of the wheels automatically reduces the force producing the slipping.

(*d*) It is an established fact that the tyres of an electric locomotive run much further before being re-turned than those on steam locomotives and that the frames are less subject to racking stresses.

(2) Repairs to the house, *i.e.*, the sides and roof of the locomotive, which requires periodically repainting and occasional minor repairs.

(3) Repairs to the electrical equipment, which consists of motors, controllers, switches, collectors, etc.

It is clear from these remarks, that large savings are to be expected in the case of the electric locomotive since :—

(1) For the reasons above given, the repairs to the frame and mechanical parts are much less per locomotive than is the case with the corresponding items in the steam locomotive.

(2) The cost of repairs to the cab is considerably less than the cost of repairing the steam engine tender, while

(3) The cost of maintaining the electrical equipment is far less than that of maintaining the boilers, cylinders, valve-gear and other parts of a steam locomotive.

(4) The electric locomotive depreciates only when it is actually running. The boiler and furnace whose renewal is the most costly item in steam locomotive maintenance are depreciating all the time that fires are lighted. Except for smaller parts, like bearings and gearing, the average life of the component parts of the electric locomotive is considerably longer than the corresponding parts in a steam locomotive.

Double Heading.—It is generally recognised that there are distinct objections to double heading in the case of steam locomotives. In the first place, each of the locomotives is independently controlled by its crew. It is therefore difficult to ensure complete unison of action between the two crews. Secondly, the rear locomotive receives the dust, cinders and smoke which have been raised by the first locomotive. These conditions give rise to increased cost for running shed expenses and repairs and renewals on the second locomotive, and, in addition, bring about unpleasant conditions for the rear crew. In the case of the electric locomotive, there is no objection whatever to double heading, from the point of view of engine operation. In the first place, the locomotives can be electrically coupled together and operated by one crew situated in the front locomotive, just as if the two locomotives were one. Absolute unison of action is thus assured. In the second place, there are no smoke, cinders, etc., and consequently the conditions under which the second locomotive operates are much improved. With electric locomotives, the practical limit to double heading is simply the allowable drawbar pull of the vehicles, if the locomotive pulls the train, but in the case of heavy gradients, if the locomotives are arranged to push the train, the drawbar limitation ceases to apply.

The conclusion is that both in capacity and efficiency, the electric is superior to the steam locomotive.

SECTION "D."

Incidental Advantages of Electrification and Summary.

Advantages incidental to Electrification.

Electric traction introduces several important advantages which, while not concerned with the actual haulage of trains, are nevertheless important.

Cheap Supply of Power for Other Purposes.—A cheap supply of power for general purposes becomes available, due solely to the fact that where a large demand for electrical energy exists, energy can be generated at a cheaper rate per unit. Consequently, the existence of the *large demand for traction purposes* enables electrical energy to be obtained for general purposes at a much lower cost per unit, than would otherwise be the case. The use of electricity in locomotive workshops, carriage repair sheds, for pumping, lighting and sundry other auxiliary purposes, possesses distinct advantages where electricity can be obtained at a cheap rate.

Risk of Fire.—The elimination of fire risk is, in every case, important, while its definite financial value is difficult to assess. It is of special importance in connection with shunting yards, where large quantities of inflammable material are frequently handled.

Absence of Smoke, Steam, Dust and Noise.—These are matters of importance, particularly in terminal stations and tunnels. The presence of a large number of steam locomotives renders terminal stations very smoky and noisy, and both these conditions take place in large cities, where it is highly desirable to reduce as much as possible both smoke and noise. Further, from the point of view of the actual safety of the public—apart altogether from consideration of comfort—the absence of smoke and steam is an important point. Several railway disasters, which involved loss of life, have been partly caused by the obscuring of signals at the mouths of tunnels.

Lighting of Carriages and Stations.—This becomes a simple matter where electric traction is in use. In the case of the trains, it is unnecessary for them to carry any special apparatus about with them – the current required can be obtained from the power circuits.

Summary.

In order to summarise the matters which have been discussed in this part of the Report, we have prepared Table III where the different points which have been fully discussed in the preceding pages are summarised.

TABLE III.

Some Possibilities of Electric traction for various classes of Traffic.

Traffic.	Fundamental conditions.	How electric traction is applied.	Improvements due to use of electricity.
Suburban passenger.	Frequent fast service of light trains to be given.	Multiple-unit trains	1. Frequent and regular service ⎫ can be economical- 2. Higher speeds . . . ⎭ ly given. 3. Improved punctuality due to ability of multiple-unit trains to make up time. 4. Capacity of terminal stations increased. 5. Train crews more economically employed. 6. Earning capacity of line increased. 7. Residential areas can be economically developed. 8. Working costs per train-mile can usually be reduced in spite of higher speed and better service given. 9. Better service can be economically run to attract traffic.
Terminal and shunting yards.	Heavy long distance trains to be worked rapidly in and out of termini, and conditions generally to be improved.	Electric locomotives	1. More margin in locomotive power can be provided due to overload capacity of the electric motor, hence heavy trains can be accelerated much more quickly and so taken in and out of the terminus more rapidly. 2. Punctuality of arrivals is improved, as trains can be speeded up when in the terminal zones. 3. Smoke nuisance, fire risk (important for shunting yards), and obscuring of signals by smoke eliminated.

TABLE III—*concld.*

Some Possibilities of Electric traction for various classes of Traffic—concld.

