SYMPOSIUM ON RAILWAY ELECTRIFICATION

No. 1293*a*

ELECTRIFICATION OF SUBURBAN RAILWAYS

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Many of the railways of this country have, so far as their suburban passenger traffic is concerned, been affected very adversely in recent years by the great and increasing competition of tramcars and motor omnibuses. The companies concerned appear undecided at present between giving up a great portion of this class of traffic permanently and endeavoring to regain it by electrification of their suburban lines. The latter expedient, although an expensive one, has hitherto invariably been found successful in regaining much of the lost traffic, and the problem confronting a company in regard to any section of its suburban lines is that of determining whether the expected gain from electrification will justify the expense to be incurred.

2 Modern electric railway apparatus leaves little to be desired in the matter of freedom from breakdown, the delays from all causes electrical and mechanical, for the month of December 1909 averaging about 33 sec. per day per train on the District Railway and only 2½ sec. per day on the Underground Electric Railways tubes. The total cost for maintenance and repairs of rolling stock on these lines does not exceed 0.6*d.* per car-mile.

3 There are 18 electric railways at present working in this country, including seven tube lines; these comprise about 200 miles of route in all, and are for the most part worked by motor coaches, employing a multiple unit system of control. The coaches are generally of the saloon type.

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[1] With British Thomson-Houston Co.

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4 In typical suburban service the greater part of the energy input is used in accelerating the train, and the energy consumption per ton-mile depends principally on the nature of the schedule; in fact, this energy consumption is a good measure of the difficulty of a schedule, but an even better measure is the uniform acceleration that would cause the train to reach the mean running speed in a distance equal to the average distance between stations. This acceleration is greatest for the Liverpool Overhead Railway's schedule, a fact which explains the high energy consumption per ton-mile actually found in this service. A high initial rate of acceleration involves great mechanical strains on the bogies, and should not be employed unless the difficulty of the schedule renders it necessary. The equipment losses during acceleration are of the same order of magnitude in the continuous-current and the single-phase systems, in spite of the rheostat losses in the former system.

5 The performance of a given electric train under given conditions of suburban service can be very closely predetermined, for the factors liable to uncertainty have but small effect on the result. Schedule calculations, however, are inadequate by themselves to determine the question of the suitability of an equipment, as the limiting features are usually connected with the heating of the motors, which again depends on the energy loss in the motors. This loss is much greater in the single-phase system than in the continuous-current system.

6 There appears little prospect of general electrification of the railways of this country, as no advantage is apparent which would in any way justify the expense. It is only in the case of heavy suburban service that there is prospect of commercial advantage accruing from electrification, and whilst there may be other local opportunities for electrical working, there is at present no indication that the steam locomotive can be superseded with advantage for ordinary main-line work.

7 The shrinkage of suburban traffic has for several years past proved a source of lachrymose complaint at many of the general meetings of our railway companies. The extensive tramway systems that radiate from most of our large cities provide a convenient, cheap and comparatively rapid means of transport with which the railways are ill-adapted to compete. Where a tramway runs directly parallel to a railway, it may be expected to secure the greater portion of the purely short-distance traffic, and it would seem that the distances over which its competition is effective are greater than might at first be supposed. At the general meeting of the London

& North Western Railway, held on February 19, 1909, the chairman in discussing this point said that, "he would be unwilling to say what the distance was (it might be 10 or 12 miles), but after such a distance the railway was the more punctual and the more certain way for a man to get to his destination. Within the 10 or 12 miles the tramway competition was very severe, but beyond that distance the railways were not so much touched by the tramways." The advent of the motor omnibus has also affected suburban railway traffics adversely, particularly in the neighborhood of London, the flexibility of its route, its speed and general convenience giving it a great advantage in ministering to the needs of comparatively short-distance passengers.

8 With the main routes of street traffic worked by tramcars and auxiliary routes by motor omnibuses, the railways as at present operated are at a great disadvantage, and bid fair to lose most of their suburban passenger traffic. The second report of the London Traffic Branch of the Board of Trade[1] gives the loss of passengers by five railways as upwards of 12,000,000 in 1908 as compared with 1907, and of 47,000,000 in 1908 as compared with 1902, both figures being exclusive of season-ticket holders, and taking no account of the increase in the number of long-distance passengers indicated by the receipts.

9 The railway companies affected appear for the most part undecided between allowing their short-distance traffic to go, employing their energies in fostering the longer-distance traffic, and endeavoring to reduce the effective range of tramway competition by electrification of their suburban lines. The latter alternative, wherever it has been tried, has invariably succeeded in recovering a portion of the lost traffic, besides creating a more desirable traffic for longer distances by the improvement of facilities. Whilst it is by no means certain that local electrification would prove the best commercial policy in the case of all railways handling suburban traffic, it is the author's opinion that there is considerable scope for well-considered electrification schemes in this country.

10 Where a suburban railway is regularly used to near the limit of its capacity and there is still possibility of increased traffic, there is every reason to expect a commercial advantage from electrification. Both here and abroad the improved service has always been the means of largely increasing the traffic, whilst the capital cost is

[1] Cd, 4988, pp. 38 and 131.

further justified by the greater use that can be made of existing lines and terminals under electrical operation. The cost of electrification should in fact be set against the cost of widening and improving the railway to accommodate the traffic in view.

