Discussion.

The CHAIRMAN, in moving a vote of thanks to the Author, said The Chairman. that the Paper was most opportune. The development of electric traction on railways had been a slow process and had presented great difficulties to engineers. When visiting Berlin with a party of engineers in 1882 he rode from Berlin to Charlottenburg on the railway then just installed ; and after an interval of 40 years he found that the development had reached that fine system which many had had the opportunity of seeing and examining on the Loetschberg line in Switzerland, from Brigue to Kandersteg. That contrast represented fairly well, he thought, the development of electric traction in the last 40 years. At the present time there was great keenness and anxiety to equip main-line railways electrically. A good deal towards that had been done already in this country, and he thought The Institution was indebted to the Author for putting his experiences forward ; they must be helpful to many who were actively engaged in the study of these difficult problems.

The AUTHOR thanked the members for their appreciation of the The Author Paper. The earliest years of any important engineering undertaking were frequently the most interesting, and during that period very useful experience should be obtained. Further, it was doubtful whether at any other stage of their existence there had been more need for railways to know exactly how they stood, and to possess the data required for carrying out the business of transport in an efficient and economical manner. The Paper attempted to summarize experience gained, in the hope that it might be of interest. The results given had been taken from the ordinary records of maintenance work on the Brighton Section of the Southern Railway. There were two points in the Paper to which he would like to refer. Two sets of the Humphris gearing mentioned on p. 209 were still in service, and, since the Paper was written, a mileage of 321,000 had been completed by one gear-wheel and pinion, still in service, and four pinions had completed between 292,000 and 321,000 miles. On p. 212 in the first paragraph dealing with bogies, the meaning appeared to be somewhat contradictory. There was naturally a great deal to be said in favour of both pressed frame and rolled-steel bogies : authorities consequently differed, and general opinion varied from time to time. In the case of the Brighton Railway, as a result of the satisfactory service given by the original motor-bogies, it had been decided that the motor-bogies of the new motor-coaches now

Th Author. on order should be again of the pressed-frame type, with, of course, minor improvements due to experience.

Sir Philip
Dawson.

Sir PHILIP DAWSON remarked that it gave him peculiar pleasure to open the discussion, because he had known the Author for many years as a distinguished student and as one of his own assistants before he joined the Brighton Railway. He (Sir Philip Dawson) took a great interest in the subject, because the introduction of electric traction, and more especially of the system adopted when the Brighton line was first electrified, had been severely criticized. It had been prophesied that the system was bound to be both mechanically inefficient and financially unsuccessful. As in other things, however, "the proof of the pudding was in the eating," and Sir William Forbes could no doubt say that the financial results had been entirely satisfactory, even, he believed, surpassing the expectations of Sir William himself—who always expected much of any new thing he installed. Those results had justified the electrification, and he wished to say a word for the particular system adopted. It was adopted because, 15 years ago, the management of the Railway Company foresaw that eventually they were bound to extend the electrification as far as the coast; and it could not be long now before such an extension was carried out. On account of the long-distance traffic thereby involved, the high-tension single-phase system was adopted, and it was for the same reason that it had been adopted to so large an extent on the Continent for main-line electrification, to one example of which the Chairman had referred. As it was sometimes thought that main-line railway electrification was entirely relegated to the United States, he would give a few figures showing its very rapid development on the Continent of Europe. At the present moment there were on the Continent, equipped with the same system as the Brighton line, nearly 2,500 miles of route, on which nearly 800 single-phase electric locomotives were in use. The Italian State Railways had electrified—on a somewhat different alternating-current system—about 500 miles, on which 150 locomotives were in use. Taking the whole of the electrified main-line railways in operation to-day on the Continent and in the United States, on the various systems, the total mileage of single-phase lines was just on 3,000 miles with 1,000 electric locomotives in operation; of three-phase systems there were 500 miles with 150 locomotives, and of the continuous-current systems just on 2,000 miles, with a little over 350 electric locomotives in operation. That showed that the decision arrived at by the Directors of the Brighton Railway was justified. The installation had been frequently examined by experts from all countries, all of whom had reported

that the system selected was the best one to meet the requirements of the Company. In spite of severe criticism in this country it had held its own, and extensions on the same system were in progress to-day. He believed that they would give still better results, because, as the Author rightly pointed out, when the present system was installed the motors were of a novel and to a certain extent untried type, comparable with the earliest continuous-current motors installed in the electrification of tramways in 1884-86. The facts that they were running to-day and giving good results, and were not yet half-way through their useful life, were sufficient reasons for feeling sure that the motors now on order would give far better results. He had seen many of the latest alternating-current traction motors recently constructed, and as regarded commutation and brush-wear there was practically no difference between them and the best continuous-current railway motors. The latest alternating-current motors made in this country, on the Continent, or in the United States, were practically similar in construction and design, showing that they had reached approximately the same position as had been reached by the continuous-current motor, where it was hardly possible to tell the difference between the products of different makers. Standardization had come about automatically as the good points had been embodied and the bad points eliminated. Maintenance would be greatly reduced. The Author suggested that, in consequence of the smallness of the oil-reservoirs, inspection had to be carried out fairly often ; but that would be avoided, and there was no reason to believe that the inspection of the motors now on order would have to be carried out more frequently than with the latest type of continuous-current motor of a similar size and doing similar work. The results obtained on the railway were particularly interesting as showing how repairs and withdrawals on account of faults in the trains had decreased as the trains became older. That indicated that the causes of the faults had been discovered and removed, and the results reflected great credit on the ability and the care exercised by the management and operating staff. Whereas in 1912 the average number of trains withdrawn per month owing to failures in the trains was 47, for 1922 it was only 9. In the following Table were given the total costs of operating in 1913, divided into three items, as compared with the costs in 1920 :—

Sir Philip
Dawson.

Year.	Power.	Labour.	Material.	Total.
1913	100	100	100	100
1920	200	425	225	250

Sir Philip
Dawson.

These figures included the maintenance of the rolling stock, switch-cabins, bonding, overhead line, motor-men, etc., and it would be seen that labour was very largely responsible for the increase. The total costs were now being reduced. The cost of labour showed the effect of the 8-hour day and the effect of the great rise that had taken place during the intervening years. He was glad to say that those costs were now falling, and the figures for 1922 would be much more satisfactory. The figures for the cost of materials did not represent the actual increase in prices, but the increase of cost to the Company; the fact that it was not higher was due to the manner in which the maintenance was carried out, the consumption of oil, etc., being reduced in consequence of the better methods of maintenance. The percentage of the total costs of the various items in 1913 and 1920 was as follows :—