Traffic.	Fundamental conditions.	How electric traction is applied.	Improvements due to use of electricity.
Terminal and shunting yards (*concld.*)	Heavy long distance trains etc.—*concld*	Electric locomotives —*concld.*	4. Noise reduced. 5. Approach flying junctions can be more freely adopted, as electric locomotives can control heavy trains readily on heavy gradients. 6. Large stand-by coal losses are avoided. 7. A great reduction in the cost of repairs and renewals of locomotives is effected. 8. A large saving can be made by economy of crew's time, absence of lighting-up wages, and heavy running shed charges.
Heavy gradient lines.	Heavy trains to be worked on steep gradients where, from the nature of the case, tunnels are frequent.	Electric locomotives	1. Smoke and ventilation troubles are eliminated. 2. Good speeds can be given even on very heavy gradients. 3. Very heavy trains can be readily handled. 4. More margin in locomotive power can be provided because of the overload capacity of the electric motor. 5. Fewer types of locomotives are required—frequently one type only is sufficient. 6. Double heading can be freely employed with electric locomotives, one locomotive crew only being employed. 7. Large savings in coal can be effected since— (*a*) Stand-by coal losses are practically eliminated. (*b*) Regeneration can be adopted by which descending trains help to pull ascending ones up. 8. A great reduction in cost of repairs and renewals is effected since, in addition to usual reductions, wear of brake blocks and wheel tyres is avoided by regeneration. 9. A large saving can be made by economy of crew's time, absence of lighting-up wages, and heavy running shed charges. 10. Rail wear is reduced.
Main lines.	Heavy trains to be hauled at high speeds.	Electric locomotives	1. Congestion can be relieved by using larger trains, which can be handled at high speeds. 2. Speeds can be readily increased where required. 3. More margin in locomotive power can be provided because of the overload capacity of the electric motor. 4. Fewer types of locomotives are required—frequently one type only is sufficient. 5. Double heading can be freely employed with electric locomotives, one locomotive crew only being employed. 6. Large stand-by coal losses avoided. 7. A great reduction in the cost of repairs and renewals of locomotives is effected. 8. A large saving can be made by economy of crew's time, absence of lighting-up wages, and heavy running shed charges. 9. Rail wear is reduced.

Second Paper

Possibilities of Steam Railway Electrification

By

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Electricity now performs every railroad service previously rendered exclusively by steam locomotives, and in every case does it better than it was done before. But in order to use electricity a large investment in equipment and installation must be made, and electrification has proceeded slowly because railroad executives were not convinced that the advantages to be gained are always worth the cost.

The progress of electrification has also been impeded, first, before the war by the difficulty in financing, due to conditions other than the merits of electrification; and second, since the war began, because every one has been too busy to consider any work that could be deferred and because the Government's taking over the railroads has created an unsettled situation not conducive to the investment of new capital for future returns. Now, however, there seems to be ground for hoping that these bars to progress will be removed in the not distant future so that electrification can be again studied on its merits, therefore our consideration of the subject is timely.

The Electrical Man versus *the Railroad Man.*

In reviewing the past 20 years' history of this question, I cannot escape the conclusion that we electrical men, and not our steam road colleagues, are responsible for the slow progress made. We have not known enough about either the science or the art of railroading. Our belief in, and our zeal for, our own profession has led us, albeit with entire honesty of purpose, to make more or less extravagant claims as to what we could do and to underestimate the cost of doing it. The inevitable reaction of mind which followed an accurate determination of facts, of course, disturbed confidence in our judgment. But if at times we have injured the cause of electrification by claiming too much, strange as it may sound, we have injured it a great deal more by not claiming enough. Electrical engineers not having always been railroad men, have been unable to study railroad problems as they should have been studied, that is to say, with only real and not with any arbitrary limitations before them. It has been natural for the electrical man to ask the railroad man for a statement of the conditions he was expected to meet. It was equally natural for the railroad man to prescribe the conditions upon which his steam service was predicted. Under these circumstances the problem became largely one of replacing one sort of locomotive with another, and of balancing hoped for economies in operation and maintenance on the one hand, against fixed charges for the additional investment required on the other. Right, there comes the mistake. A perfectly natural but yet a fundamental mistake, for which no individual or class should be censured but for which the unusual development of the art is responsible. We cannot blame railroad men for not being electrical engineers nor electrical engineers because they are not railroad men, but the progress of electrification has to lag until both should be able to see, each with the eyes of both. It is only by combining the railroad man's knowledge of the fundamental requirements of his service with the electrical man's skill in applying electricity to perform that service that all the possibilities of any specific problem may be developed.

No More Ruling Gradients.

The electrification of a railroad is not simply the substitution of one kind of locomotive for another. It is far more than that. It is the adoption of a fundamentally different method of train propulsion. It is conservative to say that, within the bounds of ordinary practice, electricity can furnish every train with all the pulling power that can be used. The limitations of the steam locomotive in this respect disappear and ruling grades rule no longer. A strictly limited locomotive power is replaced by one that is practically unlimited.

There are a number of so-called "systems" of electric traction, and heavy emphasis has been laid by the advocates of each upon its points of difference from every other. So much has been said about these differences and so little about the points of similarity as to create an entirely misleading impression. There are many more kinds and types of steam locomotives in use than there are electric systems. It is a fact that except for the storage battery locomotive, which has but a limited field of application, all electric systems have many more common features than differences. It is a fact that they agree on fundamentals and differ in detail only. Their costs may not be the same, their efficiencies may vary, but they all do their work, and do it successfully and well. The possibility of unlimited electric power is a characteristic not of any one system but of all. It is due to basic differences between steam and electric equipment. A steam locomotive is a complete independent unit which not only generates but also utilises its power. The electric locomotive generates no power at all. It is only a translating device receiving energy from an outside and a remote source. The electric power house always having much greater capacity than any one locomotive, can supply ample power for the heaviest train on the steepest grade. The steam locomotive, which carries its own power house with it, is limited to the capacity of its one boiler. By the multiple unit principle, as many electric locomotives as may be needed can be coupled together and operated in synchronism by one crew from any cab. Any required tractive effort can thus be exerted without slipping the wheels, without imposing undue strains on the rails or bridges, and without increasing the number of engine crews.

Freight Traffic Operation.

The business of a railroad is to transport freight and passengers. I put freight first because on the average it produces 73 per cent. of the revenue. Unlimited motive power permits longer trains and higher schedule speeds. On the Elkhorn grade of the Norfolk and Western the schedule speed was doubled. It cuts the operating cost by hauling more cars with the same or a smaller crew. The Norfolk and Western uses two electrics to do the work of three Mallets. These new opportunities at one fell swoop banish many of the railroad's time-honoured traditions. The traffic possibilities must be studied from a new angle and advantage taken of every facility. It is a new thought to realise that train length is limited not by motive power but by the yard tracks and length of sidings, or that all the trailing tonnage that the draw bars will stand can be hauled. Nor are these new limits fundamental. Sidings can be extended, draw bars can be made stronger, if it pays to do it. In a word electrification opens up tremendous possibilities of increasing the great capacity of a road and without it being necessary to build additional tracks.

Passenger Train Services.

