

ELECTRIC TRACTION FOR RAILWAYS.

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The question of railway transport, both at the present time and in the future, is one of extreme importance since upon its efficiency depends, in a large measure, the industrial success of the country. It is therefore well to examine present methods of haulage and see whether the best systems are being employed or whether improvements cannot be made. In this connection I wish to put forward the case of electric traction, not as an absolute panacea for the ills appertaining to the present system, but as affording very considerable improvements and making railway traction at least convalescent. I am including in electric traction haulage both by electric locomotives and motor cars.

Whatever system of traction is adopted there are three principal points to be considered. First, reliability of service; second, cost of installation, maintenance and operation; and third, simplicity of operation; or to put the whole matter in a nutshell, both passengers and goods should be transported to their destinations with the least delay, the least cost to the operators, and the greatest convenience to the public.

There are two systems only available for heavy railway traction at the present time—steam and electric—so that necessarily comparisons must be made between them. This

does not mean that there will be a battle to the death between the two systems, but there is not the slightest doubt that electricity will gradually replace steam, more especially in certain classes of traffic.

It is an unfortunate circumstance, and one which is very pronounced at the present time, that the question of change over from steam to electricity is largely one of finance.

Railways, as many of us know, are not run from philanthropic motives; the fact that they are, for the greater part, steam driven is a great obstacle from a financial point of view to a sudden change to another system. Electric traction has therefore not attained that position which its many advantages would merit.

Railway traffic generally may be divided broadly into four classes :—

- (a) Suburban passenger;
- (b) Interurban passenger between large towns up to 25 miles apart with intermediate traffic;
- (c) Goods where the railway has been electrified for (a) and (b);
- (d) Long distance passenger and goods;

and this is approximately the order in which a change over from steam to electricity would take place. The first two classes merge one into the other and considerable progress has been made in them, notably in and around London, Liverpool, Manchester and Newcastle, whilst several schemes are projected for further extensions. Electrification for the two latter classes, goods and long distance passenger depends, for the financial reasons already stated, on the progress made in suburban passenger traffic. Progress will in all probability take the form of electrifying round our large cities firstly, and then linking them up.

What then are the advantages to be looked for?

Amongst the principal ones are :—

- (a) Increased acceleration and retardation.
- (b) Higher schedule speed.
- (c) More frequent service.
- (d) Increased capacity of existing tracks.
- (e) Smaller amount of rolling stock.
- (f) Ease of operation in and out of terminal stations.
- (g) Ease with which the tractive effort can be adjusted to size of train.
- (h) Cleanliness.

These are more particularly applicable to passenger trains driven by motor cars. In addition the following advantages belong more particularly to the electric locomotives :—

- (i) Even tractive effort.
- (j) Higher mechanical efficiency and more constant efficiency during life.
- (k) No dead load due to coal and water.
- (l) Small depreciation and maintenance costs.
- (m) Continuous use.
- (n) Smaller size for given tractive effort.
- (o) Double heading possible with single train crew.

These by no means complete the list, but time will only permit of dealing with the chief ones.

I will deal briefly with them.

Taking the first five :—

- (a) Increased acceleration and retardation.
- (b) Higher schedule speed.
- (c) More frequent service.
- (d) Increased capacity of existing tracks.
- (e) Smaller amount of rolling stock.

The latter four are a natural result of the increased acceleration and retardation. This increased acceleration is due to the characteristics of the traction motor as compared with those of a steam engine. Comparing an electric and steam train with the same initial starting efforts, this initial effort is maintained up to five m.p.h. by the steam, and 25 m.p.h. by the electric, at which latter figure the tractive effort of the steam train has fallen to 45 per cent. This, coupled with the fact that the number of driving axles on an electric train is double or more than double that on a steam train, and that the whole weight of the motor car or locomotive can be used for adhesion, accounts for the increased acceleration it is possible to obtain.

In actual practice the average acceleration on suburban trains is more than double up to 10 m.p.h., and just under three times up to 30 m.p.h., that obtained by steam. The result of this increased acceleration on suburban services is that the schedule speed of the train is increased. What this means in actual practice is shown by the results obtained on the electrified systems of the L. and Y. Railway.

Between Liverpool and Southport the steam time was 55 minutes, the electric is 37 minutes—a saving of 33 per cent. ; between Manchester and Bury the steam time was 31

minutes, the electric is 23 minutes—a saving of 26 per cent. ; and since the distance between two places can be measured by the time it takes to travel between them, the advantage to the travelling public cannot be denied. It has been established that steam traction for this class of service has reached its limit ; any attempt to force the steam locomotive to run to the foregoing schedules results in prohibitive costs both in running and maintenance. As an instance of this it was found that during the transition stage from steam to electrical working on the Liverpool and Southport line in 1904, when it was necessary to run steam trains to electrical timings, that the steam locomotives which attempted to do this consumed 100lbs. of coal per train mile compared with 49lbs. of coal per train mile for electric. This latter figure is taken for a whole year at the power station. By reason of the increased schedule a larger number of trains can be run with the same headway between trains, thus giving a more frequent service and increasing the capacity of the existing tracks.

The ease of terminal station working also increases this capacity, as, instead of requiring standby engines and some fourteen signalling operations, involving the blocking of two or more roads for a period of at least five minutes, the electric train is ready to leave as soon as the motorman can walk from one end of the train to the other. Quoting again from actual results, the number of trains on the electrified lines of the L. and Y. Railway has been increased over 50 per cent., and this with a service which present conditions have restricted very much. They are capable of being increased to over 100 per cent., and though this has been brought about the traffic has been worked with less staff, and in some instances has resulted in the closing of platforms with waiting rooms and other buildings.

