

- (2) Every 25 days
  - (a) Oil axleboxes.
  - (b) Lubricate axlebox slides, bolster slides, and brake gear.
  - (c) Clean contactor interlock contacts.
- (3) Every 50 days
  - (a) Gauge tires.
  - (b) Grease gears.
  - (c) Oil motor suspension bearings and compressors.
  - (d) Gauge and lubricate conductor-rail shoe gear.
  - (e) Examine and clean traction electric equipment and auxiliaries.
  - (f) Examine and clean air-door equipment.
  - (g) Top up batteries if necessary.
- (4) Every 100 days
  - (a) Lubricate motor-generator set bearings.
  - (b) Examine and clean electro-pneumatic brake apparatus.
- (5) Every 200 days
  - (a) Change electro-pneumatic brake reducing valves for dismantling and cleaning.

#### B. *Non-synchronized Attentions.*

- (1) Every 4 months
  - (a) Lubricate traction motor armature bearings.
- (2) Every 12 months
  - (a) Clean and lubricate triple valve and interlock switch pistons and isolating cocks on brake system.
  - (b) Clean backs of switchboards.
- (3) Every 18 months
  - (a) Remove battery for renewal of electrolyte.
- (4) Every 4 years
  - (a) General overhaul at Horwich Works.

### Discussion.

**The Chairman** said he had some diffidence in following Mr. Carpmael as Chairman ; but with the splendid start which Mr. Carpmael had given to the Division and the able support that had been given by every member of it, he had no doubt of its continued success. Any suggestions for the improvement of the meetings or methods of the Division would be always welcomed by the Board.

**The Author** introduced his Paper with the aid of a series of lantern slides and a film. He said that the practical propulsion of vehicles by electricity began about 1880, and railway electrification was definitely under way at the beginning of the present century, when all the essentials were fully understood. Since then continuous improvement had occurred in the design and construction of traction equipment, the mercury-arc rectifier had displaced the rotary converter, and the single-unit substation had appeared, but there had been little other development of a revolu-

tionary character. Much of the possible interest would therefore lie in various details and points of novelty. It had been largely by the introduction of such apparently minor changes that electric railways had attained their present standards.

**Mr. W. K. Wallace** observed that the Wirral electrification had been unusual in that there had not been the very large increase in train-mileage which usually occurred after electrification, owing to the fact that a rather intensive steam-train service had been in operation, giving, he believed, a train every 15 minutes. The new electric stock was designed to be very light, and the gross ton-mileage run on the line had decreased considerably, as was shown by the wear on the rails. When the decision was taken to electrify the Wirral lines it was decided to upgrade the line from Class 2 to Class 1 and to lay rails of 95-lb. section instead of the previous 85-lb. section; and steps were taken to obtain data showing the wear of the rails. Although, owing to the war, those data were not so up to date, or in so detailed a form, as was desirable, it had been found that the wear of the rails had decreased rather than increased, particularly on curves. The line included some very sharp curves, and the rails on them had been very badly side cut by the 2-6-2 engines which had been used hitherto. The shorter wheel-base of the electric stock had undoubtedly helped in that respect, and the ample installation of rail oilers and greasers had assisted.

From the constructional engineer's point of view, he was sorry that overhead electrification had not been adopted, thus getting the electric gear out of the way. The Author, however, had done the next best thing by having only a third rail, instead of third and fourth rails. The London, Midland and Scottish Railway had third and fourth rails on some of its lines, and so far it had been found extremely difficult to maintain a good line or top with four rails. An ordinary gang could not pull the road properly with four rails, and it was much better to have only a third rail. He hoped that permission would be given for removal of the fourth rail on some of the lines where it now existed, changeover gear being put on the rolling stock. That was a matter for the Author to take up with his colleagues, and Mr. Wallace wished him success in doing so.

The line generally had not been knocked about by the stock to the extent that Mr. Wallace had expected. With some of the older and heavier electrified stock on other lines, periodic side cut occurred and tended to put the road out of line on curves to a much greater extent than did the light stock on the Wirral lines and the Southport line, which was much less severe on the road.

All the stations had been built with reinforced-concrete frames and wall fillings of brick designed for minimum cost of maintenance. The old stations had been deplorable, even for English suburban lines.

**Mr. G. H. Fletcher** observed that the Author had made it clear that the choice of the voltage had not been entirely free and that he would have

preferred a pressure of 1,500 volts. In that connexion Mr. Fletcher wished to emphasize two points. Firstly, although during the past 10 or 15 years many important developments in electrotechnics had occurred, in his opinion, the choice made with regard to voltage by the Railway Electrification Committee, in 1928 and adopted by the Weir Committee in 1931, was probably correct; at all events, he knew of no development in the design of electrical equipment, either for track or for supply, which should modify that decision. He was glad to see that, at least by inference, the Author was in agreement with him on that point. Secondly, when engineers criticized the adoption of that voltage for Great Britain, especially on the ground of what other countries were doing, it should be remembered that in many cases the electrification carried out in other countries was based, not upon the technical grounds obtaining at the present time, but upon a decision made in some cases a quarter of a century ago, which it had been necessary to follow.