While not as important as freight, passenger traffic likewise comes in for its share in the widened horizon and the vanishing tradition. Unlimited power, of course, is available, but the absence of combustion is another basic advantage. Smoke and cinders disappear. Tunnel operation loses its terrors. Unobscured signals permit normal speeds with undiminished safety. Projects like the Pennsylvania terminal in New York, depending entirely on submarine tunnel operation and previously impracticable, become immediately possible. Rail-roads owning valuable land in cities can erect buildings thereon, where before smoky locomotives made any structure above the ground level impracticable. The ærial rights are now valuable. Multiple unit operation has, in fact, made suburban traffic. The rapid acceleration made possible by electric traction has directed attention to the equal value of rapid retardation and quickened the study of braking accordingly; also of modified coach design to bring about the more efficient loading and discharge of passengers. These combined possibilities secure increased schedule speeds and attract passengers. The people not only get over the line in a short time, but as a corollary more people get over it in the same time. Again, it is seen, therefore, that in passenger, as in freight traffic, the ability to do something that could not be done before, rather than to do the same thing at a lower cost is the most valuable attribute of electrification, and again we find a greatly augmented capacity without the need of additional tracks.

It is not my purpose to make an exhaustive comparison of the relative advantages of steam and electric operation. That has been done often and well by others. What I have said about the expanding opportunities for electrified service is by way of illustration to emphasise my plea that the question should always be viewed in its broader aspect and not hampered and restricted within any narrower limitations that properly belong to it.

Possibilities of Future Electrification.

I am going to assume, then, the broadest possible treatment, and to suppose that every electrification project is to have its pros and cons most fully examined. The real and vital question then is, "How far will this lead us?" "To what extent may we expect complete electrification of all our roads?" Parts of a number of them have already been equipped. Many of these are numbered among our prominent roads, successful corporations which have had the advice of the most highly skilled executive and engineers, and which are progressive. The service performed on the electrified sections comprised practically every kind of railroad transportation. The Bluefield division of the Norfolk and Western Railroad in West Virginia is an example of an important coal road opening through the mountains. The Chicago, Milwaukee and St. Paul 440-mile main line, through Idaho and Montana, demonstrates what can be done by a trans-continental carrier on a large scale with through traffic, both freight and passenger. The New York, New Haven and Hatford Railroad 73-mile stretch between New York and New Haven shows how through freight and a heavy passenger traffic can be taken care of on the most congested four-track section of an important eastern carrier and what is possible for complicated freight yard operation, while the New York Central and the Pennsylvania out of New York city are splendid examples of our greatest modern passenger terminal electrifications. There are, of course, many other electrifications, but even if there were not, those named are of a character to command the respect and attention of the railroad world. Now, every one of these projects have been successful. Every one has justified itself. Nearly every one in its present scope represents an extension of the zone initially electrified, the most convincing evidence possible as to what views the operating companies hold regarding these several projects. Railroad officials are generally glad to give others the benefit of their experience, so it is reasonably safe to say that operating statistics are available covering long enough periods so that the results to be expected from any proposed undertakings may be predicted on established facts and not upon theories.

All Railways will not be Electrified.

In the light of present day knowledge, therefore, what answer can we make to the question "Should all railroads be electrified?"

I do not believe that all railroads will ever be electrified.. I am not sanguine even that all the tracks of any one really big system will be so equipped in our time. It is a question of economics, and the results will not justify the expenditures even when considered with such broad vision as that which guided the Pennsylvania in spending millions to put their passenger terminal in New York City without the prospect of a direct return. Electrification will increase the track capacity. But there are thousands of miles of railroad that have sufficient capacity now, frequently several times over, and where the wildest stretch of imagination fails to picture a future need of this kind. Electrification works wonders in suburban and interurban passenger service. I have riden for hours across the western prairies without seeing a single town, much less a city where these advantages would count. Electrification effects marked economies in fuel, in maintenance, in labour and otherwise through a long list; but, electrification calls for a heavy investment and unless these economies bulk large enough, the interest on such investment will wipe them out and turn the enterprise into a losing venture. I do not believe the cause of electrification is held by undue optimism on the part of its advocates. Rather should there be an enlightened partisanship, enthusiastic where enthusiasm is justified, but tinged with the sober conservatism of the man who has to put his own dollars to work.

There need be no discouragement to the electrical engineer in the views just given, nor to the railroad man who has looked towards the new motive power for salvation. There are so many cases where electricity should be used, where its advantages are clear and conclusive, that once the railroads escape from the financial slough of despond in which they are now wallowing, and are again able to get capital for their needs, there will not be enough engineers, there will not be enough electric factories in the country to serve them. Every big system has need of electricity somewhere. For some small roads it may mean the difference between solvency and bankruptcy. I electrified a short derelict line for the New Haven Road between Mariden and Middletown, long before given over into the one-train-a-day-annual deficit class, and turned it into a good earner.

There can be no rule established. Generalities are sure to be misleading, but electrification is now firmly intrenched and successful. It is recognised by railroads generally as an effective agency with great possibilities, and one which is particularly valuable for certain specific purposes. Time alone will tell how broad its application is to be, but I am confident we can await developments with tranquillity, assured that the art is in a healthy condition and that progress will be along the right lines.

Third Paper

Railway Electrification in England.

Report By

Mr. A. R. GUNDRY, A.M.I.E.E., A.M.I.M.E., Electrical Engineer, Eastern Bengal Railway dated 20th November 1919.

Electric Traction—I beg to report below the results of my investigations and observations in connection with Heavy Electric Traction.

The problem of providing an economical, efficient and commercially sound system of transport which will be popular with the travelling public and the despatcher of goods is most difficult of solution.

The method of traction is immaterial to the public providing the conveyance of them and their goods is done safely, expeditiously and cheaply.

Rapidity of transit is a most important consideration and this condition is fulfilled by Electric Traction. High acceleration and consequent high schedule speed is obtainable.

The cost of such a system of transit increases very rapidly with small increases of schedule speed, therefore increased density of traffic must be obtained to make the more rapid transit profitable.

The extent to which this greater density of traffic can be relied upon varies considerably according to the district dealt with, and whether there are slower systems of transit from which passengers can be gathered.

Heavy Electric Traction is not only an Electrical Engineerning problem; a sound knowledge of the conditions which obtain on Railways, to be acquired only in close contact with the Locomotive and Traffic Departments, is essential for solving the problems involved.