Year.	Power.	Labour.	Materials.	Total.
1913	52	24	24	100
1920	40	40	20	100

These figures emphasized the importance of keeping down the costs due to power-consumption as far as circumstances warranted it. The type of bow-gear he had adopted was practically unique, as far as he knew, in Europe or in the United States. Its design was governed by severe gradients in the overhead line, which were necessary in consequence of the difference in level of the contact-wires in Victoria Station, where headway was very limited. It had justified itself entirely and was being used in the new stock with very slight alterations. He was glad that the Author had modified the views he expressed on p. 212 in regard to bogies, because the service obtained from the pressed-steel bogies had been extremely satisfactory. Still, experience had enabled bogies to be designed for the new stock which he believed would avoid such slight troubles as there had been in the past. There was much difference of opinion as to the merits of pressed-steel bogies and structural-steel bogies, but he adhered to the view that the pressed-steel type was satisfactory. It was thought by many when the overhead line was first installed that its maintenance would involve much more work than did that of a conductor-rail, but experience had not borne that out. However, very interesting data had resulted from the careful and continuous measurements made of the wear at different points

on the overhead line. He had not yet obtained the exact law of the rate of wear, but he hoped to get sufficient data to see if one could be formulated. It would not be a straight-line law, but there was a distinct relation between the current collected and the wear on the contact-wire, and the wear increased much more rapidly after the current collected had exceeded a limit of about 100 amperes per bow. On the other hand, on sections where no current was collected, the original wire erected in 1908 was still in use, and the wear was very slight, particularly where there was no steam service: that proved that the wear was not due to friction but to the current collected. It would be very interesting to know the effects of collection of heavy continuous current from overhead wires on those wires, but there was no overhead line which had been long enough in operation under similar circumstances, or on which measurements of that kind had been regularly made over a period of years. The operation over the line might be gauged from the fact that in some places 1,160 bows passed per week, which gave some idea of the current collected. Notwithstanding that fact, the total length of contact-wire renewed since it was first installed was a very small percentage of the total originally erected. The outstanding result, as the Author said, was that the corrosion of the dropper and catenary wires was almost entirely due to steam trains. On the South London line no dropper wires and catenaries had yet to be renewed. *Fig. 19* (p. 231) was a novel diagram and served the very useful purpose of showing how futile it was to compare the watt-hour consumption per ton-mile for different lines, operating under different conditions, in order to prove that one system was more efficient than another. Similar curves for other lines, operating on different systems, would be extremely useful. The acceleration curve (*Fig. 18*, p. 230) showed that with alternating current it was possible to obtain very nearly constant acceleration through the whole period of acceleration; whereas with continuous current there was necessarily high initial acceleration, with a rapid fall as full speed was approached. He was very glad to have the opportunity of making these remarks and of complimenting the Author, not only on the Paper, but also on the work he had done for the Company.

Sir Philip
Dawson.

Sir WILLIAM FORBES thanked the Council for giving him the opportunity of being present to bear witness to the excellent work the Author had done on the Brighton Railway as engineer-in-charge of the electrical workshops and traction during the past 10 or 12 years. He could not remember during that period having had one moment's anxiety with regard to the electric services on the Brighton Railway; they had run without interruption and without delay,

Sir William
Forbes.

Sir William
Forbes.

and had also given even more satisfactory results than he had anticipated. After the old horse buses were withdrawn and the electric-tram and motor-bus services commenced, the railway traffic gradually disappeared; and the management then resolved to adopt electric traction. The result had been that, on that section of the railway which was called the South London line, between Victoria and London Bridge, where the traffic had fallen from 8 million passengers per annum in 1903 to $3\frac{1}{2}$ million in 1908, in the first year after electrification the figures went back to 8 millions, in spite of the competition of electric trams and motor-buses, and the line was now carrying 50 per cent. more; that was to say, there had been an increase of about 250 per cent. on the 1908 figures. Then another section of line was electrified, from Victoria to the Crystal Palace, where competition was not nearly so keen, and there the results had been very satisfactory, there having been an increase of over 100 per cent. in the traffic. That had been brought about by better and more frequent services, and the development of traffic in the district owing to the building of houses, etc. It had not been necessary to provide any additional terminal accommodation, as London Bridge and Victoria stations were adequate—particularly the latter, where the bulk of the traffic was dealt with. That was due in a great measure to the splendid station designed by Mr. (now Sir) Charles Morgan: and he wished to take this, the first public opportunity, to say how proud and delighted all Sir Charles's colleagues on the Brighton Railway were of the well-deserved honour bestowed upon him recently by the King. Although the services had been increased by about 100 per cent., electric trains ran in and out of Victoria and London Bridge without causing the slightest inconvenience or delay. The total traffic had grown from 14 million to over 31 million passengers per annum, and he thought that would be considered a very satisfactory result. Their neighbours—and now colleagues—the South Eastern and Chatham Railway, had hesitated on the subject. Thinking that the suburban traffic was not really worth bothering about, they had let it go and had closed certain stations. Now they had come round to the view that that was perhaps a mistake and that they would have to electrify their suburban system; and he was glad to say they were going to do it. The southern railway-systems were now united, and the more the electrification was carried out on the suburban lines, the more pleased he would be. At present the electrification was being continued to Croydon and to Purley, and he hoped that, before the end of the present year, electric services would be running to those districts.

Mr. F. A. CORTEZ-LEIGH congratulated the Author on a Paper ^{Mr Cortez-Leigh.} which was very interesting to engineers engaged in traction. He would be glad to know what percentage of traffic-delays was due to faulty operation by drivers. On the London and North Western Railway, London Section, during 1922, 16 per cent. of the traffic delays were due to, or were extended through, this cause. The Author stated that the average number of trains taken out of service on account of defects per month in 1921 was only 23·41 per cent. of the average number per month in 1912; it would be interesting to know the actual figures so as to obtain a basis of comparison with other systems. The mileages given to show the efficiency of gear-wheels, pinions, etc., did not overstate the case. He had some guarantees of 600,000 miles for gear-wheels and pinions. The railway had now been running for over 6 years with a very frequent service, and, whilst to date the gear-wheels had only done some 250,000 miles each, they appeared to be quite capable of meeting the guarantee of 600,000 miles. Astonishingly little trouble was experienced with gears and pinions. With armature-windings, etc., the greatest mileage experienced to date before re-winding on the London division of the London and North Western Railway was 217,000, and the average was about 140,000 miles. The Author mentioned that the probable life of an improved commutator was about 10 years; would he add particulars of the life of the original pattern? Mr. Cortez-Leigh had commutators, supplied by outside manufacturers, which were doing exceptionally well, and he would like to be able to compare them with commutators made in a railway company's works. He agreed that the question of tires might benefit by joint investigation on the part of those engaged in electric traction. To keep all rolling stock under cover when not in service was the right course; and he would go farther, and say that it was a financially sound step to build sheds for that purpose. In his experience it had been most difficult to do the necessary inspection work on rolling stock in the daytime, as the vehicles could not be regularly released from service, and the lines could not be spared. That was satisfactory in one way, as it meant that the utmost farthing was being obtained from the capital expenditure; but it also meant that most of the inspection had to be done at night, and sheds were provided in which the rolling stock could be inspected under proper conditions. With regard to acceleration, on the North London services between Broad Street and Kew and Richmond, the average distance between stops was 0·93 mile, the average running speed was 25·75 miles per hour, and the average schedule speed, with 20-second stops, was 22·3 miles per

Mr. Cortez-
Leigh.