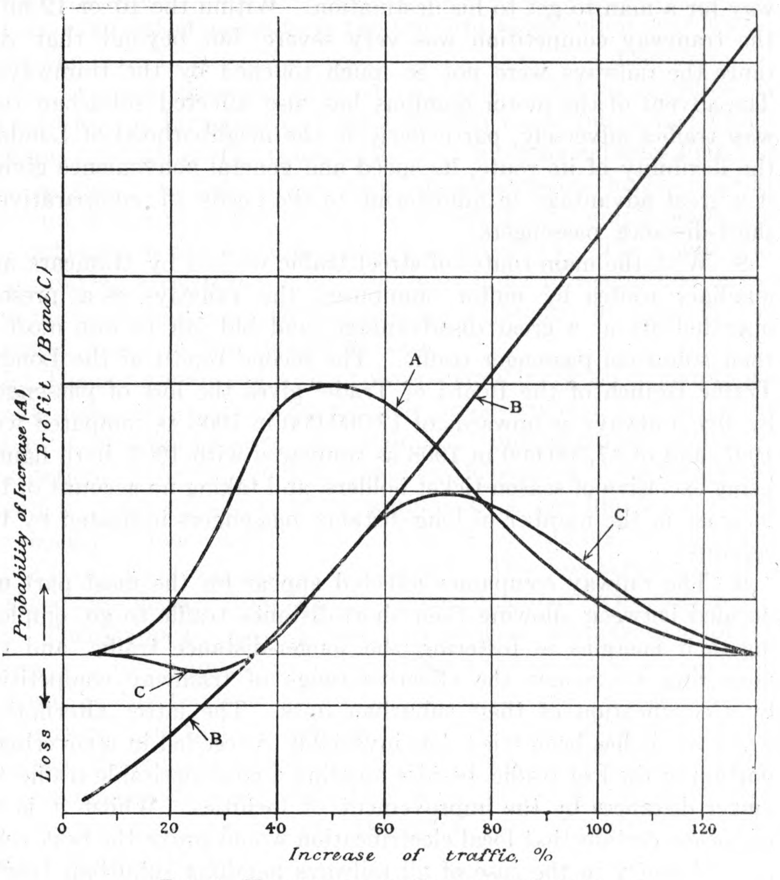

FIG. 1 ESTIMATION OF PROBABLE PROFIT

11 In the more usual case, however, the management of a railway are compelled to estimate the chances of success from far less certain data. Consider, for instance, the line from Birmingham (New Street) to Sutton Coldfield and Four Oaks. It passes through a populous and growing residential district, feeding also one of the most beautiful pleasure resorts of Birmingham people. The present trains, of which there are about 30 per day in each direction, make a schedule speed, including stops a little over a mile apart, of approximately

18 mi. per hr., the grades being rather severe. As the whole distance in question is little more than eight miles, it is small wonder that the tramway, which now parallels the line for a considerable distance and offers a frequent service at low fares, takes the greater part of the traffic so far as it extends. Although the population served has largely increased in recent years, the passenger traffic on the railway appears to have decreased considerably since the opening of the tramway, and will doubtless decrease still further as the tramway is further extended. If this section of the railway were electrified, the schedule speed might be increased by 30 per cent or 50 per cent and trains run every 15 min. or so throughout the day, say two-coach trains during hours of light traffic and six-coach trains during the busy hours. The capital cost of electrification and the expense of such electrical working could be very closely estimated. The real difficulty which confronts the management is in estimating the increase in receipts which would accrue from the improved facilities. This is an economic problem to which no certain answer is possible. So many considerations enter into the matter that experience in one locality is no sure guide in making an estimate for another.

12 The appropriate method of treatment for any such problem in estimation is provided by the theory of probability. If from the experience of other electrified lines, and from knowledge of the particular district, such a curve as *A* (Fig. 1), can be improvised (the abscissae of which represent the increase of passenger traffic resulting from a certain improvement in facilities, whilst the ordinates are proportional to the probability of such increase), the probable value of the advantage of providing the improved facilities can be deduced. Assuming the operating and capital expenses known, the net profit with any particular traffic can be deduced. Let the increase of profit above the old method of operation be represented by curve *B*, and deduce curve *C*, whose ordinate is the product of the ordinates of curves *A* and *B*. Then the area of curve *C*, as compared with that of the probability curve *A*, gives the probable value of the advantage of providing the improved facilities. While the probability curve may be subject to considerable uncertainty, the result of such calculation as indicated above, if properly interpreted, is likely to be of much greater value than a figure derived from a simple estimate of the increase of traffic.

13 It has generally been found hitherto that the increase in traffic due to electrification has exceeded the estimates formed of it. Thus at the February 1905 meeting of the Lancashire & Yorkshire Rail-

way Company, the chairman stated, concerning the electrified Liverpool-Southport line, that "the increase in the traffic had exceeded their most sanguine expectations." At the February 1906 meeting of the North Eastern Railway Company, the deputy chairman, referring to the Tynemouth electrification, said that "in the last half of 1903, with steam traction, they had 2,844,000 bookings, and in the last half of 1905, with electric traction, they had 3,548,000, an increase of, in round figures, 25 per cent. In 1903 the gross amount of money earned with steam traction was £129,000, and in 1905 with electric traction the gross amount of money earned was £151,000, and they had run in 1905 twice as many trains as in 1903. In 1903, to earn the £129,000, the running expenses amounted to £42,761, while to earn the £151,000 it cost £47,799, which was only £5000 more to do twice the work in 1905 that they did in 1903. He would give the figures in another way, as many persons were interested in train-mileage cost. In the electric traction on the 31 miles of suburban railway in the Newcastle district they had practically doubled the train mileage and doubled the accommodation of the public, and the running cost per train-mile, allowing for depreciation of stock, etc., has been with electric traction about 9*d.* per train-mile as compared with 1*s.* 5½*d.* per train-mile under steam conditions. They had run smaller trains but there were more of them. They were thus able to serve the public better and at the same time to make a better profit for themselves." At the February 1907 meeting of the North Eastern Railway Company, the deputy chairman explained that in the last half of 1906 they had carried 4,195,339 passengers on the electrified lines as against 3,548,206 in the corresponding half of 1905, a further increase of 18 per cent, making a total increase of 47½ per cent as compared with the last half-year that steam operation was exclusively employed. At the last February meeting of the London, Brighton & South Coast Railway Company, the chairman announced that the increase in passengers on the elevated electric line between Victoria and London Bridge for the two months, December 1909 and January 1910, during which the line had been open, was, as compared with the corresponding period of 1908–1909, 440,536, or 63 per cent.

14 It has been stated above that the capital outlay and operating expenses can be closely approximated in any particular case. The amount will depend largely on the difficulty of the proposed schedule. It is in the power of electricity to improve very greatly on the performance of steam trains; but the greater the improvement, the

higher the capital and operating costs and the greater the attractiveness of the line. It is a matter of nice estimation and computation to determine what improvement of service will result in the greatest commercial advantage to the railway. The Tynemouth lines and the Liverpool-Southport line do not differ greatly in the distance between stops. The schedule speed is however considerably higher on the Liverpool-Southport line, and the effect of this on operating expenses is to some extent revealed in the above extract from the statement of the North Eastern chairman as compared with that of the Lancashire & Yorkshire chairman at the February 1906 meeting: "they found after a full year's experience that the cost of electric working, as they had expected, was, when proper allowances were made for the depreciation of the more costly plant, slightly higher per train-mile run" (than that of a steam working). Other features doubtless affect the comparison,[1] but the greater portion of the difference in running cost can probably be ascribed to the difference in the schedule speeds.