The ease and celerity with which the seating capacity of a train can be increased or decreased according to traffic by the addition or taking away of motor cars, thus proportioning the power available to the power required, is another marked advantage of electric traction, and one which adds greatly to terminal facilities. With regard to cleanliness, that is so obvious that no remarks of mine are required to emphasise it.

The foregoing advantages, as I stated previously, are more applicable to heavy suburban service with motor cars. The case of the electric locomotive is rather more difficult to establish ; certainly it has not the elasticity of the motor car, but its use is essential for the electrical operation of goods

traffic if not desirable for long distance passenger traffic, especially where more than one company's lines are used.

There is no question, however, of the superiority of the electric locomotive as a locomotive over the steam locomotive. Taken as a heat engine the steam locomotive is very inefficient, and it is enough to make the central station engineer weep to see the clouds of steam, at a pressure above atmosphere, thrown away, very often mingled with particles of half-burnt fuel. It may be picturesque, but it is not efficiency.

Proceeding with the advantages more particularly with regard to locomotives, we have firstly, even tractive effort, due to the fact that the electric locomotive is a rotary engine and the steam reciprocating. The advantage lies in that there is much less tendency to slip, and therefore with the same weight for adhesion a greater starting effort is available, or in other words, the starting effort per ton is greater in the case of the electric locomotive. This gain is round about 20 per cent.

Electric locomotives can also be built of a smaller size for a given tractive effort, and the combination of smaller weight and size, which gives such a marked advantage. It is well known that on most lines the steam locomotive has reached its limits as far as size is concerned, and on some lines has exceeded its limits so far as weight is concerned.

Any increase in power and weight would therefore entail a wholesale alteration of clearances and strengthening of bridge structures. All this can be obviated by general electrification, as an electric locomotive which would pass the minimum load gauge in this country can be made 50 per cent. more powerful than the corresponding steam locomotive.

In addition to this, double heading can be resorted to where required, without additional train staff, by use of multiple unit control.

The annual costs, taking pre-war figures, have been given as £1,175 for the steam locomotive (inclusive of capital charges), and £1,250 for the electric under equal conditions, but as a set off against this it must be borne in mind that whilst a passenger steam engine runs on the average 27,000 miles per annum, the electric locomotive can run at least 40,000 miles per annum. This brings the annual costs per mile to 10d. for the steam and 7½d. for the electric.

The higher mileage of the electric is due to the fact that a steam locomotive spends 75 per cent. of its time out of

active service; the electric, because of there being no necessity to visit the shed for coal and water, etc., and because of the less maintenance required, will certainly not be more than 50 per cent. of the time out of service. The motor cars on the L. and Y. system run an average of 50,000 miles per annum, and that on the heaviest and most trying service in the country, if not in the world.

The more continuous use which can be made of the electric locomotive brings down the number of locomotives required for a given service, and this of the order of three to two, so that though an electric locomotive is more costly to build in the first instance, the smaller number required is a set off in the total cost.

May I mention also the saving of coal through not having to get up steam in a few thousand boilers, through standing in steam, especially in the case of goods traffic and through having fires left in the firebox at the journey's end.

I would add that any driver can operate any electric locomotive, a practice which does not always obtain with steam locomotives, and that an electric locomotive has the whole power station behind it instead of a comparatively small boiler.

This then is my case for electric traction; the good old steam engine has done, and is doing, yeoman service since its first inception 100 years ago, and it seems a strange thing that the part of the Newport Sheldon Line of the N.E. Railway, which is the latest form of electric traction for heavy mineral traffic, should also be part of the first track laid down for the first passenger service in the world.

I will conclude by giving the progress made between 1914 and 1917, admittedly a bad period, on the various railways in this country:—

		Miles of track.	
		1914.	1917.
London, Brighton and South Coast ...	60½	62	
London and North Western ...	—	84½	
London and South Western ...	3½	150	
Lancashire and Yorkshire ...	89½	111½	
Midland ...	21	21	
North Eastern ...	65½	130	
Total ...		240	560

An increase of 133 per cent. during war period, and with the extensions contemplated there is no doubt there will

be further large increases as times become more normal. The total miles of single track electrified in this country and in the States, so far as can be ascertained, are 560 and 2,000 respectively.

The Chairman : I am sure we appreciate very much Mr. Barnes' contribution. There is only one fault ; he ought to have made it a little longer, and given it as a complete paper. I think Mr. Barnes sums the case up very well when he says that finance is the difficulty. Of course that is the stumbling block. We must look at the question from a commercial point of view ; and it is a debatable point whether main line electrification is a sound commercial proposition. Apparently it is not unless the railway company is compelled to do so because of the limited capacity of the line or terminal stations. Then the company is forced to adopt electrical workings, the only way out of the difficulty. I can accept quite freely many of Mr. Barnes' points. There is no doubt that an electric locomotive can do more than a steam locomotive, because, as he says, it has the power station behind it. We have daily evidence of its superiority on heavy suburban traffic. As regards economy of working, many of the statements in favour of electrification are built up on the working of sections of railways where the best conditions obtain.

A certain density of traffic is required and something approaching a constant load, so that the machinery can be well occupied throughout the 24 hours. I submit that comparison should not be made on such a basis. If steam engines were confined to busy sections where there was constant work on full load more favourable results would be obtained. But other sections of the line and different working conditions have to be considered. There are the shunting operations ; working of light trains and traffic detentions to be taken into account, and I do not think we can conclude that general electrification would be justified.