hour. The energy-consumption for continuous current at the sub-stations was 77·02 watt-hours per ton-mile. A speed of 20 miles per hour was attained in $17\frac{1}{2}$ seconds from a standing start, on the level, and 30 miles per hour was reached in 31 seconds. It would appear from *Fig. 18* that, to attain a speed of 20 miles per hour on the Brighton line, required 23 or 24 seconds, and 30 miles per hour, 50 seconds. He asked whether the Author had a system of refresher courses for drivers, and whether—from the operating point of view—if he could have his own way, he would insist on drivers coming for a week or 5 days occasionally to the school for instruction: also whether he had a system of training the guards for emergencies. This was done on the North Western line, with interesting results. It was found, for instance, that the guard-driver was really a quicker learner than the old locomotive-driver. Probably it was a new thing to the guard and he took more interest in it than did the man accustomed to a locomotive. The improvement in regard to maintenance of plant referred to by Sir Philip Dawson had been experienced also on the London and North Western Railway. The men in the repair- and running-sheds had done their work more quickly as they had become acquainted with the materials, the cost had been reduced, and the appliances had lasted much longer, although they were getting older. It was very necessary that those concerned with electric traction should take great pains to educate the men who handled the electrical equipment of the rolling stock. He would like to ask Sir Philip Dawson whether he had given his figures quite correctly. He had understood him to say that there were 3,000 miles on the alternating-current system with about 1,000 locomotives, and 2,000 miles of continuous-current lines worked with 350 locomotives. There was a great difference between those figures.

Mr. Roger
Smith.

MR. ROGER T. SMITH remarked that one of the difficulties of discussing a Paper containing the condensed results of 12 years' hard and intelligent work was that there was little else with which to compare it. He wished to ask a question as to the Author's experience with the Humphris gear. The Paper stated that, with the motor suspended at one end directly from the axle, the gearing worked very satisfactorily. In this country gear-driven main-line electric locomotives for speeds above, say, 50 miles per hour, would be fitted, no doubt, with entirely spring-supported motors, and he would like the Author to say if he considered that equally satisfactory results could be expected if the Humphris gear were to be used in such a case. He wished to draw attention to some of the results that had been achieved in connection with the third principle laid down by the Author, namely, that practically all equipment

was capable of improvement with regard to its life or functioning. There was first the increase of life of the collector-bows, which was very clearly shown in *Fig. 2*; then there was the reduction in the quantity of lubricants used, clearly shown in *Fig. 5*; then the decrease, which Sir Philip Dawson had already referred to, of 75 per cent. in 9 years, in the number of trains taken out of service due to defects. *Fig. 8* showed the actual temperature-rise in the motors, but it would be interesting to know how those temperatures had been obtained. Apparently in no case had the maximum temperature of the motor reached that of boiling water. Probably the most useful record in the Paper was the fact that in the English climate, and moreover, in London, an overhead contact-wire 70 miles in length, carrying 6,700 volts, had been successfully worked when exposed to the effect of steam traffic: it could be kept in thoroughly good repair with little or no interruption to traffic; the upkeep of tunnels and structures was not impeded; and its maintenance-cost, as Sir Philip Dawson had said, compared favourably with the third-rail system. The Paper contained very few particulars of the life of the various parts of the overhead equipment; perhaps that was because Sir Philip Dawson had given those details very fully elsewhere.¹ Mention had been made of similar single-phase lines in Switzerland, and he wished to point out one or two of the differences between the single-phase overhead systems in Switzerland and in this country. In Switzerland the voltage was 15,000 volts, the frequency was $16\frac{2}{3}$ periods, and the traction was done by locomotives. On the Brighton line the voltage was 6,700 volts, the frequency was 25 periods, and multiple-unit trains were used. The lower periodicity in Switzerland reduced the weight of the transmission- and contact-wires or, alternatively, reduced the losses in both, and also the losses in the return by the rails. The lower periodicity in Switzerland increased the size and weight of the motors, but since they were used on locomotives, that did not matter much except that they cost more. It would be interesting to have the pros and cons as between the $16\frac{2}{3}$ periods in Switzerland and the 25 periods in England, and it would probably be found that, on the whole, it would be advantageous to this country to retain the 25 periods where single-phase traction was used. The main difference was one of generation. In Switzerland it paid to electrify, apart from other things, on account of the saving of imported coal, because sufficient water-power was available. In England the generation of alternating current would be done by steam turbines. It was not so uneconomical

Mr. Roger
Smith.

¹ Journal Inst. Elec. Eng., vol. lviii (1920), p. 838.

Mr. Roger
Smith.

to generate from water-power (provided the falls were high) at such a low periodicity as 16, as it would be by steam turbines. In one of the latest Swiss hydro-electric stations, that at Mühlberg, near Berne, supplying current not only for traction but also for general industrial purposes, all current was generated three-phase at 50 periods, and the part used for single-phase electric traction was converted by means of a motor-generator. There was little doubt that with steam generation in England it was not possible to take advantage of the savings in transmission, and in the contact-wire and rail return, by the use of the low periodicity used on the Continent for single-phase electric traction, and that such savings would not compensate for the extra cost of generating and sub-station plant and of their working. On the other hand the use of 25 cycles for railway purposes certainly impeded the standardization of 50 periods for the whole country.

Mr. O'Brien.

Mr. H. E. O'BRIEN, while congratulating the Author on the excellent description he had given of the technical details of the London, Brighton and South Coast Railway electrification and of the method of operation, could not help expressing great regret at the absence of all figures in regard to costs, or even with regard to the number of staff employed. The absence of that information detracted a good deal from the value of the Paper. It was only possible in the circumstances to make some comparison with the results obtained in operation on other electrifications from the technical point of view and in regard to the life of the equipment. The life of the bow strips compared not very favourably with that of collecting-shoes on a third rail; the loss per bow, according to the Author was $9\frac{1}{2}$ ozs. of aluminium per thousand miles, whereas a cast-steel shoe used for collecting from a third rail lost about $2\frac{1}{2}$ ozs. per thousand miles. The bows appeared to require constant attention, and the strips were changed every 2,000 miles, whereas the life of the cast-steel collecting-shoe averaged about 138,000 miles. No light was thrown on the life of the contact-wire. Sir Philip Dawson had previously given¹ particulars of the wear of the contact-wire, but the information as to its life was not very definite, though it seemed to be short compared with the 30 years or so which might be expected of a third rail. On the Liverpool-Southport section of the London, Midland and Scottish Railway the renewal of the third rail in the neighbourhood of Liverpool was now being begun, after 30 years. The traffic there was extremely heavy and the atmosphere particularly corrosive, and the life of the rail had come to an end,

¹ Minutes of Proceedings Inst. C.E., vol. clxxxvi, p. 54.