15 The electrification of a steam railway can of course be considered commercially expedient only when the estimated net profit under electrical operation exceeds that under steam operation by more than the interest on the extra capital involved. It is chiefly the burden of capitalization which limits electrification to lines of heavy traffic. The extent of the burden is in practice very variable. The total capital involved in the Tynemouth electrification to date is approximately £244,000, and the annual electrical train-mileage, 1,215,000[2]; taking the interest at 4 per cent, which appears to be about the average value of railway investments here, the capital burden is seen to be about 1.93*d.* per train-mile. Again, the capital involved in the electrification of the South London elevated line has been given as approximately a quarter of a million sterling[3] and the yearly train-mileage is at present some 375,000, to be eventually increased to approximately 585,000 miles.[4] The burden of the capital is therefore about 6.4*d.* per train-mile at present decreasing to 4.1*d.* if the improved service can be realized without adding to the

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[1] From Board of Trade Railway Returns, 1908, it would seem that the coaches per train average 3.4 for the L. & Y. Railway, and 3.1 for the N. E. Railway. See also President's Address, Proc. I. Mech. E., 1909, Pt. 2, p. 432.

[2] Board of Trade Railway Returns, 1908.

[3] Electrical Review, vol. 56, p. 953.

[4] Light Railway and Tramway Journal, vol. 22, p. 17.

capital expense.[1] The capital burden in the case of the Mersey Railway has been given as 4.3*d.* per train-mile, and in the case of the Lancashire & Yorkshire electrified lines as about 2*d.* per train-mile.[2] These two cases of course include generating station, which is absent in the first two.

16 An indispensable requirement to the success of any system for working suburban traffic is immunity from all forms of breakdown competent to delay the service. In this respect modern electric railway apparatus, the design and construction of which has been developed by arduous experience, if chosen with reference to the nature of the service and maintained with care, leaves little to be desired. Even when first installed the troubles are usually of a minor character, and the consequent delays unimportant, whilst ordinary operation is exceedingly reliable so far as the electrical plant is concerned. The author is indebted to Mr. James R. Chapman, late Chief Engineer of the Underground Electric Railways Company of London for the following figures, giving particulars of all delays on lines under the company's control for the month of December 1909 (Table 1). The much greater loss of time on the Metropolitan District Railway, as compared with the tube lines, is almost entirely due to the fact that district trains operate to a considerable extent

TABLE 1 TRAIN DELAYS, DECEMBER 1909

	District	Tubes*
Total number of train-miles	401,295	499,908
Total number of delays (all causes)	303	44
Total time lost by delays, min	1136	107
Train-miles per delay	1324.4	11,361
Train-miles per min. lost	338	4672
Total number of delays due to electrical troubles on the trains	54	21
Time lost due to electrical troubles on the trains, min	135½	75
Train-miles per electrical delay	7431	23,805
Train-miles per min. delay on account of electrical troubles	2961	6665
Average mileage per train per day	185	194.85
Average delay per train per day due to electrical troubles on the trains, min.	0.062	0.029
Average delay per train per day due to all causes, min	0.548	0.042

***Baker Street & Waterloo Railway; Great Northern, Piccadilly & Brompton Railway; Charing Cross, Euston & Hampstead Railway.**

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[1] This would involve running each of the present eight trains an average of 73,000 miles per annum.

[2] Proc. Inst. C. E. vol. 179, pp. 42 and 119.

over foreign lines, worked for the most part in the interests of steam trains.

17 The comparative immunity from breakdown is duly reflected in the low maintenance costs of the train equipments. Mr. Chapman dealt with this subject at a valedictory dinner given in his honor on February 7, 1910, on the occasion of his retirement from the position of chief engineer to the Underground Company. He said that they (the Underground Railways Company) "owned over 800 motors, and that every one was the same throughout, no matter whether it was working on the district or a tube, under a car or on a locomotive, all were interchangeable; and today, several years after the original purchase, they were negotiating for some more of the same motors to meet the increased traffic requirements of the District Railway. On no one of their properties did the cost of rolling-stock maintenance and repairs exceed 0.6*d.* per car-mile. The ten District Railway electric locomotives, now five years old, made 1300 mi. per day at a cost of ½*d.* per mi. for all maintenance and repairs. Two of them coupled handled a London & North Western Railway nine-coach train to Mansion House far better than a steam locomotive had ever done. The maintenance cost was 1*d.* per train-mile. The North Western costs for maintaining a steam locomotive were 4*d.* per mi.; the average cost for all English railways was 3½*d.* per mi. Five years after this system had been designed, the Pennsylvania Railway had experimented for two years at a cost of $200,000 to determine the electric system to be adopted for bringing their trains through the Hudson River Tunnel into their magnificent New York terminal, and had decided in favor of the same system as they (the Underground Railways Company) had today."

18 The railways in this country operated wholly or in part electrically are 18 in number, working over a total of approximately 200 miles of route and 410 miles of track. The trains are worked by 87 locomotives and 821 motor coaches. The aggregate nominal power of the driving motors is approximately 360,000 h.p., of which 184,000 h.p. is provided by one type of motor alone, namely, that used exclusively by the railways operated by or in conjunction with the Underground Electric Railways Company, London,[1] and partly by the Metropolitan Railway.

19 Of the 18 electric lines 13 are in the London area (including

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[1] The Metropolitan District; Baker Street & Waterloo; Charing Cross, Euston & Hampstead; Great Northern, Piccadilly & Brompton; London, Tilbury & Southend; and Whitechapel and Bow Railways.

seven tube lines), three in the neighborhood of Liverpool, one at and near Newcastle and one between Heysham, Morecambe and Lancaster. As full details of all the lines have been published (Appendix No. 1), there is no necessity to give more than a brief comparative summary here.

20 The oldest of the London lines is the City & South London Railway, which was not only the first tube railway but one of the first electric railways to be constructed, having been opened for traffic in 1890. It extends for 8 miles, from Clapham Common to Euston, and is carried in a 10 ft. 6 in. tube. It is unique among electric railways in transmitting high potential continuous current (2000 volts) and distributing to the trains by the three-wire system, the up and down track conductors being of opposite polarity, whilst the track rails form the middle conductor. The traffic is still worked exclusively by electric locomotives.

21 The Waterloo and City line of the London & South Western Railway is also comparatively old as electric railways go. It is 1½ miles long, and is carried in a 12-ft. tube. The trains are worked by motor coaches, mounting for the most part gearless motors, directly controlled. The track rails are used as return conductors.

22 The Central London Railway was the first to employ polyphase transmission of power and conversion to continuous current at sub-stations. The line is 6½ miles long, and is carried in an 11-ft. 8-in. tube. The traffic was originally worked by locomotives, but is now handled entirely by multiple-unit trains using the electro-magnetic system of control, this railway having been the first to employ the multiple-unit system of operation. Power is supplied to the trains by a third rail, and the track rails are used as return conductors.

23 The Great Northern & City Railway is the only tube sufficiently large to accommodate main line rolling stock, the minimum internal diameter being 16 ft. It is 3½ miles long, and is supplied with power from a central power station, which feeds directly to positive and negative conductor rails. The trains are of the multiple-unit type, using the electro-magnetic system of control.