There is naturally a good deal said about loss on steam engines, due to radiation, but I imagine there is also a considerable loss due to leakage on the third rail. At least to the ordinary observer it appears obvious that much energy is dissipated in the small clouds of steam which may be seen rising from the insulators in wet weather. Loss due to leakage on the line must necessarily go on all the time, but the loss due to radiation from steam engines can be kept down by economical workings, and cutting out unnecessary engines. It would appear that there is a certain loss brought about by having the power in large units. Also as the power

is centralised there is risk of complete failure of the service as opposed to failure of individual steam locomotives. A complete failure of current could be more serious if the whole line were electrified and there were no steam engines available with which to institute an emergency service. There is another point which must be taken into account when considering main line electrification, that is the difficulty of piecing up the working of trains converging on and departing from the main line. Assuming that the electrification of the trunk line of a large railway is under consideration, there is probably a heavy traffic and good mileage and on the face of it plenty of scope for the electric locomotives, but when the detailed workings are analysed the problem is by no means straightforward. The trunk line is of course fed from branch lines then along the track, and later probably diverge from it to other lines. The trunk line only is electrified, there must be a change over from steam to electric and *vice versa* at each junction with a branch line. These locomotive changes would cause considerable delay, which would be aggravated by the uncertainty of the electric trains arriving at the exchange point. The alternative would be to electrify the branch lines, but that would entail the electrification of sections of line on which the traffic would be light and insufficient to justify the expenditure.

The equipment of a new railway does not present the same financial proposition as that of conversion from steam to electric. In the latter case the cost of electrification represents an additional capital charge over and above the capital already invested in steam plant, therefore much greater efficiency in working must be possible to enable the necessary interest to be earned on the increased capital invested.

Mr. J. W. Smith (G.C.R., Gorton): I have been interested in the discussion and came here to-night expecting to hear that the steam locomotive was doomed, but find the position is pretty much the same as existed some 20 years ago. At that time a friend of mine, an electrical engineer, very enthusiastic about electrical traction, said that the steam locomotive builders would have to pack up their traps in about five years. This time limit has been exceeded considerably, and it seems to me that the state of affairs is still only slightly advanced. I think the greatest difficulty was pointed out at the opening of the discussion, *i.e.*, the one of finance, which would certainly be great. That may be the greatest difficulty, but another is the one as to whether electrical engineers are quite satisfied as to which is the best system. There seems to be a great diversity of opinion

amongst them as to what system of electrification to adopt. The proposition of electrification for main line working is a difficult and costly one, and the steam locomotive, to my mind, except for suburban passenger line working, has still a considerable future. If all wagons were fitted with power brakes, it would enable steam locomotives to work with more efficiency than they now do. In America, as you may know, they have very big trains, which when made up, run for long distances, but the Americans found that before they were able to work these heavy trains satisfactorily, they were compelled to fit their freight cars with power brakes. I think the step to help us with our steam locomotives in the economical working of freight trains, would be the one of fitting our wagons with power brakes. I put the point of working traffic to an American friend of mine, and he replied, "Why, you have only little toy trucks and little toy engines in England." I answered that our traffic was such that we had to run short distances and the traffic was required quick and often. I asked him if he had been to England and he answered, "Not so far, but have only seen pictures." "Then perhaps you will change your mind when you come across." Later on he came to England, and a further discussion took place between us, when I reminded him of our previous talk *re* the working of traffic. He said he had not forgotten it, and had been studying the question since he came over, and had come to the conclusion that the "Americans did not begin to work traffic, as compared with the railway companies in this country," and he was satisfied that the traffic requirements of the two countries were entirely different. We both agreed that for this country the traffic is so dense that it was necessary to move goods trains quickly, and this cannot be safely accomplished without the use of power brakes on the goods stock for heavy trains and, failing that, the best results could be got by shorter trains, which would be under the command of the engine brake power, enabling locomotives not only to start quickly, but to stop quickly when required.

Talking about systems of electrification, I should like to ask Mr. Barnes which is considered the best, overhead, third rail, etc. It seems to me that before anyone will go in extensively for electrifying railways in this country, they will have to know definitely which is the best system. Electrification seems to be quite suitable for working dense suburban passenger traffic, in fact, I question if it could be improved upon. The steam locomotive is, however, much

more elastic and so far as I can see, it seems that for the next 20 years, at any rate, our old friend the steam locomotive will be with us.

Mr. J. R. Billington (L. & Y.R., Horwich): There is quite a large amount of matter in Mr. Barnes' Paper with which one must agree, when it is realised that the success which has attended the majority of these undertakings has far exceeded the anticipations of the promoters.

Mr. Barnes' title really expresses a problem which at the present time is before all railway engineers, and one which is very difficult of solution. To illustrate this by taking the simple case of starting a new railway, two kinds of railway might be assumed:—

- (1) A railway through a sparsely populated district, and with no appreciable amount of traffic between termini.
- (2) A railway in a thickly populated industrial centre radiating to suburban residential districts.

No. 1 is obviously a case for steam traction, and No. 2 for electric traction, but in actual practice one is not confronted with the problem of dealing with traffic on a new railway, but dealing with traffic on an existing railway, under conditions which come in between the two cases mentioned above.

The features to be considered in coming to a decision of *electric* versus *steam* are:—

- (1) Weight and density of traffic.
- (2) Proportion of goods to passenger traffic.
- (3) Distances between stations.
- (4) Gradients.
- (5) Cost of land, especially at the terminals.
- (6) The capability of the present equipment for dealing with the traffic offered.
- (7) The probable effects of electric traction on the creation of new traffic.