owing first to the disappearance of the head, and secondly to severe Mr. O'Brien. corrosion at the fish-plate joints. With regard to the life of commutators, on the Brighton Railway, the estimated life appeared to be about 10 years, which seemed very short compared with the life of a continuous-current commutator, which apparently was about 20 years with current supplied at 600 volts, and seemed likely to be about 40 years with current at 1,500 volts. On the later commutators on the Manchester and Bury line the wear during the 7 years the line had been in operation was hardly perceptible. The life of the gears and pinions was much the same on both systems, and it seemed to be so prolonged in the case of electric rolling stock that it would not appear as if there was very much to be saved in maintenance by changing to a better type of gear, particularly if it were more expensive. No information was given as to the life of the brushes, which was an important point. Judging from the comparatively short time that elapsed between the truing-up of commutators in lathes, brush-maintenance was heavy. Neither was any information given as to the life of the armatures between re-windings. Comparing the continuous-current motor with the alternating-current motor, the life of the stator was given as 4 years, whereas the average life of the field-coils in a continuous-current motor, which might be compared with the stator, was 10 to 15 years. The Author gave the average mileage for the life of brake-shoes, but did not indicate clearly whether that was the average for both motors and trailers or for the former alone. Very interesting information was given in *Fig. 10* as to the life of the tires. The Author had evidently come to the usual conclusion that in electric traction maintenance-costs were very largely dependent on the life of the tires. With the continuous-current system the electric equipment would run without overhaul for a much longer time than the tires would. If, as was usually the case, wheels could not be removed without dismantling the bogie, it was almost impossible to resist giving a thorough overhaul to the electric equipment at the same time as the wheels were removed for tire-turning. Anything steel-makers could do in the way of producing a reasonably cheap tire which would give double the mileage obtained from the tires to-day would help very largely to reduce the cost of maintenance with electric traction. Experience on the Liverpool-Southport line had shown about 25 per cent. of the gradual loss of weight of tires was due to wear, and about 75 per cent. to turning the tires to bring them to profile. Usually a tire stood three turnings, and it would be possible, by taking it out of service a little earlier, to get four; but although something was gained in mileage in that way, the cost

Mr. O'Brien involved in taking the wheels out made it cheaper to let the wheels run rather longer and to turn them only three times. He noticed that the Author had accommodation for twenty-six coaches under cover for inspection purposes and fifty motor-coaches were retained. That seemed a fairly reasonable allowance. He would be interested to know why the Author found it necessary to have a night shift at work on maintenance. It was probably a question of arrangement with the traffic department, and on at least one of the electrifications in the north they had found that, by arranging with the traffic department for trains to run regularly to a certain spot, it had been possible to do away with the night shift altogether. Work could not be so well done or supervised at night. The clearance between the axle-box and horn cheeks appeared to be rather on the large side. Within reason, on the bogie of an electric vehicle it was important to keep that clearance at a minimum. The constant stopping and starting gave shocks to the motor which were intensified by every clearance given; hence clearances should be kept as small as possible, having regard to rigidity of the bogie. If a bogie tended to warp under the irregularities of the track, it was necessary to allow larger clearances in order to avoid the possibility of axle-boxes or other parts binding in the frame. Perhaps the Author would state what the clearances were when the vehicles came out of the shops. In a number of motor-coaches on the Manchester and Bury line, built with cast-steel axle-boxes and horns, the wear had been very severe indeed. They had now been altered to cast-steel boxes with cast-iron horns, and the wear was very much reduced and was not likely to be serious from the point of view of maintenance. If the Author would give the actual costs of maintenance, in material and labour, or particulars of the staff required for maintaining the fifty motor-coaches or—which would be better still—the number of man-hours spent yearly on maintenance, some comparison could be made between what had been done at home and abroad in connection with suburban electrification, and it could be seen how far the particular system described had been successful. The account of the heavy repairs to the overhead equipment done between traffic hours and of the accidents which had taken place were of great interest. He might be regarded as rather prejudiced on the question of single-phase as against continuous current, or on the question of overhead equipment as compared with the third rail, but it was almost impossible not to be so. In spite of what the Author said about the accidents and the results arising from them, it was a grave objection to overhead equipment that a serious derailment might cause a very prolonged interruption to the traffic.

on a busy section of the main line. When he was in Switzerland last summer, a bow of a locomotive came off the contact-wire and tore down three or four lengths; and for 4 hours the whole of the international traffic passing through the Loetschberg and Simplon tunnels had to be hauled through the station at Thun by two diminutive steam locomotives. Such a breakdown could not be contemplated on a main line in this country, and apparently had not occurred on the Brighton Railway. The advocates of the overhead system might argue that they had worked that railway for 15 years without any such dislocation of traffic, and that it never would happen; but the Brighton Railway was mainly a passenger line, with no great volume of goods-traffic, and the majority of troublesome derailments took place with goods-traffic. He knew of a case of derailment—not on an electrified line—in which a brake-van and the last two or three wagons of a goods train came off the line, and the driver dragged them nearly $\frac{1}{2}$ mile before he became aware that anything was wrong. The derailed wagons demolished a signal-box and would certainly have brought down any columns supporting overhead equipment unless they had been of a very stout nature indeed.

Mr. J. DALZIEL explained that his colleague Mr. Josiah Sayers, with whom he had been associated in connection with the Midland single-phase electrification at Heysham Harbour to Morecambe and Lancaster, had been anxious to speak in the discussion, but was unfortunately too ill to attend. He would like, therefore, to be permitted in the first place to be the medium of expressing Mr. Sayers's views and afterwards to make some remarks on his own behalf. The Midland electrification had now been in service for nearly 15 years. It began running about 12 months before the London, Brighton and South coast electrification, and, as those connected with it had gladly welcomed Sir Philip Dawson several times to see it, it might be said that to some extent they had collaborated in the results which the Author brought forward. It had entirely justified its inception as an engineering experiment. It was started to try the use of high-pressure alternating current, the collection of current by a bow from an overhead wire, the use of single-phase traction-motors, and the supply of energy from a small harbour power-station. The general result had been to establish the reliability of supply from an overhead wire to a train. The atmosphere at Heysham was highly corrosive. During the 15 years the mileage had been approximately 100,000 miles per annum. The wear was between 4 and 8 per cent., the bow pressure about 10 lbs., and the slope under bridges 1 in 100. Insulation was simply a matter of sound porcelain, and no failures of catenary insulators

Mr Dalziel had occurred for 12 years. *Fig. 20* showed the method of suspension which was now being adopted. The catenary was swung across from

Fig. 20

one side of the centre of the track to the other. The contact-wires followed the track of the catenary, but not fully, and therefore there was a spring effect in the contact-wires and in the catenary, without hard spots. That system had been found to be a great improvement on the original pull-off system, which was now being abolished, as it eliminated weak insulation and gave uniform flexibility, both vertically and horizontally, along the whole length of the wire; whereas with pull-offs the rigidity varied. Four miles of successful line of that kind had been working for 2 years without any trouble. The most important point of the system was its simplicity. They considered, with all respect to the Author, that the Brighton construction was much too heavy and had many more hard spots than they cared to see in an overhead line. There had been no trouble with bonds at Heysham. As a matter of fact it would almost appear that they could run without bonds, as the current disappeared about 100 yards behind the train. Painting was a source of considerable expense, which might be reduced by using tar paints, and possibly in future lines, by using poles of reinforced concrete and making the supports more accessible for painting without cutting off the current. There had been only one

accident, an explosion and fire at Torrisholme filling-factory during the war. Only one pole was hit, and that was still standing. The wiring was destroyed by the fire and the explosion, which lasted 60 hours, but the rails were also damaged. There had been no difficulty in reconstructing the overhead wires over the Lune viaduct

near Lancaster, without interruption to the traffic. The overhead lines were protected against high-frequency surges by Moscicki condensers, against moderate-frequency surges by Giles valves, and against static charges from thunderclouds by an iron-core reactance. Very considerable voltages had been experienced on the overhead line from static charges. Notwithstanding the satisfactory nature of the Heysham installation, Mr. Sayers held—and he fully agreed—that inductive interference entirely condemned the use of single-phase current for traction in this country, seeing that there was now an alternative available. Inductive interference was certainly more important here than in any other country, and probably more important on the old Midland line than anywhere else, because that line carried to a very large extent the Post Office trunk lines, the importance of which was greater than the importance of using single-phase rather than the alternative form of traction. When single-phase traction was adopted at Heysham, no other system was available for use with overhead collection, and Mr. Sayers and himself were then believers in overhead collection—a belief which experience had confirmed.