24 The Underground Electric Railways Company of London operate three tube lines, namely, the Baker Street & Waterloo Railway (4½ miles), the Great Northern, Piccadilly & Brompton Railway (9 miles), and the Charing Cross, Euston & Hampstead Railway (8 miles). These are all run in tubes of 11 ft. 8 in. minimum diameter. Power, which is generated at the company's great power-station at Lots Road, Chelsea, is supplied to the railways through 12 sub-

stations, being distributed to the trains by positive and negative conductor rails. The traffic is worked exclusively by multiple-unit trains using the electro-magnetic system of control.

25 The Metropolitan District Railway comprises 25 miles of route, but, including running powers, operates over 56 miles in all. Of this, 41 miles is supplied with power from Lots Road power station, through 15 sub-stations, it being distributed to the trains by positive and negative conductor rails. The District trains are of the multiple-unit type, using the electro-magnetic system of control. A number of foreign trains are brought to the company's lines at Addison Road Station, whence they are hauled by electric locomotives. The Whitechapel & Bow Railway and the electrified portions of the London, Tilbury & Southend and the London & South Western Railways are worked in conjunction with the District, using the same or similar rolling-stock and their route mileage is included in the 41 miles given above.

26 The Metropolitan Railway has some 26 miles of its lines electrified. It employs the same system of operation and the same location of conductor rails as the Metropolitan District Railway; the Inner Circle being, in fact, jointly worked by the two companies. The Metropolitan Company generate power at their own power-station at Neasden, which feeds their lines through nine sub-stations. The trains are, for the most part, of the multiple-unit type, both the electro-magnetic and the electro-pneumatic systems of control being used. A number of trains are made up of the old steam stock and hauled by electric locomotives, which also handle the goods traffic over the electrified lines.

27 The Hammersmith & City Railway is a joint Metropolitan & Great Western line. Except on the Metropolitan section between Aldgate and Pared Street Junction, the power is supplied by the Great Western Company's power station at Park Royal. The trains are of the multiple-unit type, the electro-magnetic system of control being used.

28 The electrified section of the London, Brighton & South Coast Railway extends for 8½ miles from Victoria to London Bridge Stations, via Bruxton. It has the distinction of being the first of the London railways to adopt the single-phase system of operation. It is supplied with power at 6600 volts, 25 cycles single-phase, by the London Electric Supply Corporation, the feeding cables being run to a central distributing cabin at Denmark Hill through a metering cabin near Queen's Road Station. Thence the power is conveyed

to a number of switch cabins which feed the overhead track conductors. The outer of the concentric distributing cable is bonded to each length of track rail and forms the return conductor. The trains are of the multiple-unit type, employing the electro-magnetic system of control.

29 The Liverpool Overhead Railway is one of the oldest of electric railways, having been opened for traffic in 1893. It is 7 miles long, and carried on an elevated structure alongside the docks. It is a third-rail line, fed from a power station near its centre. The service was reorganized and greatly accelerated in 1902. The trains are worked by means of motor-coaches, the motor control being directly operated by the driver.

30 The Mersey Railway has 4¾ miles of route, connecting Liverpool with Birkenhead by means of a sub-aqueous tunnel. It was converted from steam to electricity in 1903, largely on account of the difficulty in maintaining efficient ventilation in the tunnel. Power is supplied from a central power station directly to the conductor rails. The trains are of the multiple-unit type, the electro-pneumatic system of control being used.

31 The Lancashire & Yorkshire Railway have some 28 miles of route electrified in the neighborhood of Liverpool. Power is generated at Formby power station, and transmitted to four rotary sub-stations, whence it is distributed to the third rail, and also to a number of battery sub-stations. The return conductor is an uninsulated fourth rail, bonded to the track rails. The trains are worked by motor coaches, of which the motors are for the most part directly controlled by the driver, although a few multiple-unit trains have recently been introduced, using an electro-magnetic system of control.

32 The North Eastern Railway have about 30 miles of electrified route in their Tynemouth lines. Power is bought from the Newcastle Electric Supply Company and transmitted three-phase to the five sub-stations which feed the conductor rails. The track is used as return conductor. The trains are of the multiple-unit type and employ the electro-magnetic system of control. Some of the later coaches are equipped with commutating-pole motors, the North Eastern being the first railway in the country to use this type. A quantity of fish and parcel traffic is handled by special motor-vans, whilst two electric locomotives handle goods trains, particularly on the Quayside line.

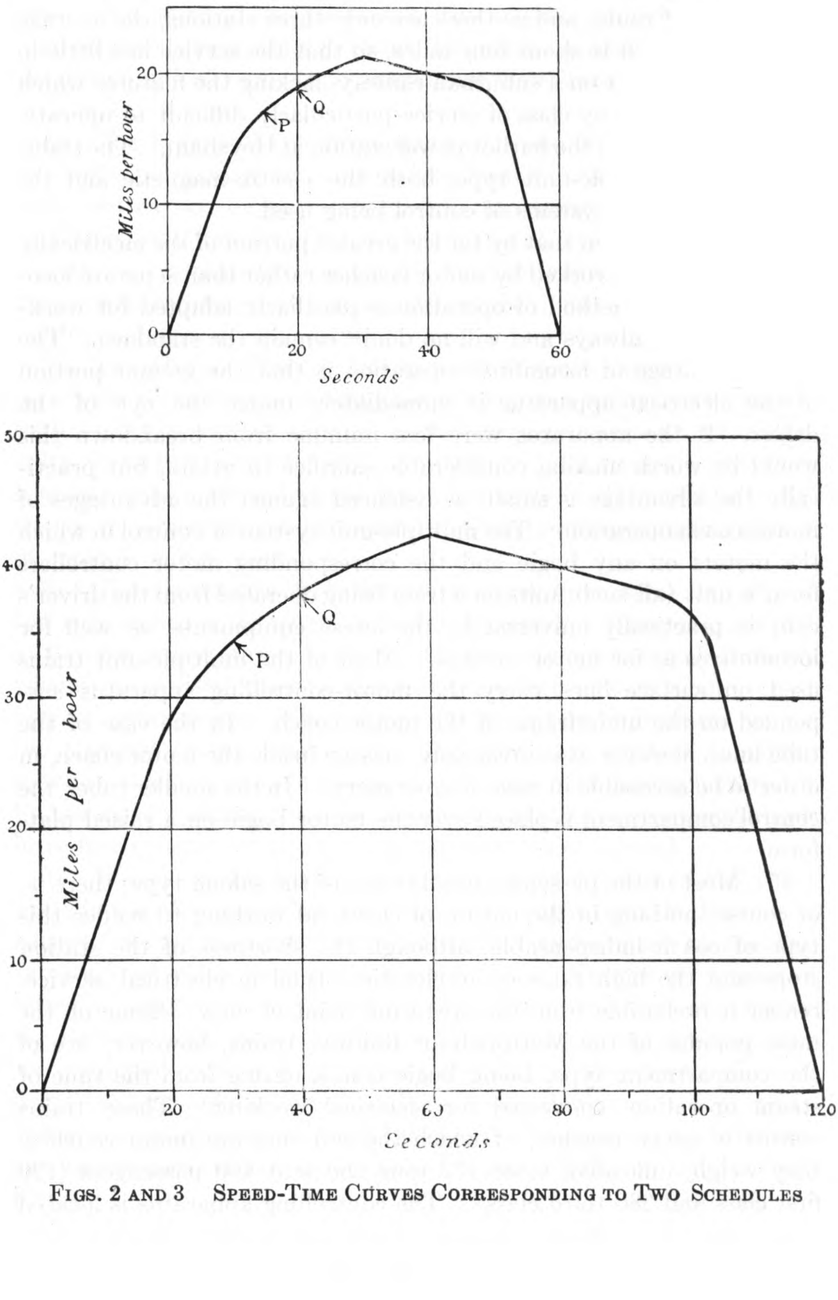
33 The Midland Company's electrified line at Heysham is an interurban one of an experimental nature, it being the first single-