The electrification of existing railroads must either produce one or both of two things:—

It must either decrease the working expenditure or increase the receipts, in such a way that the profits give a proper return on the increased capital expenditure. Suburban traffic usually comes under the second item, and long through distance mineral traffic is likely to come under the first, such as the electrification of the Chicago, Milwaukee and St. Paul line through the Rockies, where four steam

locomotives and seventeen electric locomotives did the work of twenty-seven steam locomotives.

It will be realised that to bring electric locomotives or electric coaches in amongst steam stock entails difficulties, resulting in extra cost to the working of the traffic, as instanced by Mr. Barnes in his statement regarding the Liverpool and Southport line, where steam locomotives consumed 100lbs. of coal per train mile when forced to work the same schedule as the electric trains. I do not, however, agree to the figure of 49lbs. of coal per train mile for electric, because, as far as my information goes, the 49lbs. should be nearer 75lbs., which, by the way, is the steam consumption of a high-speed express passenger engine when hauling eight or ten bogie coaches.

The point I wish to make here is that there are other problems besides that of finance and merely electrifying the roads; there is the question of operation, because whatever traffic exists must not be interfered with in the slightest during the early stages of growth of the electric system, but no doubt we have plenty of running department men who can bring this matter out much better than I can.

With the continued rise in the cost of coal, and the urgent necessity for conserving it, anything which tends to reduce coal consumption must be considered favourably, so that from this point of view electrification undoubtedly scores a good point because an up-to-date power station can produce current at less than 2lbs. of coal per Board of Trade unit. This current, after being transmitted to the sub-stations, transformed down and converted to D.C. and fed to the train motors, the overall efficiency from the power station busbars to the rim of the driving wheels of the electric train being about 62 per cent., gives one B.O.T. unit per 3.2lbs. of coal, or 1 h.p. hour for 2.4lbs. of coal. Now, from a test of a steam passenger train, it requires six to eight lbs. of coal to be burnt in the locomotive firebox per h.p. hour delivered on the tender drawbar, for express running. Goods trains, of course, the power is considerably less, being around 4lbs. At any rate, there is ample margin here for coal economy to be brought about.

Mr. Barnes mentioned under "G" the ease with which the tractive effort can be adjusted to the size of train. Presumably he means the addition or deletion of a motor coach to a train, and of course there are limits even to that; it takes time and can only be done at terminal stations, or where the stock is housed. There is not the elasticity in a motor coach or electric locomotive that there is in a steam

locomotive, which will adjust its tractive effort within wide limits to any load automatically. Thus a steam locomotive can take a train at $1\frac{1}{2}$ miles per hour over a weighing machine steadily and easily, and it can be attached immediately to a goods train and take it at 25-40 miles per hour, or a passenger train (Blackpool excursion train in mind) at 50-60 miles per hour, and even if it failed it would not shut 10-20 miles of railway down.

The Author has stated at the commencement of his Paper that finance stands in the way of electrification and so has paved the way for himself to steer clear of matters of costs. It may be interesting, however, to know that the electric locomotive costs three or four times that of a steam locomotive.

Mr. Ernest F. Lang (Gorton): The subject so ably presented to us to-night is a very interesting and important one, and in discussing the pros and cons for the electrification of railways, a great many points have to be considered, as we have already seen.

The question of electric traction is mainly one of providing cheap electric current, and in view of the ever increasing shortage of coal, alternative sources of power will have to be looked for.

I remember that in the interim report of the Water-Power Resources Committee issued by the Board of Trade it was estimated that water-power stations could be built in this country at a cost of £38.5 per effective electrical h.p. in certain localities. It has been stated on good authority that throughout the British Isles the power capable of development with modern high-capacity turbines was not less than three or four millions of horse-power. At present, however, only a relatively small proportion of this could be economically developed. It is interesting to note that electric traction has had its most successful development in those countries where coal is scarce and where there are plenty of waterfalls. The utilisation of water-power has attained its highest technical perfection in Italy, Savoy and Sweden, and this is an index of what will happen elsewhere when the coal difficulty becomes sufficiently acute.

Probably this country would be one of the last to experience serious difficulties through an actual shortage of coal, but nevertheless the hard logic of events would compel us sooner or later to conserve our coal supplies by using them more economically. In those days to come locomotives would be fired by coal which had already gone through a

process of low-temperature distillation, thus increasing the amount of oil fuel available for other engines.

It was evident from what they had heard, that the conditions under which electric traction could at present be economically embarked upon were well defined, and would be but slowly extended. The steam locomotive would inevitably have to give way to the electric locomotive where the conditions called for maximum capacity over short distances, but if one looked at a railway map of any part of the world and realised the enormous extension of transport facilities for which the steam locomotive alone was suitable, it was obvious that locomotive builders had nothing to fear for a great many years yet. It is interesting now to look back upon the unnecessary alarm with which locomotive builders first viewed the introduction of electric traction.