Speaking from his own point of view, he considered the Paper very interesting and practical. Heysham had been entirely a pioneer and experimental installation, and its engineers had succeeded in running quite a heavy train-service from a very small station. To run a traction system from one gas-engine set of 350 kilowatts was something of an achievement. It was not done without a battery, but it was done. Another achievement had been to bring, in those early days, two different makes of equipment, one American and the other German, into line with each other, and make them capable of working in multiple unit with each other. He doubted whether that had been done anywhere else at that time, and it was not easy to do now. Also the motor-coaches were built for 6,600 volts without using a single foot of length of the car for anything but passenger-accommodation. He noticed that several single-phase and high-tension continuous-current systems used a considerable length of car for apparatus. That was allowable in some cases, but on the tubes and underground railways in London it would be quite impracticable, as it was necessary to make the maximum use of platform accommodation. Now that high-tension continuous-current was available, he thought common-sense dictated that, since it could be used without disturbance to message circuits, it must be used to the exclusion of the single-phase system. In the same way common-sense indicated that overhead collection must also be used, as it was the only system that could be applied throughout the whole length of a line without interruption and without

Mr. Dalziel.

Mr. Dalziel. resort to any other type of collection, which, emphatically, was not the case with a third-rail system of any kind. Whether 1,500 volts was high enough for collection from overhead he did not know. It might be necessary to collect anything up to 2,500 kilowatts at high speeds. The collecting limit, of course, was set by the upward pressure which might be applied to the overhead wire, because that affected its clearances, which were pretty fine in some cases, and it was not possible to use a double collector-strip without doubling the upward pressure, while there was objection on the score of complication of erection and of maintenance to putting up a double overhead wire. At Heysham in some items the results had not been equal to those described by the Author. The use of two different equipments had added interest to the results, the work done by them being exactly the same. The service was not of a suburban type, as the stops averaged 4 miles apart. The weight of the trains varied considerably—from about 40 tons up to 200 tons—and they were worked by a single motor-coach. The car-miles per car per annum were about 35,000, and the consumption 50 to 55 watt-hours per ton-mile. There was a considerable amount of shunting which added to the consumption, but was indicated in the figures given. The commutators in both equipments had lasted for slightly more than 10 years. They were lightly skimmed each year when the car came into the shops for tire-inspection. The brass armature-bearings on one make of car had lasted 14 years. The white-metal bearings of the others required retapping every 2 years. The gearing results were similar to those given by the Author. There was one gear still in use after about 400,000 miles. On the other make of car the gears had to be renewed after slightly less than that mileage. Bow-strips of American galvanized steel type lasted 5,500 miles. Aluminium strips, of similar type to those in use on the Brighton line, lasted on the Heysham line 11,600 miles. The life of the brushes was very variable, ranging from 50,000 miles to 12,000 miles. Those of shortest life generally failed by breakage rather than by wear. Brush-holders wore very rapidly, and that was the principal cause of brush-breakage. Curiously enough, one make of motor ran best with unslotted mica in its commutator and the other was the reverse. There was considerable initial trouble with the motors, and wherever a leak could develop by surface creepage he believed it developed. Fibre wedges had to be fitted, and increased surface insulation given at practically every point. Considerable mechanical defects also developed in one make of motor, and many insulation troubles occurred, due to vibration set up by the current. That was damped down at the corner of the armature slots, and the consequent minute

pounding caused insulation-breakdown. In the end, on that make of motor, a form of construction was adopted which had been already followed on the other make; all the ventilating-ducts and air-spaces were done away with and the whole thing was filled solid with cement, which eradicated most of the troubles. The most serious troubles had been with resistance-strips, but in that respect matters had been improved by reducing the resistance per unit length of strip and increasing the length of the strips, the longer strips dissipating the heat better. One make of motor had the resistance-strips at the bottom of the slots, and in that case there had been no trouble, a fact which he attributed to the heat being carried away into the iron of the armature. Resistance-strips had been tried at the bottom of the slots in the other make of motors, and so far that had been successful. The electrically-operated contactors had not been entirely satisfactory; they were expensive to maintain and not over-reliable. On one make of car there were electro-pneumatic contactors, which had given no trouble.

Dr. S. PARKER SMITH remarked that the Paper would be particularly welcomed by engineers, who had often wondered what results were being obtained in the most important single-phase electrification in this country. One of the chief things of interest in the Paper was the curve shown in *Fig. 19*, giving the energy-consumption, and he would like to compare it with some others in the following Table:—

	Continuous Current.		Single-phase.	
	1,200 Volts. Manchester- Bury Railway.	600 Volts. L. & N.W. Railway.	South London Line.	
Average distance between stops (Mile) .	1·4	0·93	1·4	0·96
Average running speed (Miles per hour).	26·4	25·75	27·0	24·5
Power-consumption (Watt-hours per ton-mile)	69·4	77·0	60·0	70·3

Those figures showed that the Brighton line was not doing badly with regard to energy-consumption, which was the item railway engineers wished to reduce to the minimum. The figures for the Manchester-Bury line were taken from Mr. Hughes's Paper,¹ while those for the London and North Western Railway had been given by Mr. Cortez-Leigh (p. 239). The consumption indicated by the

¹ Minutes of Proceedings Inst. C.E., vol. ccviii, p. 196.

Dr. Smith. Author's curve for such conditions as obtained on the Heysham line was 50 watt-hours per ton-mile, and Mr. Dalziel had given a figure varying from 50 to 55, which was a remarkable confirmation of the curve in *Fig. 19*. The curve showed the low energy-consumption of the single-phase system, and he thought the reason for that was that with the continuous-current motor the speed was controlled by means of resistances, but with the single-phase it was controlled by voltage-tappings from the transformer. In order to increase the speed of a single-phase motor the voltage was increased by taking a higher pressure from the transformer. In order to increase the voltage of the continuous-current motor, resistance was cut out, and that had a serious effect where the distances between stations were short, as in the case of suburban traffic. There was another point, which might be of value in the future. If the regeneration of

Fig. 21.