With regard to the Author's analysis of the energy used on the train, it would be seen that 15 per cent. of the energy was used in resistance and 40 per cent. in the brakes. A fair inference to be drawn from that was that, whilst electricity was quite good for running a train once it had been started, it was rather poor for starting, and worse for stopping. Electrical engineers were not at all satisfied with that position and had been trying for many years to solve the problem. Not only was there a loss of 40 per cent. of the energy in braking, but also useful energy was employed for destroying perfectly good material, namely, brake-shoes, some of which, if of the fabric type, were rather expensive. Moreover, a by-product resulted which formed a serious menace to the electrical equipment. Therefore every effort should be made to avoid mechanical braking and to adopt some form of electrical braking, particularly in view of the fact that the motor was quite as good for converting mechanical into electrical energy as vice versa. Many difficulties were involved, particularly with the series motor. That motor had had a long sway, and it was necessary to consider whether it would meet the conditions in the future. Certain alternatives existed, namely, regeneration, rheostatic braking, and eddy-current braking. The first of those involved certain difficulties, such as the question of the receptivity of the line, whilst in some cases control difficulties arose. Rheostatic braking involved more weight on the train and difficulty with regard to control in some cases. Doubtless the Author had considered those methods of braking very carefully before making his final decision and the grounds on which he had rejected them were sound, but Mr. Fletcher would be interested to know what those grounds were, because electrical engineers, on both the manufacturing side and the railway side, had to tackle the problem and try to find a solution. During the past 3 or 4 years greater developments had taken place in electrical engineering of certain types, particularly in certain classes of direct-current apparatus, than would have taken place in normal times in

10 years, and he believed that a change could be made in the excitation motor which would not only retain but also accentuate the good points of the series type and make the control much less rigid than with the series motor.

In reading the section of the Paper dealing with the layout of the substations, he had noticed that one of the chief factors taken into consideration had been the question of emergency and spares, and he had recalled a Paper read by Mr. Bianchi in 1931, describing a transportable substation. Whilst no one would think of using transportable substations instead of rigid or permanent substations, he wondered whether there was not a field for the transportable substation for emergency running and as a sort of adjunct to the normal permanent substation.

The electrification described in the Paper, although not very large, marked a definite advance, and he felt that the Author and the other engineers concerned were to be congratulated on so fine an achievement.

**Mr. F. E. Harrison** said that he was interested in the Paper from the point of view of track equipment maintenance, because for a long time he had been concerned with a somewhat similar installation—self-contained and on the third-rail principle—on Tyneside. The electrification on the north side had been carried out in 1904 and had been extended from Newcastle to Shields about 5 years ago. On the north side there were about 30 route-miles, and on the south side about 10 route-miles.

He would like to learn how the allocation of maintenance duties was carried out on the Wirral lines. Originally on Tyneside the permanent way staff was responsible for the track section switches and the continuity cables, as well as for the track itself, but recently the arrangements had been altered so that the permanent way staff no longer had any responsibility for the switches or continuity cables.

The Author's mention of the standard position of the third rail had reminded him of an interesting undertaking on Tyneside. When it was proposed to electrify the line to the south as well as to the north of the Tyne, attention had been called to the fact that the third rail was not in the standard position, and request was made that it be put in the standard position. The district engineer at Newcastle had thus been faced with the problem of shifting the third rail  $3\frac{1}{2}$  inches closer to the track rail within the shortest possible time. Owing to the great care and detail which he put into the work, he had, in fact, made the alteration within the limits of one extended week-end—a creditable performance. That had been done before the South Shields line was brought into use, so that now the standard was the same throughout.

On Tyneside the atmosphere was far from good and considerable corrosion occurred. Paint had been tried on the third rail, but had not been very effective. The next step, taken some years ago, had been to install a rail which was very nearly rectangular, in place of the flat-bottom section; but that had not been successful, because, owing to its base not

being so wide, it was inclined to become displaced. The latest section, which was now the standard on the line in question, was the flat-bottom heavier section of 120 lb.

The Author's reference to anchors was interesting, because on Tyneside stops on the rail to engage with the insulators had not been used. The third rail there was divided into sections about  $\frac{1}{4}$  mile in length, and there was an anchor at about the centre of the section. That was attached to the bottom flange and to the sleepers and might be called a two-way anchor, as it was meant to prevent the pull in either direction. It had proved satisfactory, but at the ends of the section of the third rail, in intensely hot weather, the insulators were rather inclined to tilt. He did not know whether any tilting had occurred with the stops, but he thought that the method adopted by the Author should be given consideration.

On the Tyneside line the track-rail fishplate was, so to speak, a compromise between the short fishplate which most railways had tended to adopt in recent years and the four-bolt fishplate, and under difficult conditions it had proved very satisfactory. He thought that, in the case of ordinary steam traction, some were beginning to be doubtful about the efficiency of the short fishplate when the track was showing a certain degree of wear; and perhaps the semi-short fishplate, as it was called, might come to be regarded, in ordinary traction, as a very useful track component.