phase railway opened for traffic in this country. It comprises some eight miles of route, and as there are only three stations, the average length of the run is about four miles, so that the service has little in common with that on a suburban railway, lacking the features which go to make the latter class of service particularly difficult to operate. The line is fed from the harbor power station at Heysham. The trains are of the multiple-unit type, both the electro-magnetic and the electro-pneumatic systems of control being used.

34 It will be seen that by far the greater portion of the electrically operated traffic is worked by motor coaches rather than separate locomotives. This method of operation is peculiarly adapted for working suburban railways and will no doubt remain the standard. The chief advantage of locomotive operation is that the greater portion of the electrical apparatus is immediately under the eye of the driver. If the apparatus were less immune from breakdown this would be worth making considerable sacrifice to attain, but practically the advantage is small, as balanced against the advantages of motor-coach operation. The multiple-unit system of control in which the motors on any bogie and the corresponding motor controllers form a unit (all such units on a train being operated from the driver's cab) is practically universal in the latest equipments, as well for locomotives as for motor coaches. Most of the multiple-unit trains used on surface lines carry the motor-controlling apparatus suspended on the underframe of the motor coach. In the case of the tube lines, however, it is invariably located inside the motor coach, in order to be accessible in case of emergency. In the smaller tubes the control compartment is placed over the motor bogie on a raised platform.

35 Most of the passenger coaches are of the saloon type; there is, of course, nothing in the nature of electrical working to render this type of coach indispensable, although the shortness of the station stops and the high rates of acceleration usual in electrical service, render it preferable from the operating point of view. Some of the most popular of the Metropolitan Railway trains, however, are of the compartment type, being bogie trains, dating from the time of steam operation, converted for electrical working.[1] These trains consist of seven coaches, of which the end ones are motor coaches; they weigh, unloaded, some 172 tons and seat 400 passengers (120 first class and 280 third class). The controlling apparatus is located

[1] Tramway and Railway World, vol. 20, p. 325.



FIGS. 2 AND 3 SPEED-TIME CURVES CORRESPONDING TO TWO SCHEDULES

in what was formerly the guard's compartment, of which the fore-end forms the driver's cab.

36 The London, Brighton & South Coast Railway have sought to combine some of the advantages of both types of coach in the new rolling-stock for their South London Elevated Electric line. The coaches are of the corridor type, being divided into compartments, and having side doors, but having a corridor running the length of the coach for distributing the passengers. The trains consist of three coaches, of which the two end ones are motor coaches; they weigh unloaded some 138 tons and seat 188 passengers.

37 Although most of the railways in this country employ the vacuum brake, the electric railways, with the exception of the Lancashire & Yorkshire and the Midland, have adopted the Westinghouse type of brake. The chief reason for this is that compressed air can be stored to take off the brakes at a moment's notice. If the vacuum brake be employed it is necessary to use a rather large exhauster, in order to fulfil the function of the large ejector on a steam locomotive in producing a vacuum rapidly. The space and material are, therefore, not used to advantage in this system as compared with a pressure system. The locomotives used on the London Underground Railways, having to work trains of all kinds, are fitted to use either system.

38 In suburban service the greater part of the energy expended is used in giving speed to the train and is ultimately dissipated in the brakes. Other things being equal, therefore, the more frequent the stops the greater is the energy required per mile, and the more difficult the service. The energy consumption per ton-mile, unless abnormal, is, in fact, a very good measure of the difficulty of a service. If this were more generally realized the world might be spared some of the absurd comparisons of energy consumption between different systems, in which credit is claimed for obtaining a low energy consumption, which is really due to comparatively easy service. As the author has pointed out elsewhere,[1] the figures derived from test of 42 watt-hr. per ton-mile for the energy-consumption of the Central London Railway trains and 137 watt-hr. per ton-mile for the Liverpool Overhead Railway trains, are strictly comparable and indicate no more than totally different services on totally different railways.

39 If it be granted that the natural and normal energy consumption per ton-mile is a reasonable measure of the difficulty of a schedule,

[1] Proc. Rugby Engineering Society, vol. 6, p. 39; Electrical Engineer, vol. 43, p. 303.

an even more reasonable measure is to be found in a certain acceleration immediately expressible in terms of the particulars of the service, namely, the acceleration that would cause the train to reach a speed equal to the mean running-speed in a distance equal to that between stops. This is merely a dynamical result, and in order to show it, let Figs. 2 and 3 represent speed-time curves corresponding to two schedules, the curves being such that that of Fig. 3 is simply that of Fig. 2 magnified twice in every direction. The distance represented in Fig. 3 is then four times that in Fig. 2. At corresponding points *P* on the two curves, the acceleration, and therefore the tractive effort per ton necessary to produce it, will be the same. The power per ton required at *P* to produce the acceleration, being proportional to the tractive effort and speed, is twice as great in Fig. 3 as in Fig. 2. The energy per ton required to accelerate between corresponding points *P* and *Q*, being proportional to the power and to the interval of time, will be four times as great in Fig. 3 as in Fig. 2. But the distance is also four times as great, and thus the energy per ton-mile used in accelerating (probably some two-thirds of the whole) is the same for the two services. If the mean train-resistance per ton were the same for the two curves, the energy per ton-mile required to overcome the resistance would also be the same, and we might then assert that the total energy output per ton-mile would be the same in the two cases. As it is, there is a small error affecting a comparatively small portion of the energy, which will have to be neglected. This is in general of little consequence in cases in which it would be expedient to employ the result, that is, in suburban service, where a ratio of four to one in distance with similar speed curves is, of course, a very exaggerated case. It will be seen that the acceleration referred to above, which will be called the specific acceleration of the schedule, is the same for the two curves, being the square of the mean running speed divided by twice the distance. It will also be seen that the method is perfectly general: so long as the speed-time curves for two services are similar the specific acceleration will be the same, and the energy output of the equipments practically the same. It follows that of two services, that having the higher specific acceleration may be expected to show the higher energy consumption per ton-mile. Also that if two services have the same specific acceleration but differ in energy consumption the higher can be reduced, in so far as it is not due to lower equipment efficiency, by running so as to assimilate its speed-time curve to that of the lower.