REPULSION MOTOR WITH PHASE COMPENSATION.

energy could be effected on a commercial scale without undue complication of apparatus, he thought the matter, as a technical problem, would be simpler with alternating than with continuous current. When the Brighton line was equipped, practically only experimental apparatus was available, and very few countries had adopted single-phase traction on any large scale; but at the present day there was far more single-phase main-line electrification at work or under construction than continuous-current, on the Continent and in the United States, and the single-phase system was growing much more rapidly than any continuous-current or three-phase system. When the work was put in hand on the Brighton railway practically the only type of motor available was what was known as the repulsion motor with phase-compensation (*Fig. 21*). Like all motors of its kind it did not work well at any speed that

differed much from synchronous speed. The motors on the Brighton Dr. Smith. Railway worked best at about 700 to 750 r.p.m., 750 being their synchronous speed. About 1911 he was interested in this problem and presented to The Institution a Paper¹ in which he pointed out that in the future a motor of another type, the neutralized series motor (*Fig. 22*), would probably be used. That motor had now conquered the field for single-phase traction: it was being used wherever single-phase lines were equipped at the present day, and he understood it had been adopted for the new rolling stock on the Brighton line. The reason why that motor was better than any other type for single-phase work was that it was possible to get an indefinite number of speed curves from it. In Switzerland they often obtained

Fig. 22.

NEUTRALIZED SERIES MOTOR.

as many as twenty-two. The driver of the train could run on any one of those speed-curves and could thus control his speed to a finer degree than with any other type. The trouble with continuous current was the serious limitation of speed-control. The continuous-current motor had many great advantages, but the number of economic speeds on full field was only two—in series or in parallel. For other speeds it was necessary to weaken the field, which was not altogether free from objection and did not enable the material to be used as well as in the alternating-current motor. The Author and the Brighton Railway had done the manufacturers in this country a great service by successfully equipping the line with the single-phase system, a service it would have been impossible for anyone outside the country to render.

¹ Minutes of Proceedings Inst. C.E., vol. cxc, p. 310.

Dr. Smith. England was largely dependent, as a manufacturing and engineering country, on exporting all types of machinery, and could not afford to neglect alternating-current traction any more than it could neglect continuous-current traction. Hitherto nearly all traction equipment had been imported into this country—or the designs had been imported, although there were, of course, notable exceptions. Fortunately, at the present day the conditions were changing. Not only was this country commencing to manufacture equipment on a much wider scale, but firms were beginning to design it, and that must be done if the country was to take its share in the vast amount of electrification work going on. Many countries were now utilizing their water-power more rapidly than their industries were increasing; instead of using coal they were using water-power to produce energy, and every waterfall utilized, and every engine that used oil, reduced the demand for coal, so that it was likely that in the future coal exports from this country would decrease rather than increase. That might be a blessing for future generations; but the fact that more than half the countries which were now busy with electric traction were working on the same system as that of the Brighton Railway, and that in England there was a railway on that system working under more intense conditions than any railway in Switzerland, Germany, or Austria, gave rise to important considerations. He thanked the Author for his Paper, which showed the manufacturers of electrical equipment in this country how to become competitors in the world's markets.

Mr. Partridge. Mr. G. W. PARTRIDGE observed that the arguments against the alternating-current system reminded him of old days, 30 years ago, when the same sort of discussion took place in the Institution of Electrical Engineers as to the best system for the generation and distribution of electricity. In those days 90 per cent. of the experts advocated the continuous-current system; alternating-current men were looked upon more or less as dreamers, and certainly as great wasters of money. Had it been possible in those days to form a standardizing committee, the experts would certainly have standardized the continuous-current system as being the only one suitable for the generation and distribution of electric energy. When it became necessary, however, to generate large quantities of electrical energy and to transmit them over long distances, all the experts had to put their heads together in order to find the best system to adopt. It was found that very great improvements had been made in alternating-current machinery, and to-day, he thought, everybody would agree with him that the only system—or, at least, the best—for generation and distribution was by means of alternating

current. To-day the same question arose in connection with traction, Mr. Partridge. namely, the best system for getting large quantities of energy from the fuel to the drawbar of the train. Up to the present he did not think that the single-phase system, especially before and during the war, had had a fair trial in this country. Many had been prejudiced against it, and continuous current had been more popular mainly because people did not thoroughly understand the alternating-current system. Once more the question arose of transmitting large quantities of energy over long distances, particularly for long lengths of railways, and the alternating system to his mind had many advantages, namely, its extraordinary flexibility; the use of static sub-stations with no running machinery; and the reduction in the arcking when making and breaking circuit, particularly on bows and section switches. This phenomenon could be observed in London in any theatre where there were two supplies for lighting. The alternating-current switchboards looked as good as new, while the continuous-current boards had their fuses and contacts badly burned. There was also the possibility of regulating the pressure by means of static or auto-transformers; and lastly, the additional advantage of being able to work at any pressure up to and from the contact-wire. He had watched the Brighton system for the last 15 years, as he had been supplying the whole of the energy to that line. He had seen the troubles they had had, and he could confirm all that Dr. Parker Smith had said about the more or less experimental apparatus in use at the outset. He congratulated the Author and his staff on the manner in which they had overcome those difficulties—when the peculiarities of the London atmosphere were considered—and had worked the line. He was certain that there was a great future for the single-phase system, and he thought the sooner designers, contractors, and consulting engineers, as well as users, got together and discussed that system, the better it would be for the country as a whole and for the manufacturers who wanted to export their goods. He also congratulated the Author on the manner in which he had trained his drivers to economize in the energy-consumption. He fully appreciated the value to the railway-company of the measures they had taken, which enabled them to maintain the same service whilst taking less units from his company.

Mr. H. E. O'BRIEN feared that his remarks earlier in the dis- Mr. O'Brien. cussion might give rise to misapprehension as to the view he took of the relative merits of alternating and continuous current, and he therefore wished to say that there was no prejudice in the minds of railway engineers on that question. They had to consider which system was most applicable to the general conditions of railway-

Mr. O'Brien.

COMPARISON OF SPEEDS, DISTANCES, TIMES, ETC., ON THE SOUTHERN AND L. M. & S. RAILWAYS.

	Southern Railway (L.B. & S.C.).		L. M. & S. Railway.	
	Average of Trials over the Average Distance on a Straight and Level Track. Victoria to London Bridge.	Average of Trials over the Average Distance on a Straight and Level Track. London Bridge to Victoria.	Manchester to Bury.	Trial of a Train in Traffic 22nd June, 1922. Liverpool to Southport.
Total distance	8·64	8·64	9·8	18·45
Number of train-stops	9	9	7	14
Average distance between stops.	0·96	0·96	1·4	1·32
Actual running-time	21·25	21·07	22·00	37·75
Average running-speed	24·4	24·62	26·7	29·9
Running-time, including 20-sec. station stops . .	23·92	23·73	24·00	42·08
Average schedule speed including 20-second station stops . . .	21·65	21·82	24·5	26·3
Percentage time current on to actual running-time . . .	43·0	41·7	47·8	67·0
Watt-hours per ton-mile.	73·5	67·1	68·5	68·2
			-car train with 2 motor-cars)	(5-car train with 2 motor-cars)

Equipment.	
<i>General Overhaul :—</i>	
Bogie frame	Overhaul Horwich
" "	Superficial examination
Wheels	Re-tired Horwich
"	Between turning
"	Axle-bearing
Motors	Main
"	Armatures
"	Bearings
"	Electrical control-gear
Pump-motor	
Pump-exhauster	
Rotary transformer	
" "	Electrical control-gear
<i>Running Maintenance :—</i>	
Main knife switch	
Main circuit-breaker	Overhauled
" " "	Examined
Main contactors	Overhauled
" "	Examined
Plugs and sockets	Examined and greased
Rotary transformer switch-gear	Overhauled
" " "	Examined
Pump main switch-gear	Overhauled
" " "	Examined
Brush-gear main motor	
" rotary	
" pump-motor	
Shoes and connections	
Brakes examined and adjusted	
Brakes over pit	
" axles	
" armature	
" pump	
" rotary and pump-motor	
" motor-gearing	
" axle-box slides	

BETWEEN OVERHAUL.