In this country the first electric railway was the City and South London, Sir John Fowler being the consulting engineer. Alternative designs for the electric locomotive were put forward by Messrs. Mather and Platt and Messrs. Beyer, Peacock and Co. In the former case direct acting motors were used for the first time, the essential and distinguishing feature being that the armatures of the electric motors were mounted directly upon the axles, the field magnets being supported at one end by bearings on the axle, and at the other by links which connected the magnet yokes to crossbeams of the locomotive frame. There was thus some amount of angular play permissible in order to compensate for a rise and fall of the axleboxes in the horn-blocks. The two motors were capable, together, of exerting 100 h.p. at a speed of 25 miles per hour, corresponding to 310 revolutions of the axle per minute. This type, designed by Dr. Hopkinson, was the one adopted. In the latter case both armatures were included in the same magnetic circuit, and both magnets and armatures were carried on the frame of the locomotive and not on the axles. They were geared to the axles by diagonal connecting rods, the axlebox guides being inclined so as to permit the vertical movement of the axleboxes to be at right angles to the central line of the armatures. The distance between the centres of the armatures and wheel axles was therefore not affected by the rise and fall of the axleboxes, and no abnormal strains were put on to the connecting rods. This design, which was patented by my father and Colonel Peacock, allowed of the motor armature being placed on the floor level of the locomotive, where it was much more easily accessible. This arrangement naturally appealed to the locomotive engineer, and Sir

John Fowler had a working model installed in his office. This working model was eventually presented to the Manchester College of Technology. The construction can be readily observed from the photograph, Fig. 1. The patent was before its time, the early conditions favouring the direct acting or geared motors, but it is interesting to note that in some large electric locomotives of to-day, long after the expiration of the patent, the motors are mounted on the platform, and the coupled wheels driven by connecting rods from an intermediary shaft, an arrangement also mentioned in the aforementioned patent.

When Dr. Hopkinson lectured upon the subject of electric railways before the Royal Institution in 1893, he drew an interesting comparison between the City and South London Railway and the Mersey Railway, where the gradients and the nature of the traffic were similar. In the former case the cost of working, including all charges, was 7d. a train mile, and in the latter case, for which the locomotives built by Messrs. Beyer, Peacock and Co. were then the most powerful in Great Britain, the cost per train mile was 14d. Owing, however, to the greater loads hauled by the steam locomotive the position was exactly reversed when ton miles were considered. When, however, the cost per passenger mile was considered, the advantage was easily on the side of the electric railway, and from this Dr. Hopkinson argued that whilst electric traction could not take the place of steam traction on trunk lines it would have its proper function on the underground lines then projected for London and some large Continental cities, and for urban lines like the Liverpool Overhead Railway, where frequent service was the main object.

Dr. Hopkinson's prophecies were amply realised, and the conditions he set forth have remained on the whole unaltered.

Since then a powerful aid to the use of electric traction in populous districts has been the cheapening of electric current, brought about by the invention and perfection of the steam turbine.

The greatest drawback to the extension of electric traction in a highly developed country like Great Britain will be the enormous expense of changing over from one system to another.

In an address recently delivered to the Manchester Chamber of Commerce by Sir Hugh Bell, it was stated that the total value of the railways before the war was estimated

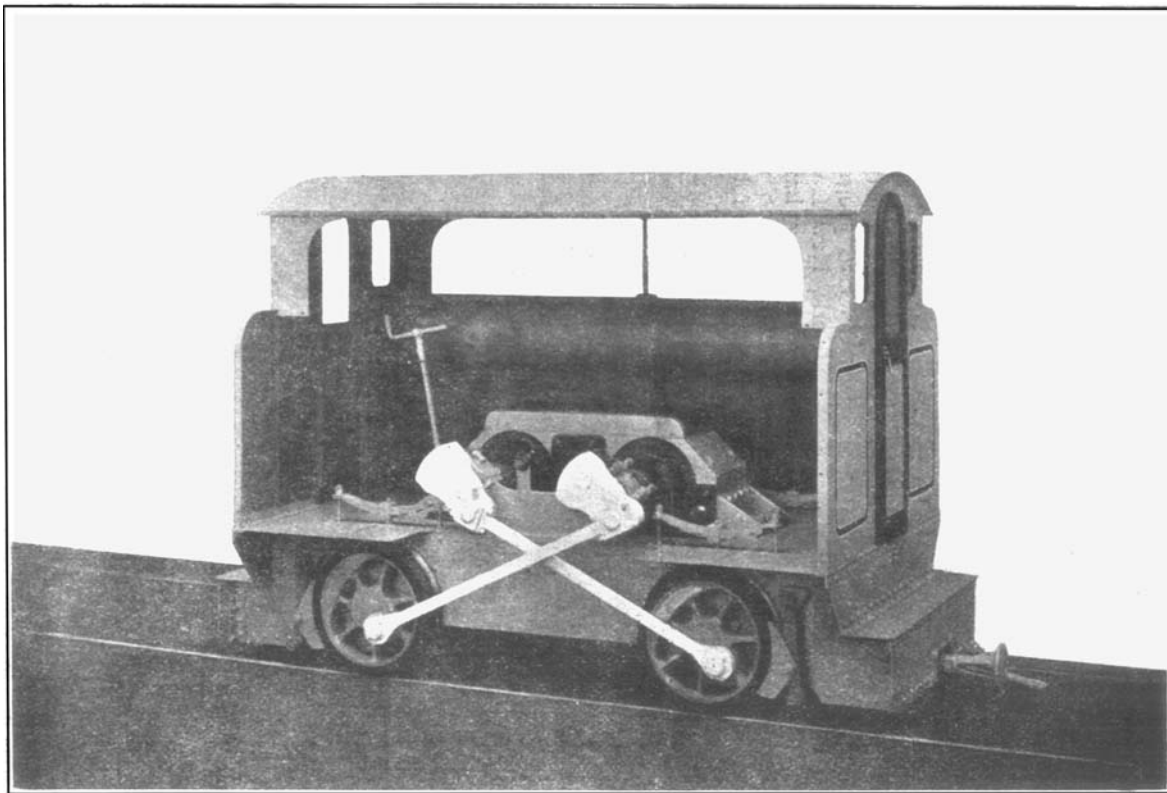


FIG. 1.—ELECTRIC TRACTION FOR RAILWAYS. Illustrating Mr E. F. Lang's remarks.

as being from £20,000,000,000 to £25,000,000,000. Before the war the total annual receipts were £139,000,000, giving a surplus of £50,000,000. It is now stated by Sir Eric Geddes that the railways are worked at a loss, and in face of the immense financial burdens imposed on this country by the war it is evident, for financial reasons alone, that very many years must elapse, even under the most favourable conditions of technical development, before it is possible to electrify the greater part of our railways.