40 The specific acceleration of a schedule is a better index of the

difficulty of the schedule than the energy consumption, inasmuch as it is independent of the equipment efficiency and of the particular manner of running the schedule, in effect reducing equivalent services to the same mode of operation. This, of course, presupposes that the line is not specially graded to reduce the difficulty of operation. The Central London Railway, for instance, was so laid out that each station is at the top of a grade; thus energy that would otherwise be dissipated by the brake shoes is stored and used for accelerating, making the line easier to work and the energy consumption lower than would be indicated by consideration of specific acceleration alone.

TABLE 2 CHARACTERISTIC SCHEDULES

Line	Average distance between stops, ft.	Schedule speed, mi. per hr.	Time of stop, sec.	Average speed excluding stops, mi. per hr.	Specific acceleration, mi. per hr. per sec.
Liverpool Overhead	2145	19.5	11	22.9	0.179
Liverpool-Southport	6535	30	15	33.4	0.125
Underground, Inner Circle	2555	15.7	20	19.2	0.106
Baker Street and Harrow	5000	23	20	26.6	0.104
South London Elevated	4540	21.5	20	25	0.101
Hammersmith and City	2830	16	20	19.2	0.096
Central London	2540	14.7	20	17.7	0.090
North-Eastern, Tynemouth	6000	20.5	30	24.1	0.071
Midland, Heysham-Morecambe	23500	26.7	120*	33.4	0.035

*Assumed.

41 The above is an application of a method which the author has more fully elaborated elsewhere.[1] Table 2 gives some characteristic schedules arranged in order of difficulty as indicated by the specific acceleration.

42 A difficult service (in the sense of a service in which the specific acceleration is high) is one in which it is advisable, in the interests of low energy consumption, to employ high rates of acceleration and retardation; in an easy service this is of smaller consequence and hardly worth securing at the cost of heavy mechanical strains on the bogies, etc., with the great draft of power incident to the use of a high rate of acceleration. The account of the tests on the Liverpool Overhead trains indicated a maximum rate of acceleration of 4.2 ft. per sec.[2] (2.9 mi. per hr. per sec.), and this is perhaps as high as it

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[1] Trans. A. I. E. E., vol. 20, p. 991; Journal Proc. Inst. E. E., vol. 36, p. 240.

[2] The Engineer, vol. 93, p. 284.

is advisable to employ in service. The author has a record of a run actually made with a coach carrying a motor on each axle, in which an average rate of acceleration of 4.2 mi. per hr. per sec. was maintained until a speed of 21 mi. per. hr. was reached (Fig. 4). The test was made with a view of showing the possibility of electrical equipments in this connection, and the acceleration was certainly faster than would be considererd comfortable to passengers.

43 During the period of acceleration by controller notching, considerable energy loss is inevitable in the equipment. In the continuous-current system the average equipment efficiency during notching is usually only about 57 per cent, the remaining 43 per cent being lost in the motors, rheostats, etc. It has been hastily assumed by some that the avoidance of rheostat losses in the single-phase system would result in much lower losses and higher mean efficiency during notching. That this is an unwarranted conclusion is shown by the authors of a recent paper on the Heysham electrification,[1] who, although by no means blind to the merits of the single-phase system, found as the result both of test and calculation, that the mean efficiency of the equipment during notching was only 56 per cent in the cases considered. The efficiency after notching is of course con-

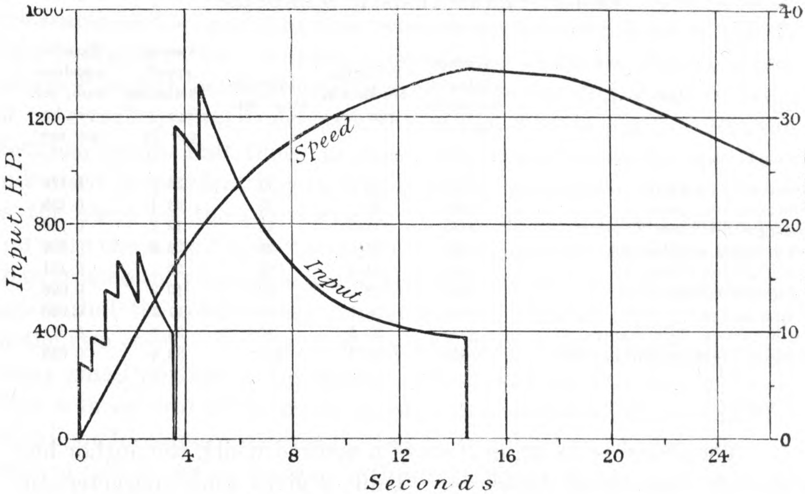

FIG. 4 TRAIN CHARACTERISTICS

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[1] Proc. Inst. C. E., vol. 179, pp. 188, 189.

siderably higher for continuous-current than for single-phase equipments.

44 The claim that the performance of a suburban electric train can be very closely predetermined may seem an extravagant one, until it is considered how very few are the conditions on which it depends. The relation between the tractive effort and speed of a given motor is perfectly definite, but subject to small known variation with temperature, at any given voltage, as is the current taken, whilst different motors of the same type agree closely in their characteristics. Assuming the train known as to weight, size, etc., the resisting forces due to grades, inertia and train resistance are known. It, therefore, requires a dynamical calculation of no great difficulty to determine the effect of the motors on the train for any particula rroute or schedule. The quantities most likely to be subject to some uncertainty beforehand are the voltage at the train and the train resistance. In suburban work, however, a small error in these has but little effect either on the schedule speed or energy consumption. Perhaps an idea of the accuracy with which the running can be predetermined will be best conveyed by disclosing that the author's practice, in making a guarantee of energy consumption, is to compute it as closely as possible under the expected conditions of test and add 5 per cent to cover bad driving and other unforeseen contingencies. Such a guarantee would, of course, be of little use unless accurate instruments were available for making tests. Train-testing instruments should be specially designed for the work, so as to secure exceptionally large torque and heavy damping. The delicacy of ordinary stationary instruments renders them useless for train-testing where they are subject to great vibration in all directions.