Electric Traction must be carefully considered from the railway standpoint; the scheme must be financially sound, it must conform as closely as possible to railway conditions, and then comes the Electrical Engineering part of the problem.

The advantages of Electric Traction are very clearly outlined on pages 1 to 18 of Messrs. Merz and McLellan's report of March 1914 (reprinted as the first part of this paper); it is therefore not necessary for me to repeat them here. I have, however, endeavoured to obtain first-hand information from Electric Railways operating in England, also from manufacturers of the apparatus and plant used on Electric Railways.

The Lancashire and Yorkshire Railway.—The Lancashire and Yorkshire Railway have two portions of their line electrified, one between Liverpool and Southport and the other between Manchester and Bury, the former is run on the 600 Volts Direct Current System and the latter on the 1,200 Volts Direct Current System.

This railway has for the last eight years been making exhaustive experiments in connection with the Direct Current System at different Voltages and they have had running a length of experimental line working at a pressure of 3,500 Volts.

With the high pressure of 3,500 Volts D. C. considerable difficulty has been experienced with the overhead equipment and they are not at present in a position to recommend a direct current pressure higher than 1,200 Volts or thereabouts.

This pressure of 1,200 Volts they have adopted for their Manchester to Bury service with unqualified success. The pressure recommended by Messrs. Merz and McLellan for the Eastern Bengal Railway is 1,500 Volts. The following interesting results were obtained after the electrification of the Liverpool and Southport section of this Railway.

Under steam conditions there were about 26 trains per day in each direction between Liverpool and Southport eighteen and a half miles, and a similar number running in each direction between Liverpool and Crosby and Hall Railway stations some six and a half miles from Liverpool.

The majority of these trains stopped at every station, a few expresses being run in the morning and evening for the accommodation of the business men.

Under electrified conditions the daily train mileage has increased from 1,900 to 3,500 and the number of trains in each direction between Liverpool and Southport has increased from 36 to 70 and between Liverpool and Crosby and Hall Railways from 36 to 70. Moreover, the running time from Liverpool to Southport, which with steam was 54 minutes has decreased to 37 minutes and from Liverpool to Hall Road from 25 minutes to 17 minutes.

This railway's Electric Motor Cars run 50,000 miles without visiting sheds other than for stabling and can be kept in continuous service for 20 hours daily, the only attention required being brake adjustment.

Steam Locomotives on similar service require coal every 150 miles and require thorough washing out and overhaul every 1,200 miles at least.

Experience in dealing with the varying condition and character of the traffic on this section led the railway authorities to adjust their trains in point of accommodation to meet such conditions, and as a consequence the trains consist of two motor coaches and of one, two or three trailers as required, the five coach trains being worked during the rush hours of morning and evening and the light trains during the slack hours of the middle day and early afternoon.

The empty weight of the motor cars is roundly 46 tons, and that of the trailers 26 tons so that

A three-car train weighs	118 tons.
A four " " "	144 "
A five " " "	170 "

First class cars accommodate 66 passengers. Third Class Motor Cars accommodate 69 passengers and in addition a Luggage compartment 9'-10" by 7'-0" and a motorman's compartment.

The Standard Train consists of two first and two third class cars, the latter being at either end and equipped with motor bogies, each bogie carrying two 150 Horse Power motors, there being, therefore, eight motors totalling 1,200 Horse Power per train, and accommodate 270 passengers.

The latest 65 feet trailer cars accommodate 76 passengers in the first class and 103 passengers in the third class carriages.

The system of having large side doors at each end of a 60-feet car which doors are readily opened or closed by the public themselves, saves the waste of labour, causes the passengers to move quickly in and out of the cars and has shown in practice in England that the trains can be got away from the station in less time.

The most crowded cars are always emptied during the rush hours in about 50 seconds to pick up and set down passengers.

I will now proceed to record the results of my investigation in connection with High Voltage Direct Current Electrification. The very satisfactory results obtained by the Lancashire and Yorkshire Railway on their Liverpool to Southport line, induced them to apply Electric Traction to their Manchester Bury section.

The live rail Direct Current System as used on the Liverpool and Southport section is adhered to on the Manchester and Bury section, but the Voltage has been raised from 600 to 1,200 Volts.

The length of the Manchester to Bury line is 22 miles of single track. The system adopted is the third rail with track-return augmented by a fourth rail; the contact shoe collects the current from the side of the live rail instead of on top; this facilitates the protection of the third or live rail from accidental contact by the staff more necessary due to the high pressure; the guard on this rail is of Jarrah wood.

The live rail is anchored every 100 yards by anchor insulators supplied by Messrs. Buller and Company, Limited.

The live rail insulators are of Messrs. Doulton manufacture. The cross sectional area of the rail is 8·35 square inches and weighs 85 lbs. per yard. Its resistance ranges between 6-7 and 7-0 times copper of equal area and length; the normal length of rail is 60 feet. The track is fed from sub-stations through short feeders; no supplementary feeders are used.

The live rail is divided up into sections which are connected through section switches placed alongside the live rail, and operated as ordinary link switches.

Rolling Stock.—The motor bogies carry two 200 Horse Power motors mounted and geared to the axle through speed gearing, the ratio being 59/25 or 2·36 to 1-0.

On each side of the bogie is mounted a shoe beam carrying the collecting shoe.

Each motor car is provided with two of these bogies totalling 800 Horse Power per motor car. The gradients on this line range from 1 in 40 to level.

Each motor is series wound for 1,200 Volts with commutating poles and the armature is insulated with mica throughout, no hydroscopic material being used whatever.

The motors are controlled by electrically operated and insulated contactor switches which are controlled by a master controller fitted in the Driver's compartment.

The brake is the standard automatic vacuum brake and if necessary ordinary steam trailer cars can be coupled to them, the brake still being effective.

The vacuum is produced by means of a cylinder exhauster driven through gearing by a 5 Horse Power, 100 Volt motor.

Heating is also provided from the main circuit at 1,200 Volts, and the lighting pump motor and control off the 100 Volt circuit.

The electric trains consist of either two, three, four or five bogie cars according to the requirements of traffic—the standard train has five cars, the front, centre and rear vehicles being third class motor cars, and the intermediate vehicles 1st and 3rd class trailer cars.

A feature of the design is that the driving compartments for the driver are at each end of all cars, which enables the trains to be made up to any accommodation required with the minimum of shunting operations, time being of the utmost importance on an electric service.