In newer and less developed countries electric traction has had, and will have, more scope. When Mr. Rogerson and I visited the United States in 1908, we already found extensive developments taking place. Good progress had been made in electrifying the New York, New Haven and Hartford Railway. Since then this company has nearly completed the single-phase electrification of 220 miles of railway with, in all probability, 250 miles more to follow, and the locomotives have increased in size until they now employ freight locomotives capable of developing 50,000 lbs. tractive effort, and hauling 1,500 tons.

Other electric railways we came in contact with during our travels were the New York Central and Hudson River Railroad; Long Island Railroad; Indianapolis and Cincinnati Railroad; Lackawanna and Wyoming Valley Railroad; and the Brooklyn Rapid Transit Company. The New York, New Haven and Hartford locomotives had specially designed single-phase motors capable of being worked by direct current when running over the direct current third rail system of the New York Central, with which it connected. We heard a good deal about the battle of the systems and were reminded of the old battle of the gauges in the early days of the steam locomotive. It is to be hoped that in view of the economical importance of the question, that international action will be taken to secure uniformity of practice according to the best advice obtainable.

At that time, in the States, the future was held to be with the single-phase, and they were transmitting main supply current at pressures up to 11,000 volts, and the system was largely adopted on the Continent, but in this country everything seems to point to the extension of the direct current third rail system.

The chief interest of the American practice in electric traction was its use under conditions comparable with main line conditions in this little island of ours, and it was also obvious that in course of time there would be a great exten-

sion of electric traction in various countries largely as a result of American experience.

Nevertheless, when all is said, the fact remains that the steam or other self-propelled locomotive will be required in ever increasing numbers for many years to come, to play an indispensable part in that vast programme of railway construction which will be necessary both to improve already existing transport facilities and to provide new ones in many parts of the world, and towards which developments the economic consequences of the war will inevitably provide a powerful impetus.

Mr. E. N. R. Hurt (L. & Y.R., Horwich): Mr. Barnes has told us that an electric locomotive will run 40,000 miles per annum. We have steam locomotives that will run that mileage, although that figure is not maintained as an average, but if we had as many electric locomotives in the country as steam locomotives I think we should find that the average for the electric locomotives would be considerably reduced. Another point Mr. Barnes mentions is the possibility of running a goods train with one set of men by being able to couple up electric locomotives to be worked by one. I think this suggested advantage may be crossed off, as there is no doubt that the men's union would never agree to such a method of working. In regard to working of goods trains, the extent of acceleration was mentioned; if screw couplings can be introduced, well and good, but with the present form of couplings a steam locomotive will start a 120-wagon goods train quite fast enough, and could start such a train more quickly but for the risk of broken couplings. The electrical people in my opinion would say that they require all trains fitted with continuous brakes; the running and the average speed would be very much greater. A great deal of the slow running of goods trains at present is entirely due to the care which has to be taken in starting and stopping, which time is shown in the average running time. The electric traction adherents do not appear to be inclined to start the electrification of any line until there is a certain minimum of traffic. The steam men, however, have not been able to make that reservation, certain traffic is given them and they have to work it, and the railways electrified at present are those in which there has been ample traffic to justify the electrification. Therefore any average figures are misleading, as we are comparing electrically worked sections with a maximum of traffic with figures from the steam lines which include sections of line over which there

is very little traffic, and which the electrical people would not undertake to work.

Mr. J. H. Haigh (L. & Y.R., Horwich): There are so many points for and against electrification of railways that it is difficult to arrive at a proper decision. I quite agree with Mr. Barnes that a certain density of traffic must be shown to warrant the expenditure of laying cables, third and fourth rails, etc.

In the case of long distance traffic, where trains following close behind one another are most unlikely, electrification as at present designed would not pay, because the gain obtained from the rapid acceleration of electric trains would be more than counterbalanced by the higher and more variable speed possible with existing steam trains.

Electrification of short distance sections between terminal passenger stations is a good commercial proposition because firstly, of the higher average speed obtained and, therefore, fuller employment of rolling stock; and secondly the immense economy in terminal station space and shunting operations, which reasons combined made it possible to convey many more passengers in a given time than would be possible with steam.

A saving in coal consumed would also be possible on heavy short distance goods traffic or where with a congested main line it was necessary to put trains into loops at frequent intervals in order to allow fast trains to pass, principally because a steam locomotive could not stand in a loop for any length of time and have the fire in such condition that quick movement to the next loop a few miles away could be effected without, on arrival, having a much heavier fire than was necessary to maintain steam while stationary.

As Mr. Barnes has only come to open the discussion, I do not think it is quite fair to ask questions, but I will presume on Mr. Barnes's good nature by asking whether with a heavy electric locomotive and loose coupled goods train it is possible with economy to take up the slack of the train with the same ease and safety as with a steam locomotive.

Structurally electric rolling stock, locomotives and motor coaches, are entirely wrong, because the low centre of gravity leads to wear and tear on, and stresses in, track and wheel flanges which no steam locomotive ever constructed would produce.