45 These schedule calculations are easy and commonplace but quite inadequate by themselves to determine whether an equipment is suitable for a given service. More important in this connection are the calculations involving the magnitude and distribution of the losses in the motors, with the facilities for transferring and dissipating the heat generated. Such calculations are, however, almost necessarily confined to the designers of equipments, as the data on which they are based are not generally available. In order to give a rough idea of the quantities involved, it may be stated that the ultimate temperature rise of the hottest accessible part of an ordinary railway motor, totally enclosed and without forced ventilation, as measured by centigrade thermometer after continuous service, is given approximately by

$$T = 7Ww^{-\frac{2}{3}}$$

where W is the mean motor loss in service (not including gear loss) in watts, and w is the weight of the motor in lb., excluding gear and gear case. The motor losses in suburban service usually take from $6\frac{3}{4}$ per cent to 7 per cent of the input to the driving equipment, that is motors and rheostats, in the continuous-current system, and from 15 per cent to 18 per cent of this input in the single-phase system. The great motor losses incident to the single-phase system form the foundation of all the objections raised to the use of this system for suburban service.[1]

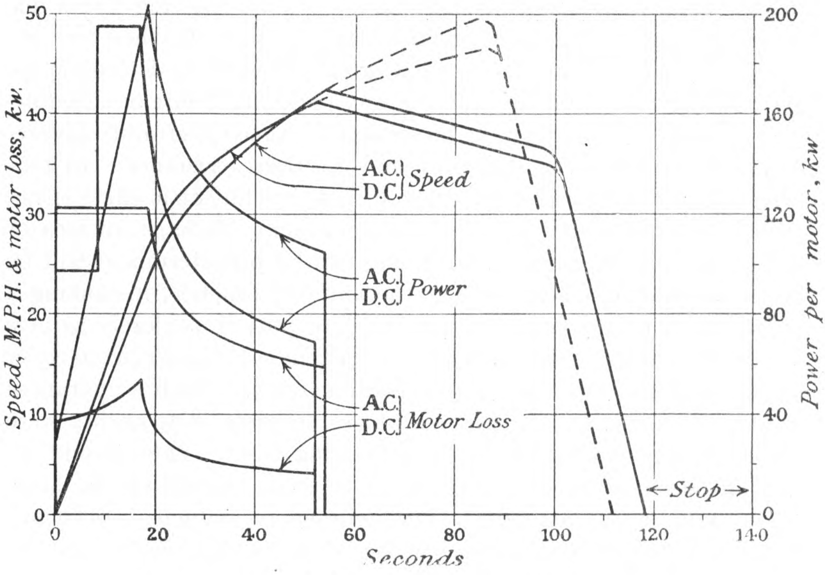

FIG. 5 TRAIN CHARACTERISTICS

46 The heating of the motors has always been a limiting feature in the design of equipments for this class of service, and the practicable and desirable means of dealing with it are well understood. The use of forced draft for cooling the motors whilst practicable for locomotives and single cars, is quite out of place on multiple-unit trains intended for suburban service, where, since the equipment

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[1] **Proc. Inst. E. E., vol. 36, p. 253; also Proc. Inst. C. E., vol. 167, p. 88, and vol. 179, p. 138.**

may not be inspected for hours together, it cannot fail to lead to breakdown, increasing maintenance charges and causing delays to traffic.[1]

47 Fig. 5 gives speed, power and motor-loss curves corresponding to typical suburban schedule runs with continuous-current and with single-phase equipments, the former of which carries 20 tons per motor and the latter 23 tons. Figs. 6 and 7 show the corresponding motor characteristics. It will be seen that the great difference between the systems is in the motor loss, which amounts to 6.75 per cent of the input in the continuous-current case and to 17.8 per cent in the single-phase case. Although both motors are dynamically capable of working the service, the former alone has sufficient thermal capacity for the purpose, the other having to dissipate three times as much energy as it can get rid of by natural cooling.

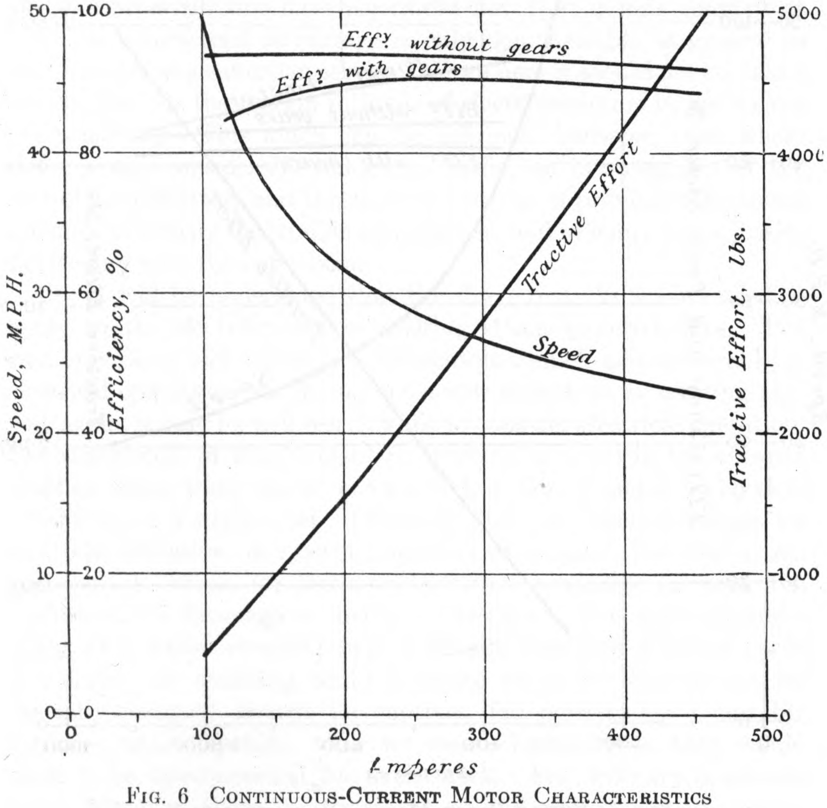

FIG. 6 CONTINUOUS-CURRENT MOTOR CHARACTERISTICS

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[1] Electric Traction on Railways, by Philip Dawson, p. 165.