With the exception of the upholstering and carpets the vehicles are practically fire-proof, all framework, etc., being of steel; panelling, hat racks, and electric fittings, etc., being of aluminium.

Total length of five-car train	326 feet 3 inches
Seating accommodation	72 First Class
	317 Third „
TOTAL . .	389 passengers.

Length over body	63′-7″
„ „ couplers	65′-3″
Height from rail to roof	12′-4½″
Bogie centres	45′-0″
Wheel base of motor car bogie	9′-0″
„ „ trailer „ „	10′-0″
Total weight of five-car train	220 tons.
Weight of motor car	54 „
Weight of trailer car	29 „

Power Station.—The Power Station is situated at Clifton Junction about 4½ miles from Manchester.

The ground level is 37 feet below the main line, thus affording admirable facilities for dealing with the coal and ashes.

The boiler room contains three 32,000 lbs. per hour Babcock Boilers fitted with the loose link type chain grate; this type has proved very satisfactory on low grades of coal but is not recommended for high grade coals.

The superheating surface is 2635 square feet. The economisers (Greens) are fitted above boilers to economise space and reduce the length of flue to a minimum; each boiler has its own economiser of 256 tubes.

The chimneys two in number are 87′-6″ above firing level and each chimney deals with the gases from two boilers assisted by an induced draught fan with water-cooled bearings.

The ash from the boilers after passing over the end of the grate falls into a hopper which is periodically opened to allow the ashes to drop into a small motor driven crusher, which breaks the larger clinker to a suitable size for conveyance through a suction pipe which is 8″ in diameter.

The suction for the conveyance of the ashes and soot from the dumping level through the suction pipe, to the receiver from which the wagons 37′-6″ above ground level are loaded, is provided by an inverted "Roots" blower.

The Turbine room contains two 5,000 K. W. 6,600 Volt 3 phase 25 cycle Turbine driven Alternators by Messrs. Dick Kerr and condensing plant for same by Messrs. Allen and Company; these sets supply the main power.

The auxiliary plant is supplied with power by a 500 K. W. gear-driven turbo alternator complete with condensing plant at 440 Volts 3 phase 25 cycles. The reduction gear has a ratio of 3600/750 R. P. M. and was manufactured by Messrs. David Brown and Sons, Limited, Huddersfield.

The auxiliary plant is also supplied with power from the main supply through step down, transformers 6600/440 Volts.

The feed pumps two in number are both capable of delivering 10,000 Galls. of feedwater per hour against a head of 217 lbs. per square inch.

One is a reciprocating pump and the other a turbine pump absorbing 40 B. H. P. and is driven by a 45 B. H. P. high pressure turbine of the Horizontal Curtis type running at 3000 R. P. M.

There are three separate switchboards:

1. The main switchboard for operating the main units and feeders.
2. A 440-Volt alternating current switchboard for controlling station auxiliaries.
3. A 100 Volt Direct Current switchboard for the main switchboard control circuits, lighting, cranes and stand-by battery for the control circuits.

High Tension Feeders.—These consist of two lines, the "North Line" and the "South Line." The North Line which is four miles long runs from Clifton Power Station to Radcliffe sub-station. The South Line is 4½ miles long and runs from Clifton Power Station to Manchester Victoria sub-station.

The aerial conductor is of 7/16 S. W. G. and the three core cable of 19/14 S. W. G. per phase, the standard span for the aerial line is 70 yards.

Sub-stations.—Each substation referred to above is a combined rotary and battery sub-station, the equipment in each is identical, and contains three 1,000 K. W. 1,200 Volts 6 phase 25 cycle 10 poles rotary converters running at 300 R. P. M. capable of 100 per cent. overload momentary and 25 per cent. overload permanently.

Three transformers are used for each rotary, each 350 K. V. A. with a ratio of 6600/900 Volts, they are of the oil-cooled type.

The Battery which is housed in a separate building consists of 580 Plantide Cells (Chloride Storage Company), the capacity is 500 ampere hours on 1 hour rating and charging current can be raised up to 1,500 amperes for 15 seconds.

An "Entz" automatic reversible booster is also provided for use in series with the battery for charging and discharging as the load demands.

The North-Eastern Railway.

General.—The electrified line which I was given facilities to inspect has a route of approximately 18 miles and connects the mineral sidings at Shildon which forms one of the largest marshalling yards in Great Britain, with the Erimus sidings at Newport near Middlesborough, and deals with freight only.

Including sidings about 50 miles of single track are equipped for electric working. The line from Shildon to Erimus is practically all on the down grade and is in favour of the laden traffic, as the line carries the heavy mineral traffic from the South West Durham coalfields to the Middlesborough district, supplying iron works and blast furnaces there.

The steepest gradient is 1 in 103. The return journey from Erimus to Shildon consists mainly of empty wagons.

Overhead Equipment.—On this line it was decided to install the high tension direct current system with track return, current being supplied to the motors through overhead contact wires at 1,500 Volts (similar to the system proposed by Messrs. Merz and McLellan for the Eastern Bengal Railway).

The overhead contact wire consists of two copper conductors of 0·155 square inches section, each supported by a solid steel auxiliary catenary clip. This auxiliary catenary is in turn suspended from the main stranded catenary by means of single steel wire droppers.

The normal span is 110 yards but this is considerably reduced at curves. In exposed position the 110 yards spans have been found too great and intermediate posts from which to support the line have had to be erected.

The normal height of the conductor is 16 feet 6 inches, but at level crossings this has been increased to 18 feet 6 inches.

To avoid the possibility of undue sag on the contact wires due to temperature variation, automatic tensioning is adopted.

This tension is maintained by the attachment of weights at the end of each section of 1,100 yards of contact wire.

The track rails are bonded with two stranded copper bonds each of 0·109 square inches section and cross-bonded between the two rails at every 300 feet also between the two inner rails of adjacent tracks at the same space interval.

Locomotives.—The Locomotives were built in the North Eastern Railway Locomotive work shops at Darlington, the electrical equipment being supplied by Messrs. Siemans Brothers' Dynamo Works.

They are designed to haul trains weighing 1,400 tons at a speed of 25 miles per hour on the level, the normal load, however, is approximately 1,000 tons.

The current is collected by two pairs of bow collectors with aluminium contact strips, mounted on the roof of the cab and are raised and maintained in contact with the overhead contact wire by compressed air.