Finally the whole fabric of electric traction depends on

a central power station, at least for a fixed length of track, and there is always the risk that a spanner or even a strand of copper wire falling into the wrong place may bring the whole to a standstill for an indefinite length of time.

Mr. W. Sinclair (N.S.R., Stoke-on-Trent): Mr. Barnes seems to be scoring very few points in the discussion. His introductory remarks were too short and the discussion has taken rather a different line to what I thought it would take. I thought that steam men were beginning to feel that after all there was something in the electric working of the railways, and that a discussion would develop more on the lines as to which was the best system by which electrification could be done, for after all the steam engineers in this country have been following up this question of electrification for some years, and the fact that they have gone into the question and electrified to a considerable extent, proves that there is something in it. The Chairman, I think, was correct when he brought electrification of the railways down to a question of finance, and he followed on by saying, "Do we want this state of affairs?" Well, the Minister of Transport seems to think we do, and there is talk about "rivers of electricity flowing through the country." I have a point respecting this that I will bring up later.

Mr. Haigh talks about the demand, and asks if there is a demand. Considering the present congestion of railways, it would appear that there is a demand for acceleration at any rate, and acceleration is one of the first principles in favour of electrification. In a lecture delivered before the Institute of Civil Engineers some years ago, the author's belief was (I quote from his remarks) that quick acceleration is probably more to be desired in passenger traffic, but electric working shows to least advantage in fast passenger service, and that in this country its application to such services will follow its adoption in the far wider and more useful field lying ready for it in the working of heavy mineral and goods traffic, the result being increased line-capacity due to the general levelling up of speeds and increase of train-weight, and the same remark applies to local and passenger traffic. Particularly will this be so on lines and sections with large traffic or having heavy gradients, or both; and the fact that by its agency a train 38 per cent. heavier could be taken from Derby to Ancoats on the Midland line in 40 per cent. less time than by a steam locomotive of the maximum weight permissible on that line, and without the electric locomotive exceeding this weight, is evidence enough of the importance of this view of the situation,

particularly when regard is had to the congested state of many of the principal main lines. If the electric locomotive can do so much more work in less time without exceeding the weight of the steam locomotive, then I think it gives food for thought considering the fact that increase of loading gauge and strengthening of bridges, etc., is necessary in this country before further increase in size or axle-weight of our heaviest steam locomotives can be made. The expenditure incidental to the increase of loading gauge, etc., might be set off to a great extent against the expenditure on electrification given the more powerful electric engine of the same, or less weight.

Mr. Barnes talked about a reduction of the coal consumption. By using same at the power house, we are told by the scientists that the coal supply is limited, then why not use the coal at the power station and conserve what we can? Incidentally the quality of coal used in the power house with the present high grade boilers and mechanical stoking plant is, I think, much below that of the good steam coal we are using with the steam locomotive.

One of the great difficulties in the way of electrification of main lines is the tunnel. There would necessarily be the working of electric and steam trains through the same tunnel, within short periods of each other. This point is ably put forward by the Author of the aforementioned lecture. I take the liberty of again quoting from his remarks:—"The maintenance of a high-pressure overhead conductor in the normal British tunnel is a matter of great difficulty, for various reasons. First, and perhaps foremost, a very large number of tunnels in this country require frequent repairs and overhaul, and as such work cannot possibly, save in a small proportion of cases, be done on Sundays, it is difficult to see how with an overhead high-pressure contact wire it can be carried out, at any rate more than six feet above rail level. The erection of staging for the relining or repairing of tunnels would render it impossible to keep an overhead wire through the tunnel. Secondly, supposing this difficulty met, as it possibly may be, the insulation would be a difficult matter, and with the very foul condition of most English tunnels, due to the frequent trains through them, the insulation would prove to be a very difficult problem. Thirdly, the formation of ice is another difficulty, as is well known to railway engineers. Ice already causes great trouble in tunnels, and constant care is required to effect its removal without danger to the traffic. The presence of an overhead contact wire would

probably result in the wire itself becoming overweighted with ice, and in any case would render the proper removal of ice more difficult. The alternative is, of course, the provision of two rails at the side of the track in the six-foot way, more or less protected from accidental contact, the rail being connected to the low-pressure side of transformers fixed at each end of the tunnel, and the high-pressure side being connected to the overhead contact wire; the shoes on the car would be connected to the low-pressure side of the car transformer. It would be quite easy and inexpensive to light the space occupied by the two collecting rails in a tunnel in such a manner as to enable platelayers to work near them without danger from shock."

Mr. Haigh raised the question of the strengthening of couplings which must come with electrification and the larger loads to be hauled. It seems to me that even with steam locomotives we shall have to consider very soon the use of stronger couplings. Increased loads are the order of the day and break-aways are all too frequent. Reverting to "rivers of electricity," a novel point was raised by one speaker during a recent discussion at the Institute of Mechanical Engineers on "Mechanical Road Traction." It was remarked that the statement made in the House of Commons that the railways were to be rivers of electricity would not meet with general acceptance among those concerned with the problem of transport in this country, and he suggested that the rivers of electricity should flow along the main roads. He maintained that light and power along the main roads would develop village and family life and manufacture in a manner impossible if the transport facilities were confined to the railways. The point is a novel one and like some of the other points I have raised may give rise to further discussion.