48 The author has confined his remarks to the subject of suburban electrification, inasmuch as there appears little prospect at present of general electrification of railways in this country. The properties which give to electrical working its predominant advantages in the case of heavy suburban service become of minor importance when the distance between stops is considerable and the service infrequent. This matter was dealt with by Mr. Aspinall in his Presidential address,[1] and having also been recently discussed by the author[2] need not

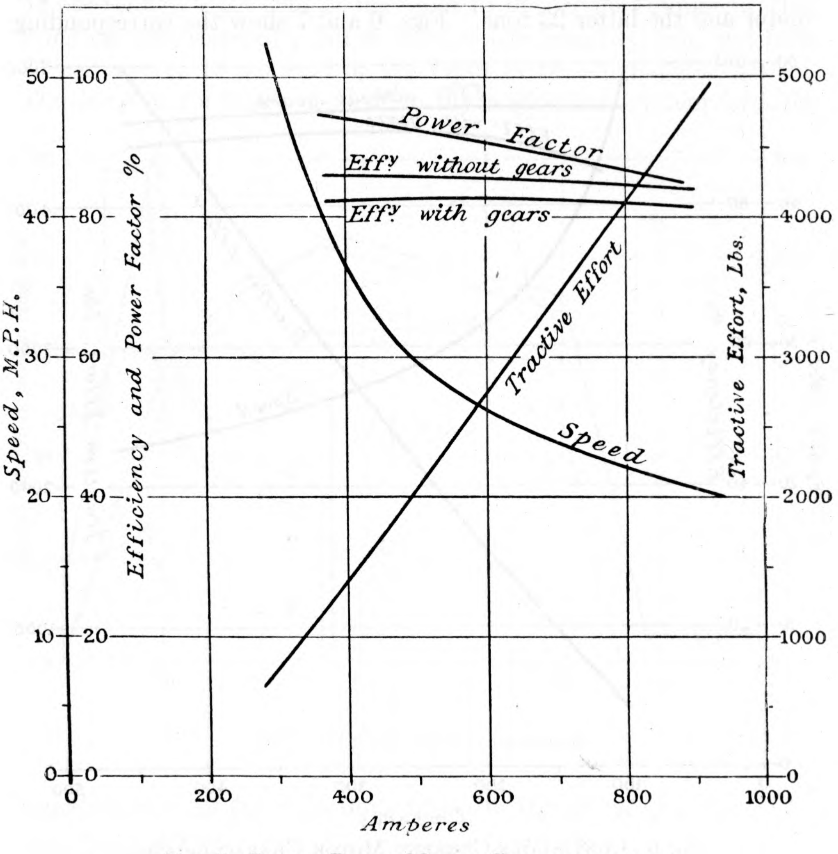

FIG. 7 SINGLE-PHASE MOTOR CHARACTERISTICS

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[1] Proc. I. Mech. E., 1909, pt. 2, p. 425.

[2] Proc. Rugby Engineering Society, vol. 6, p. 47; Electrical Engineer, vol. 43, p. 305.

be further pursued. Whilst it is, perhaps, gratifying to the electrical engineer to reflect that he can propose means fully competent to work the whole railway traffic of this country and can offer three distinct methods of doing it, it is futile as things are to regard the problem of electrification from any other point of view than that of the ultimate commercial advantage of the railway companies. The author's investigations have convinced him that in this country at least the commercial advantage is only demonstrable in general in the case of heavy suburban service. Even here it should not be taken for granted, for the margin in favor of electrification is by no means overwhelming. This much can be affirmed, however, that where there is any considerable suburban traffic, an investigation of the cost of electrification and the economic results of providing improved facilities will repay the trouble and expense, and in many cases, justify proceeding with the conversion.

49 It will be understood that the above remarks are intended to apply to the electrification of existing steam-operated lines. The case of entirely new railways is different and much more favorable to electrical operation. In laying out a new branch to an existing railway again, it may be well worth while to consider electrical operation, the capital cost of which might be more than saved in the cheaper roadbed, since steep grades are much less objectionable on an electrical than on a steam road. Of course, there are likely openings for local electrification on existing railways even apart from suburban systems. It might, for instance, be found profitable to work the pushers on the Bromsgrove incline electrically. It is quite possible, again, that where electric power is already available at goods yards and docks, the shunting could be more efficiently carried out by specially designed electric locomotives, fed perhaps by a suitable surface-contact system, than by steam locomotives, that would seem to be uneconomical for such work. For ordinary main-line work, however, there is at present no indication that the steam locomotive can be superseded with advantage in this country.

APPENDIX No. 1

50 Following are references to selected articles, papers, etc., where further particulars of British Electric Railways can be found:

a CITY & SOUTH LONDON RAILWAY
Electrician, vol. 48, pp. 166, 256, 337, 529, 564, 684, 774; Journal Inst. E. E. vol. 33, p. 100.

b WATERLOO CITY & RAILWAY
Proc. Inst. C. E., vol. 139, p. 56; Tramway and Railway World, vol. 17, p. 247.

c CENTRAL LONDON RAILWAY
Traction and Transmission, vol. 7, p. 265, and vol. 8, pp. 60 and 140; Electric Railway Engineering, by Parshall and Hobart.

d GREAT NORTHERN & CITY RAILWAY
Electrical Review, vol. 54, pp. 134, 179, 344; Street Railway Journal, vol. 23, p. 340.

e BAKER STREET & WATERLOO RAILWAY
Tramway and Railway World, vol. 19, p. 197.

f GREAT NORTHERN, PICCADILLY & BROMPTON RAILWAY
Tramway and Railway World, vol. 20, p. 527.

g CHARING CROSS, EUSTON & HAMPSTEAD RAILWAY
Tramway and Railway World, vol. 22, p. 1.

h LONDON UNDERGROUND RAILWAYS
Street Railway Journal, vol. 25, p. 388.

i METROPOLITAN DISTRICT RAILWAY
Tramway and Railway World, vol. 17, p. 97.

j LONDON, TILBURY & SOUTHEND RAILWAY
Tramway and Railway World, vol. 23, p. 342.

k METROPOLITAN RAILWAY
Electrician, vol. 54, pp. 340, 381, 417, 473; The Engineer, vol. 97, pp. 158, 183, 202, 253; Tramway and Railway World, vol. 20, p. 325, and vol. 22, p. 204.

l HAMMERSMITH & CITY RAILWAY
Tramway and Railway World, vol. 22, p. 89.

m LONDON, BRIGHTON & SOUTH COAST RAILWAY
Electric Traction on Railways, by Philip Dawson.

n LIVERPOOL OVERHEAD RAILWAY
Electrician, vol. 30, p. 421; The Engineer, vol. 93, p. 284; Electrical Review, vol. 51, p. 20.

o LANCASHIRE & YORKSHIRE RAILWAY
The Engineer, vol. 97, pp. 275, 321, 338, 357, 388; Proc. Inst. M. E., 1909, Pt. 2, p. 423.

p MERSEY RAILWAY
Proc. Inst. C.E., vol. 179, p. 19; Journal Inst. E.E. ,vol. 33, p. 979.

q NORTH EASTERN RAILWAY
Tramway and Railway World, vol. 15, p. 17.

r MIDLAND RAILWAY
Proc. Inst. C. E., vol. 179, p. 47; Tramway and Railway World, vol. 23, p. 437.