By making the compressed air cock handle also the key of the contactor chambers, these compartments cannot be entered while the bows are in contact with the overhead wire, therefore accidental contact with any electrically alive portion of the equipment is impossible.

In the cabs are two master-controllers by which the motors are controlled through electrically operated and interlocked contactor switches and drives a centrifugal fan for supplying ventilating air to the main motors.

The main motors of which there are four, two on each bogie, are all wound for 750 Volts, the pair of motors on each bogie being connected permanently in series.

The four main motors of each locomotive thus form two units which are controlled on the series paralelled system. Each motor is capable of developing 275 brake horse-power at a speed of 20 miles for one hour with forced ventilation.

The motor equipment is capable of exerting a torque sufficient to skid the wheels under any conditions of rail and will exert an average pull of 28,000 lbs., at the tread of the wheels when starting under normal conditions of rail. The normal quantity of air passed through each motor for ventilating purposes is 700 cubic feet per minute.

Several experiments have been carried out on certain locomotives with a train load of 1,400 tons taken down from Shildon to Newport and a train of 800 tons handed from Newport up to Shildon with stops on certain of the heaviest gradients.

The 800-ton train was stopped and started on a grade of 1 in 103. The maximum draw bar pull during the tests reached 16 tons; average speed from Newport to Shildon was 18·3 miles per hour and the maximum speed 26 miles per hour.

Another test on these locomotives was in connection with shunting operations, and while they proved equally as efficient as steam the results were not satisfactory, in as much as it was proved that for continuous shunting at low speed this particular type of locomotive was at a disadvantage due entirely to overheating on the regulating resistances which at no time could be cut out of service on shunting work. However, this difficulty is a minor one and can easily be overcome in the design of the motor reduction gear and resistances.

Very little shunting is done with these electric locomotives as all loads are pushed over the humps into the yard by steam locomotives; they are then marshalled by men controlling the wagon while walking, the average speed of a wagon in these hump yards being approximately 3 miles per hour.

To obtain this speed with a loaded wagon the gradient is about 1 in 500.

I noticed a very useful appliance which is in use in these yards replacing the usual wooden scotch, this appliance is capable of pulling up 60 loaded wagons in a hump yard within 30 yards.

Sub-stations.—The power which is primarily purchased from the Local Power Companies' system is converted from High Tension Three-Phase to 1,500 Volts Direct Current for supply to the overhead track.

The sub-station at Ayrcliffe contains two 800 K. W. rotary sets each consisting of two 400 K. W. 750 Volts.

The Erimus sub-station is similarly fitted but one of the rotary sets is of 1,200 K. W. capacity.

Both sub-stations are supplied with Three-Phase current from the North East Power Companies through Cleveland and Durham Electric Power Company. Ayrcliffe is supplied at a pressure of 20,000 Volts between Phases through two overhead lines. The Erimus sub-station is supplied at a pressure of 11,000 Volts between Phases through underground cables.

The method of conversion adopted is that of rotary converters on account of their high efficiency and large overload capacity.

The system of connecting two 750-Volt machines in series was adopted to enable the machines to be designed with a safe commutator speed and a very conservative value of Voltage between commutator bars.

The London, Brighton and South Coast Railway.—This railway has approximately 70 miles of electrified track which includes the South London Section running between Victoria and London Bridge and the Crystal Palace Section running in a loop from London Bridge and Victoria.

The system adopted by this railway is entirely different to any other electrified railway in England. High Tension 6,700-Volt Single-Phase 25-cycle current is supplied to the overhead line which is transformed down to Voltage ranging between 250 and 750 Volts at the motor terminals on each motor car.

This system has been subjected to a considerable amount of criticism by most English engineers, and it was owing to the fact that no English electrical contractor could undertake the manufacture and instal the equipment for Alternating Current Single-Phase Traction that the whole contract was placed with the A. E. G. Company of Berlin 1907.

From my observations I am of opinion that these criticisms were to some extent warranted, but the simplicity of distribution and the inexpensive sub-station or switch cabin, containing only section control switch-gear with one attendant are certainly points in its favour. With the Direct Current System, running machinery in the shape of rotary converters or motor converters are required in each sub-station with the necessary attendants, maintenance and running charges.

On going through the repair shops, however, I was struck by the number of motors under repair and I could only conclude that maintenance charges on the actual train equipments were high.

I was, however, informed that the motor cars were overhauled annually and that they ran approximately 4,500 miles without overhaul. This, however, was not borne out by my inspection of the shops as far as the motor equipment was concerned.

This railway purchases their power in bulk from the London Electric Supply Company on a sliding scale and before the war was paying 0·5 pence per unit; this however, owing to high cost of coal and labour, has now been raised to 1·0 pence per unit with a consumption of 16 million to 20 million units per annum.

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Overhead Equipment.—The overhead contact wire consists of one copper conductor of ·155 square inches section, this is suspended from two main catenarys by two droppers to which it is connected by sliding clips, the point of attachment forming the apex of a triangle and the two droppers being the sides of the triangle.

This construction, although slightly more expensive than that adopted by the North Eastern Railway, appears more efficient and enables much longer spans to be used without the danger of contact wire being blown from its normal position by strong winds, a serious defect which has actually occurred on the North Eastern Railway and is mentioned in the report of my inspection of that Railway.

The spans on the Brighton Railway range from 75 yards to 220 yards and I am informed that they have never had a moment's trouble due to the above.

No special means of adjusting the tension is provided, the main and auxiliary catenarys are strained between each span and the tension adjusted by the usual turn-buckle.

The structural work for supporting the overhead contact wire is of very heavy construction and could with safety be considerably reduced in weight. I much prefer the lighter structure used on the North-Eastern Railway.

Rolling Stock.—The motor car bogies on the South London Section, each carrying two 115 H. P. motors mounted and geared to the axle through gearing the ratio 60—14 or 4·2 to 1.

The total horse-power per motor car is therefore 460. On the Crystal Palace Section the motors are 150 horse-power each totalling 600 H. P. per motor car.

All motors are wound for single-phase 25-cycle 350-750 Volts. The transformers stepping the line Voltage down to these Voltages are mounted on the underframes and there is one to each pair of motors.

The air compressor driven by a 6 H. P. motor at 300 Volts supplies compressed air for the Westinghouse Brake and the contact bows lifting gear is also mounted on the underframe.