Mr. O'Brien.

MANCHESTER AND BURY.		LIVERPOOL AND SOUTHPORT.	
Period.	Mileage.	Period.	Mileage.
4 years	150,000	6 years	..
9-10 months	29,000	7-8 months	40,500
4 years	116,000	3 years	120,000
9-10 months	29,000	7-8 months	40,500
9-10 "	29,000	7-8 "	40,500
9-10 "	29,000	7-8 "	40,500
9-10 "	29,000	7-8 "	40,500
9-10 "	29,000	7-8 "	40,500
18 "	58,000	7-8 "	40,500
18 "	58,000	7-8 "	40,500
18 "	58,000	7-8 "	40,500
9 "	29,000	..	..
9 "	29,000	..	..
2 months	8,000	20 days	3,600
10 days	1,500	20 "	3,600
3 "	500	10 "	1,800
10 "	1,500	3 "	500
3 "	500	..	..
14 "	2,000	3 days	1,800
10 "	1,500	..	..
3 "	500	..	..
10 "	1,500	..	..
3 "	500	..	..
7 "	1,000	10 days	1,800
3 "	500	..	..
7 "	1,000	5 days	900
7 "	1,000	10 "	1,800
daily	150-350	(Daily. Wheels every 12 hours in traffic)	100-300
3 days	500	..	No pits
20 "	3,000	Monthly	5,400
7 "	1,000	7 days	1,300
7 "	1,000	4 "	700
10 "	1,500	..	..
2 months	8,000	..	..
3 days	500	7 days	1,300

Mr. O'Brien. working, and into that came the question of capital costs and charges. The London, Brighton and South Coast Railway unfortunately never gave any information about either the capital expenditure or maintenance costs of their electrified line, thus making it impossible to judge whether the obvious economies effected by the elimination of sub-stations were counteracted by charges in other directions. As to the manufacture of electrical equipment in Great Britain, he did not know what other railways were doing, but as far as the Liverpool-Southport and Manchester-Bury lines were concerned, the whole of the equipment—rotary converters, power-stations, turbines, motors, control, and everything else—had been made in this country to English designs, the Liverpool-Southport equipment in 1903, and the Manchester-Bury in 1913. Dr. Parker Smith would know that in 1903 the design of the continuous-current traction motor was as much in its infancy as that of the alternating-current motor. Therefore the figures he had given comparing the Liverpool-Southport and the Brighton line mileages were of some value because the equipments were of much the same age. To provide means of making an accurate comparison between the conditions of the two railways, he had prepared three Tables (pp. 254-257) similar to those given in the Paper, showing the average schedule speed, weight of coaches, frequency of stops, etc.

The Author. The AUTHOR, in reply, observed with reference to Mr. Cortez-Leigh's remarks, that it would be found on investigation that the particulars given by Sir Philip Dawson regarding the respective route-mileages equipped for alternating-current and for continuous-current electric traction, and the respective numbers of locomotives used thereon, were quite correct. The proportion of delays due to faulty operation on the part of drivers amounted in 1922 to 4·43 per cent. The number of train-withdrawals in the last 6 months of 1922 averaged 7·83 per month, and during that period on the South London line, with the oldest motor-coaches, there were altogether only four on account of motor defects. The first commutators had an average life of 260,000 miles, which was equivalent to 7·65 years service. With regard to the average life between re-windings; since the renewal of the commutators on the South London line there had only been ten cases of armature re-winding, and those armatures had averaged 138,000 miles. The remainder had averaged 121,000 miles and were still in service; a life of 282,154 miles had been reached with Crystal Palace type armatures, the average life of the 74 per cent. still in service being 169,246 miles. In the case of stator fields, forty-five original fields were still in service at various mileages from 394,700 to 552,600, and the average life of all the stator fields

as now running, since the last re-winding, was at the moment 185,444 The Author. miles. Armature-shafts hitherto had an average life of 120,000 miles, but they had been taken out of service at mileages up to 400,000, and longer lives were anticipated owing to improvements in mechanical design. Mr. Cortez-Leigh compared the conditions and energy-consumption on the North London line, namely, 77·02 watt-hours per ton-mile on the rail at an average running speed of 25·75 miles per hour, with those on the South London line specified in *Fig. 18*, namely, 71·87 watt-hours per ton-mile at an average running speed of 24·24 miles per hour, but the Author thought it would be fairer, in comparing with the Brighton line, to take the high-tension watt-hours delivered to the sub-stations, and not the energy delivered from the sub-stations to the rails. If the over-all efficiency of the sub-stations were taken at 85 per cent., that would give 90·6 high-tension watt-hours per ton-mile. He thought that in every electric-traction undertaking it would probably be found that the cost of energy ranged between 40 and 50 per cent. of the total cost of operation, and consequently economies in current were very desirable. He agreed with Mr. Cortez-Leigh's remarks about the training of guards. Trained guards usually made better drivers than did men from the locomotive department, but men had had to be taken from the locomotive department for some years, and they had soon learned the importance of rapid work. With reference to Mr. Roger Smith's remarks, the temperatures of the motors were taken with a special L-shaped thermometer enclosed in a wooden box, which was placed on the commutator with the bulb of the thermometer towards the windings. It was not contended that the Humphris gearing was going to solve all gear troubles, but it was a peculiar gear, which had given good results and was quiet in working. With the high-quality gears in use to-day the question of life did not enter into the matter in the same way. It was thought that that gearing would work satisfactorily with an entirely spring-supported motor. The motor-coach fitted with that gearing had appeared to accelerate slightly better than the average, and efforts had been made to find out whether that was really the case by taking comparative Hasler speed-time records on coaches with wheels of similar size, etc., but the test records did not show definite results, perhaps because the scale was too small or because the distance taken was not long enough. It was regretted that for some years past no firm could be found who would undertake the manufacture of Humphris gearing, and consequently a more extended test had not been possible. Mr. O'Brien had remarked that 9½ ounces of aluminium was lost per bow per 1,000 miles. As there were two bows per motor-coach, but