Mr. W. A. Barnes: There are a few points which have been raised to-night, to which I might briefly reply. The live rail leakage, which was mentioned by the Chairman, is a very small matter with present-day insulators, and the present method of laying the track. On the line which runs out from Manchester to Bury periodical tests are taken both in winter and summer, for about a fortnight on each occasion, of the live rail leakage in the early morning before the traffic starts. That is the worst possible time for leakage. Our worst conditions in foggy weather in winter time are about one ampere per mile, *i.e.*, $1\frac{1}{2}$ h.p. per mile of single track. In dry weather, say a frosty day in winter, or in summer, we cannot measure it even on delicate instruments.

There is, however, a certain loss between the power station and the train, but the figure of 38 per cent. which Mr. Billington gives is on the high side. That might be true of the old systems, but on the more modern systems it amounts to 25-30 per cent., *i.e.*, the loss between the live rail and the bus-bars at the power station.

Mr. Billington : My figure was between the bus-bars at the power station and the rim of the wheel on the motor car.

Mr. Barnes : Then your figure is approximately correct. The failure of the power station and its consequences has been mentioned several times. Things have altered since the early days of the Southport Line, and modern power stations are as reliable as it is humanly possible to make them. In the early days of any electrification you have all your eggs in one basket, and a little break-down at the power station very often has serious results, but as electrification increases so does the number of power stations, and those power stations are capable of helping any other which has trouble, so that the possibility of a total shut down even in a section becomes more and more remote the more electrification increases. Imagine the parallel case of a railway worked by, say, two locomotives.

A good deal has been said about the question of finance, but there is another vital question which has been touched upon by one of the speakers. We as a nation have a certain amount of capital locked up underground in this country. Our coal resources will only last so long, and it is necessary to make use of that coal in as good a fashion as we can, and, therefore, if it can be used more economically by means of electric traction, it is a very strong argument for its adoption.

Mr. Haigh spoke about the handling of goods trains by means of electric locomotives. I had the privilege a few weeks ago of travelling on the Newport-Sheldon Line with an 800-ton train drawn by an electric locomotive. It was not an ideal road for good working, having many and severe gradients. There are very few broken couplings, and the trains were handled quite as well at least as with a steam locomotive, because with a four-motor electric locomotive you can have three running speeds, and a vast number of intermediate speeds by judiciously designed resistances, so that it is possible to run at $1\frac{1}{2}$ miles per hour over a weighing machine, or 35 miles per hour at full speed. Forty thousand miles per annum is the figure which is done on the Liverpool

and Southport and the Manchester and Bury Line. The figure of forty-nine pounds of coal per train mile, which Mr. Billington challenged, is quoted in Sir John Aspinall's Presidential Address before the Mechanical Engineers in 1910. That was the figure at Formby power station for the year 1908. The figure for the Manchester and Bury Line last year was 62lbs., with a very inferior class of coal and a lower load factor.

The systems of electrification are now in a period of evolution, but they are approaching finality, unless some new and very drastic change takes place, and it would appear to be in favour of high tension direct current. America is putting down the biggest plants now with high tension direct current, and passing over the alternating current. On the Chicago, Milwaukee and St. Paul Railway there are 610 miles electrified with 3,000 volts direct current. Another railway is using 5,000 volts, and that seems to be the present trend of affairs. In this country there is no increase in alternating current taking place. The Midland Railway put down about 20 miles at Heysham. The London, Brighton and South Coast have an alternating current system working to-day, and perhaps will have to extend with it, but I can quite believe that the people who have to deal with it would wish otherwise. The North Eastern is 1,500 volts, the Lancashire and Yorkshire 1,200 volts, direct current, showing that the tendency is for high tension direct current.

The Chairman : You said an electric locomotive would do 40,000 miles per annum. Is it 40,000 for one locomotive, or for the whole of the locomotives?

Mr. Barnes : That is the average of all cars in service, about 800 miles per week—the total mileage divided by the number of cars.

Someone raised the question of alternating current motors. In 1905 the Westinghouse Co. were developing their alternating current motor, and everything pointed to the A.C. motor coming forward, and although it has had a great measure of success in the United States, and a considerable mileage of railroads have been electrified with this system, direct current high tension system has now taken the lead, as instanced by the Chicago, Milwaukee and St. Paul Railway, which is 3,000 volts D.C., and the Bute, Anaconda Railway, which is 5,000 volts D.C. The primary, and one might say the only, advantage of the A.C. system was the small size conductors (and consequently small cost) employed, due to the high working voltage, but by the

employment of high tension direct current system this advantage is negatived, and you have a system with all the inherent advantages of the D.C. motor.

Practically all traction power stations at the present time supply alternating current to sub-stations, where it is transformed and converted for traction needs, but this method of supply should not be confused with alternating current systems. In the A.C. system the motors on the train are A.C., and in the D.C. system the motors on the train are D.C., the generated A.C. supply being only a means to an end.

The Chairman: The advance of electricity is very marked; at any rate we know that in the workshops. I think in that case you had so very much for it to do. We know that electricity is improving in its developments and applications; and, there is no doubt about it, the capital of this country lies underground, and anything that can be done to preserve that capital and make the best use of it should receive attention.

Road traction from the point of view of cost will never compete with the main railways to-day, whether steam driven or electric.

In regard to the Newport-Sheldon Line, this is a line I know very well. It was most interesting to hear Mr. Barnes say that it was one of the earliest routes worked by the steam locomotive, and I presume from what he said it is now one of the routes which has got the most up-to-date electric locomotives working over it, which are chiefly used for goods traffic. He has explained how they get over the difficulty of "snatching" couplings, *i.e.*, having four motors, and so get various speeds and start a train with the least power, and accelerating without putting too much "snatching" on the couplings, and as they get going increase the power as they require it.

I propose a very hearty vote of thanks to Mr. Barnes for coming to-night and opening this discussion.