The air pressure is automatically maintained at between 95 and 110 lbs. per square inch by a governor control.

The trains are run on the multiple unit system, with train units of one motor car and one trailer car, one motor car and two trailer cars, two motor cars and three or four trailer cars to suit traffic requirements.

This railway has adopted the compartment type of coach in most cases, but have experimented with the compartment type and end type combined with considerable success; it maintains the combination, enables the passengers to sort themselves out when in the car, a distinct leaning towards the end door type of car.

For the inspection of the overhead track two special petrol electric motor cars are provided; built by Messrs. Dick Kerr and engined by the Daimler Motor Car Company.

These cars are fitted for carrying out all ordinary repair work and are 25 feet 4-wheeled vehicles.

The actual inspection is made from the roof of the coach which is specially built for the purpose.

The London and South-Western Railway.—This railway has 150 single line miles of track electrified which includes the Wimbledon and Waterloo Line *viâ* East Putney, the Kingston *viâ* Wimbledon and Richmond route, the loop line from Darnes to Twickenham *viâ* Hounslow, the Thames Valley to Shepperton, the Malden Hampton Court Junction and Clygate Lines.

The system adopted by this railway is the 600-Volt Direct Current with live conductor rail and track return.

Track.—The conductor rails are of 100-lb. flat bottom section supported by insulations. Straight and cross bonding is used to connect the track rails and to ensure the equal distribution of the return current over all tracks.

An important piece of constructional work in connection with the track at Hampton Court Junction, where a flyover junction has been constructed to avoid the crossing of the new electric trains on the level, and to enable acceleration to be attained.

This new piece of line is 1½ miles in length, and includes a steel-girder bridge of 160 feet span, which carries the track for electric services over the original lines at this junction.

Rolling Stock.—This railway decided upon the compartment type of train with a view to utilising the companies' standard type of coach for all trailer cars.

The empty weight of the Motor Cars is 44 tons and the empty weight of the trailer cars is 24 tons.

The trains are equipped for multiple unit working and are made up of three coach units, consisting of two motor coaches with a trailer coach close coupled between them. The individual three coach units are intended to be permanently coupled together and work as three or six-coach trains according to the traffic requirements.

Each train unit is equipped with four motors, each of 275 H.-P., the axial system of air circulation is adopted, the motors being totally enclosed.

Each three coach unit will accommodate 190 passengers and luggage for which there are two compartments.

Power House.—In preference to the purchasing of power from a public supply company it was decided to erect an independent Power Station at Wimbledon.

The Power House equipment consists of 16 Babcock and Wilcox boilers, each capable of evaporating 20,000 lbs. of water per hour at 200 lbs. per square inch with a super heat of 200 degrees F.

The boilers are fitted with chain grate stokers.

Coal is fed to the boiler hoppers from overhead bunkers.

The turbine room contains five 5,000 K. W. turbine-driven three-phase alternators which generate current at 11,000 Volts.

To provide current for lighting the building and driving the auxiliaries for the condensing plant, etc., three turbine-driven 400 K. W. direct current generators have been installed.

The condensing plant is of the surface type with the necessary air and circulating pumps.

The ground level of the power house is below the railway level approximately 14 feet, and to enable coal to be fed direct from wagons into the overhead bunkers a special ramp has been constructed.

Sub-station.—Current from the power house is distributed to nine sub-stations through paper insulated, lead sheathed, three core cables which are run along the line supported on short posts.

The sub-station equipment includes the usual static transformers and rotary converters with the necessary switch gear for control.

These sub-stations convert 11,000 Volt Alternating Current to 600 Volt Direct Current for supply to the track.

The Underground Railway of London, Ltd.

This Combine includes the District and Metropolitan Railways and the Bakerloo, City and South London, Central London, Hampstead and Finsbury Park Tubes.

All these railways have adopted the 600 Volt Direct Current System. The District and Metropolitan use an insulated return and the tubes a track return.

The insulated return was adopted with a view to avoid electrolocis and damage to gas and water pipes in the tunnels; while this has been accomplished considerable trouble has been experienced with the insulation on motors and train equipment, due, I am told, to the high pressure which accompany the grounding of either main.

This Combine have taken every advantage of the flyover Junction at busy crossings; a typical junction is to be seen at Earl's Court where there are two main roads and two tunnels one above the other with the result that there are no crossings.

Rolling-Stock.– I inspected the stock on the District Railway only. This Railway, in fact, all the lines in the Combine, have adopted the end and centre door type of coach.

The empty weight of a motor car is 31 tons and the empty weight of a trailer car is 21 tons.

The trains are equipped for multiple unit working and are made up of two-coach units consisting of one motor car; and one trailer car, these are run as two, four, six or eight-coach trains.

Each train unit is equipped with two 150 H.-P. motors totally enclosed and each two-coach unit will accommodate 120 passengers.

Motor cars on this railway run approximately 50,000 miles without overhaul.

To give an example of what this railway is doing in the way of acceleration, a train runs between two stations, a distance of half a mile, in 85 seconds, not including stops.

All the equipment of this railway is of American manufacture.

Power Supply.—This Combine owns the large Central Power House at Lots Road, Chelsea, and most of its railways are supplied from this source.

Current from this Power House is distributed to numerous sub-stations, situated at suitable points throughout London.

The sub-station equipment is similar to that installed by the London and South-Western Railway and includes static transformers, rotary converters and the necessary switch gear.

General.—The High Tension Direct Current System of Electric Traction is no doubt very much in favour at present not only in England but in America where High Tension Alternating Current has so long been boomed.

I do not say that this is any guidance in deciding the most suitable system to adopt for the special conditions met with on the Eastern Bengal Railway or any other railway, but I do say that it compares very favourably with any other system and that the increase of pressure from 600 Volts to 1,500 Volts or even higher has in no great degree affected the reliability and efficiency of the Direct Current System which has given such good results.

Having dealt with the system of Electric Traction I will now deal with the application of Electric Traction to Suburban Traffic.

Due to the ease with which high acceleration can be obtained, Electric Traction lends itself to the most economical running.

High acceleration means high average speed approaching the maximum speed. Thus the train obtains its maximum speed very quickly, and the power may be cut off and advantage taken of the good coasting qualities of electric stock to run the greater part of the journey absorbing the energy stored in the train.