The Author: only one bow in use at a time, the loss in aluminium was actually $4\frac{3}{4}$ ounces per 1,000 motor-coach miles. For the same reason the strip changing averaged 4,000 motor-coach miles—approximately once a month. The average life of brushes on the original motors was low compared with what would be obtained on certain continuous-current equipments, and varied from 6,000 to 16,000 miles. The life of brake-block shoes was the average for all motor- and trailer-coaches. Tests had been carried out from time to time to find the difference between motors and trailers, but *Fig. 12* gave the average conditions. It would be interesting to know what were the usual ranges of axle-box clearances, since Mr. O'Brien considered that the clearances given in the Paper were on the large side, namely, $\frac{1}{32}$ inch, or $\frac{1}{64}$ inch a side, when fitted, and a maximum of $\frac{1}{4}$ inch, or $\frac{1}{8}$ inch a side, when the U-shaped liners were renewed. Although twenty-six coaches could be accommodated for inspection, only ten motor-coaches could be examined under cover. Night shifts were in use at one depot only, and were it not for the fact that that depot was a long way from the place where trains went out of service, he did not think there would be much difficulty in getting all the work done by day. The average life of the contact-wire up to date, which depended on the service it had to deal with, was 20 years on the existing electric line, and the average life of the catenary wire, which was subject only to climatic conditions, was 15 years in the London area. Mr. O'Brien apparently considered that the use of an overhead contact-wire resulted in a risk of considerable dislocation of traffic in the event of a serious derailment. Derailments, both of passenger- and goods-trains, had occurred on electrified lines, but hitherto, as stated in the Paper, very little damage to the overhead equipment had resulted, and in certain cases it had prevented more serious trouble than actually occurred. It was also pointed out that electric trains could lower bows and coast for long distances, and experience gained hitherto did not indicate that the presence of the overhead equipment resulted in more difficulties on such occasions, possibly less in fact, than would be the case with live rails of high or low voltage. A collision resulting in the derailment of three trains and damage to the overhead equipment on four tracks occurred near Streatham Common in January, 1915, and from what occurred on that occasion it appeared that the overhead equipment could be repaired as quickly as the permanent way could be put in order. As to the question of general cost and results, the Paper had been written in an endeavour to give as much information as possible as to results. The costs had been gone into very fully by the Advisory Committee to the Ministry of Transport, and they were

primarily a question for the management. He believed, however, The Author. that the Advisory Committee had found no serious differences. Mr. Dalziel had described an ingenious method of staggering an overhead contact-wire by means of the catenary wire, but the Author thought this method was more applicable to the comparatively short structure-distances on the Midland Railway than to the longer distances used on the Brighton Railway; also that this method was not so simple for renewal work as the triangular construction used on the Brighton Railway, where each bay was completely self-contained. Further, the pull-offs were extremely flexible, since they were fixed to the catenary wires and not to the supporting structures. As a result of Sir Philip Dawson's inspection and analysis of most of the overhead systems in Europe and America, a combined triangular and catenary pull-off construction had been designed for the extensions now in progress, which would enable a standard distance between structures to be maintained, regardless of curvature. The triangular system did not of itself necessitate the use of more insulators; and the heavier the train service, the greater the need for each bay of overhead wire to be self-contained and easily renewable. In the case of the Brighton Railway only four men were required for the bonding work of 70 miles of track, and the high voltage used, and the small currents dealt with, reduced the importance of bonding work, so that it could be carried out very economically, since it was not necessary for rail-bonding to synchronize exactly with the track re-laying work of the Engineer's Department. Mr. Dalziel apparently considered that inductive interference was a serious drawback to the use of alternating current. No induction trouble was experienced on the Brighton Railway, and it was understood that the same could be said about the electrified sections of the Swiss State Railways and of the New York, New Haven and Hartford Railway. It was important to note that it was now the policy of the Post Office to adopt underground cables for all important main routes, and doubtless the havoc caused by the great storm a few years ago was well remembered in the midlands. Mr. Dalziel appeared to be rather doubtful whether a voltage of 1,500 volts would be high enough for contact-wire collection, presumably for electric locomotives of high power, and the Author quite agreed with that. In order to get the maximum amount of economical operation from an overhead contact-wire, the line voltage, as intended by the Brighton Railway, should certainly be at least 11,000, or possibly as much as 17,000 volts. Sir Philip Dawson had pointed out that practically no information was available about heavy current-collection for frequent train-services; even on the

The Author. Milwaukee and St. Paul electrification at 3,000 volts continuous current there were only very few trains each way per day. The shape of the acceleration curves in *Fig. 18* was good evidence of the voltage control of alternating-current motors, whereby a steady rate of acceleration was maintained up to a relatively high speed. The actual overall rate of acceleration adopted in any particular case of course depended on the permissible energy-consumption, whether alternating or continuous current was used. The particulars given in *Fig. 19* had been referred to; and the explanation of the causes which probably made up the difference of 13·6 per cent. between the actual rate of energy-consumption for the year 1921, i.e., 75·8 high-tension watt-hours per ton-mile and the rate of 65·5 high tension watt-hours per ton-mile for a distance between stops of 1·14 mile, derived from the results of test runs and given in this Figure, was as follows :—

- (1) If the actual South London and Crystal Palace ton-miles for 1921 were multiplied by their respective test rates of energy-consumption given with *Fig. 18*, and if the total energy-consumption so obtained was divided by the total ton-miles, a true average figure of 67·5 watt-hours per ton-mile for the actual train-service run would be obtained ;
- (2) Train-lighting averaged about 1 watt-hour per ton-mile ;
- (3) Air-compressor motors accounted for something approaching 1 watt-hour per ton-mile ;
- (4) Line-leakage amounted to approximately 1 watt-hour per ton-mile ;
- (5) Heavy loading of trains, traffic conditions during certain hours of the day and during fog, bad driving, and transmission-losses together accounted for the remaining 5·3 watt-hours per ton-mile. The smallness of this figure indicated that the transmission-losses amounted to very little, and that, in spite of the fact that during certain hours of the day one or two additional signal stops were made on each trip, the general standard of train-driving was not very far removed from that obtainable on test runs.

Mr. Partridge's comparison between the generating situation of 30 years ago and the traction situation of the present day appeared to be very sound, and, with his knowledge of the working of the Brighton Railway, it was clear that his opinion was based on views of similar broadness to those expressed by Dr. Parker Smith. His

comments with regard to flexibility and reduction in arcking on switch-gear were fully borne out by the particulars given in the Paper. The Author.

Correspondence.

Mr. G. WÜTHRICH congratulated the Author upon the able manner in which he had demonstrated, by many years' practical operation, the suitability of high-tension single-phase traction, even for suburban traffic. The efficiency with which apparently he organized and handled the maintenance-department showed what excellent results could be secured with that system, even under conditions not particularly favourable to its use. The methods employed and the labour-saving arrangements tested in actual practice by the Author would be welcomed by other railway engineers who had to run and maintain suburban electric train-services. The results recorded were all the more remarkable in view of the old design of the motors and equipment. Sir Philip Dawson also was to be congratulated upon his courage and foresight in applying that system, bearing in mind the state of electric traction at the time when he had had to formulate his recommendations and decisions. The value of the data collected by the Author was accentuated, of course, by the fact that very considerable progress had been made in high-tension single-phase electric traction since the London, Brighton and South Coast Railway Company inaugurated its suburban electric services. The Behn-Eschenburg system of regenerative braking, as applied by the Oerlikon Company since 1918, was remarkably successful and compared very favourably with regenerative braking appertaining to continuous-current systems. Great progress had been made in the overcoming of the initial difficulties of interferences with telephone and telegraph systems, the solution lying mostly in the correct design of the motors, etc. When it was further considered that 15-cycle single-phase electric motor-coaches or locomotives compared favourably, as to weight and cost, with continuous-current motor-coaches or locomotives, especially when the latter were built for voltages higher than 600 volts, it would be realized that the studding of the country with converting-stations was a luxurious, costly, and, in the end, destructive means of earning dividends. Too much money had already been sunk in British

Mr. Wüthrich.