For the same schedule, the lower the acceleration, the longer the power must be used which reduces the time of coasting and results in most of the energy put into the train being absorbed in the brakes.

The speed during coasting decreases very slightly and a train is still travelling at a high speed when the brakes are applied. A considerable amount of energy is therefore absorbed by the brakes.

Since all this energy must necessarily be imparted to the train during acceleration and as the amount of energy required on short runs is proportional to the weight of the train, it follows that this latter is a matter for serious consideration; therefore all cars should be as light as possible, consistent with safety and comfort.

In electrifying the Liverpool and Southport section of the Lancashire and Yorkshire Railway, it was necessary in the transition stage to run steam trains to nearly the same schedule as the electric ; as a result it was found that the coal consumption of the slower steam train was nearly double that of the electric trains, the running wages were doubled and though these steam trains were only run for a few weeks the engines showed that the repair bill would have been enormous had the steam service been continued.

Table I gives the following interesting figures in connection with train weights :

Table I.

No. of motor cars	2	5	5
No. of trailer cars	2	0	0
Weight of motor cars . . .	46 tons.	22 tons.	15 tons.
Weight of trailer cars . . .	26 tons.	...	...
Over all length of train . . .	248 ft.	242 ft.	248 ft.
Weight of train	144 tons.	110 tons.	75 tons.
Total area per train	2,400 sq. ft.	2,135 sq. ft.	2,400 sq. ft.
No. of seats (1 per 10 sq. ft.) . .	240	213	240
Seats per ton	1·66	1·94	3·2

Table II shows clearly the effect which the reduction of weight per seat has on the energy consumption.

TABLE II.

Energy delivered to train in Watt-hours per seat mile :

Length of run . .	½ mile	1 mile	2 miles	3 miles	4 miles	5 miles	6 miles.
Average speed M. P. H.	22	29	36	40	42	43·5	44·5
144-ton train . .	61	51	41	36	33·5	32	31
110-ton train . .	52·5	45	36·5	33	31	30	29
75-ton train . .	32·5	27·5	28·5	22·5	21·5	21	20·5

In short runs, the energy is almost exactly proportional to the weight of the train, but this is not so for longer runs. This is due to the energy on shorter runs, being almost entirely used in accelerating the train, whereas on the longer runs the effect of the train resistance predominates.

The electric service is more flexible and by adding more motor cars to a train, or trailers within the limits of the motors, all fluctuations in traffic can be easily met.

It is, therefore, clear that for suburban traffic, with short distances between stations, electric traction shows considerable economies over steam, and the earning capacity of the trains is much greater.

I visited the works of Messrs. The British Westinghouse Company, The English Electric Company, The Chloride Electric Storage Company, and Allen West and Company, with a view to seeing the manufacture of the different parts of a train equipment. I was, however, somewhat disappointed as none of these firms had any equipment for heavy traction in course of construction.

Messrs. The British Westinghouse Company.—I visited these works at Manchester and was given every facility for inspecting the work under construction in the shops. I also took the opportunity of going thoroughly into their method of insulating the windings of electrical machinery. I was impressed with the quantity of mica used, and the elimination of cotton for insulation is a step in the right direction and should be encouraged especially in India. For Indian conditions we ask for a 60° F. rise of temperature above atmosphere. This, however, was for treated cotton insulation, and if mica is used I am strongly in favour of this temperature being raised to 75°, and any contractor quoting for mica insulated machines being given the benefit of a greater rise in temperature.

This company had a number of large turbine generators in course of construction including two 20,000 K. W. sets for Glasgow and two 10,000 K. W. sets for the North Tees Power Company. They also had a number of 1,000 K. W. 1,500 Volt Rotary Converters under construction for traction work in Australia.

The English Electric Company.—This Company's Preston works I found in a state of reconstruction after being entirely on munition work ; there were, however, a great number of light traction motors of various sizes going through the shops and on test,—these motors are for Electric Tram service and are extremely well constructed and of very ample dimensions throughout.

Asbestos insulated wire is used on these motors with good results in England but I cannot suggest that this material could be used for insulating motors for India where in places the humidity is over 100 per cent. There was also one 20,000 K. W. set for Glasgow and one 10,000 K. W. set for Bradford under construction.

This firm has in hand at the present time one of the largest contracts ever placed for electrical construction, this contract is unique in as much as no Consulting Engineers are engaged and the English Electric Company are entirely responsible for preparing the site and foundations and piling, if necessary, erecting the Power House building, supplying and erecting all the plant and handing the complete Power Station over ready for duty.

I also visited the Bradford works of this company which was originally the Phœnix Dynamo Company's ; these works are exceptionally well laid out and should be a great asset in mass production which it is proposed should be undertaken by these works.

The majority of the motors built at these works are fitted with roller bearings or ball bearings.

The gear for short circuiting the slip rings and raising the brushes on slip ring motors is extremely simple and effective, the brushes are not actually lifted, but the tension is removed and owing to the brush being set in a horizontal position they automatically leave the ring.

These works also manufacture electric battery run-about trucks suitable for workshop or platform use. The trucks weigh approximately 15 cwts and are built in sizes to carry 15 cwts to 20 cwts ; they are fitted with 14 Chloride Ironclad Exide Accumulators which supply current to 1½ H. P. motor.

The capacity of the battery is 150 Amperes and is capable of driving the truck at 6 M. P. H. There are a number of firms manufacturing these very useful trucks including the British Electric Vehicles Company and Messrs. Roadcraft Engineering Company. They are in use on all important Railway Stations for luggage and in many of the large Engineering workshops for material and I am informed that they have given every satisfaction and effect considerable saving over any other form of goods trolly.

The Chloride Electric Storage Company.—I visited this Company's works with a view to seeing the construction of their Ironclad Exide Storage Battery which is specially designed for traction work.

The positive plate consists of a number of vertical pencils joined top and bottom to a horizontal bar.

Each pencil comprises a core of hard lead alloy (antimonial lead) which is surrounded by active material ; the whole is enclosed in an ebonite tube having a large number of horizontal slits, or giving the electrolite access to the active material, on the other hand, they are not sufficiently large to allow of the active material washing out.

It is claimed that with this form of construction buckling or distortion of the plate is prevented.

The negative plate is the usual hollow grid on which are fixed two lattice structures which support the active material between them. The whole is a very solid and well made cell and has in many cases replaced the Edison cell for electric vehicles.

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