**Mr. H. W. H. Richards** considered that the Author's logical reasoning made both the design and the subsequent maintenance results exceptionally interesting.

Directors and managers sometimes said: "Why do not engineers settle what system of electric traction ought to be used? Then we could go ahead. We see one system in one country and another in another country." Broadly speaking, if the extreme cases were ignored, capital cost and maintenance cost did not vary widely, and the answer was that the system in each country was selected in accordance with the requirements of the train service and the national system of electrical generation and distribution.

The Author had dealt at some length with the weight of the rolling-stock and the importance of saving energy-consumption. On the North Tyneside line, about 5 years ago, completely new rolling-stock had been provided, of a more or less normal conventional construction; the bogies were of the usual press-frame type and were riveted, welding not being used to the extent adopted by the Author. The average weight on the North Tyneside line was 0.5 ton per foot, whereas on the Wirral lines it was only 0.45 ton per foot—a saving of 10 per cent. The cost of high-tension energy for traction purposes only was approximately £39,000 on the North Tyneside line in 1942, so that a 10-per cent. saving would amount to about £4,000. The cost of maintaining the rolling stock, including

cleaning, was approximately £30,000. If the use of lighter rolling-stock resulted in more maintenance work and heavier repairs, it would not be long before the saving of £4,000 would disappear. Mr. Wallace had referred to the benefit to the track resulting from the use of the lightest rolling-stock. It was very desirable to save energy in every direction, but Mr. Richards thought that engineers should keep a rather careful balance between their efforts to save weight in order to save energy and the subsequent cost of rolling-stock maintenance, which might not be apparent in the first few years. It was nearly 30 years since he had first been responsible for maintaining rolling-stock, in the early days of the Brighton electrification, and he knew how the mechanical work piled up sometimes and what a tremendous amount it cost.

He had been particularly interested in the results of the electro-pneumatic braking given by the Author. That type of braking had been adopted on the North Tyneside coaches, and the results had been similar to those obtained by the Author.

The Author had also stated that the number of defects had been reduced considerably on the Wirral lines. On the North Tyneside line, which had been electrified in 1937, four trains had been taken out of service in 1942—equivalent to 200,000 train-miles per failure. On the shorter South Tyneside line four trains had been taken out of service in 1942, representing an average of 93,000 train-miles per failure.

When the new rolling-stock was provided for the North Tyneside line the scheduled speed was 20 miles per hour, whereas on the Wirral lines the average scheduled speed appeared to be just under 22 miles per hour. An increased speed of  $23\frac{1}{2}$  miles per hour had eventually been adopted on the North Tyneside line, which was equivalent to just under 20 per cent. increase in energy-consumption in comparison with the original running. The engineers had been asked to consider increasing the scheduled speed to 25 miles per hour, which would have meant a 45-per cent. increase in the consumption of energy in comparison with running at 20 miles per hour. That showed the importance of reducing weight as much as possible. On the other hand the stations on both the lines in question were only about 1 mile apart, and that short distance between stops involved a considerable increase in maintenance costs with higher scheduled speeds.

With regard to the general results of working given at the end of the Paper, if "service faults" meant trains taken out of service, the number of 2.6 faults per 100,000 motor-coach-miles was certainly very good. The Wirral lines had the additional complication of air-operated doors. On the Tyneside lines, with rolling-stock of about the same age, the corresponding numbers of faults were 0.57 on the North Tyneside line and 1.75 on the South Tyneside line. Therefore, broadly speaking, the lines were very much in step. From time to time information had been exchanged by the London Midland and Scottish and the London and North Eastern Railways, and he hoped that as time went on the results

of the two different types of rolling-stock with similar braking would become valuable to both railways.

**Mr. W. G. Graff-Baker** observed that a great deal could be said against the adoption of a higher pressure than 650 volts, but at the moment he was almost a lone voice crying in a moderately large wilderness.

The Author had indicated that one reason why he had adopted the third rail was because it was cheaper than the third and fourth rails. Doubtless he had been helped in that consideration by the fact that his line was hand-signalled and not track-circuited. The effect of track-circuiting was that, if there were between nine and ten track circuits per mile, the cost of impedance bonds for the signalling was equal to the cost of the additional current-rail; but the latter had the advantage that a train could operate for a time successfully with an earth on either pole, and it did not necessarily have to come out of service immediately.

Mr. Graff-Baker would do his best to discourage the permanent way staff of his own lines from bending down the end of the current-rail instead of putting on a proper splay. Trouble with shoes tended to start from the end of the current-rail, and even with a splay there was not entire freedom from trouble. Perhaps he felt more keenly on the matter than the Author because he had twice as many shoes to look after, but he would regard the bent-down current rail as entailing very considerable risks of breaking off shoes and overturning the rails.

The Author had elected to use tapped-field motors. The London Passenger Transport Board had considered that matter and had tapped-field motors running, but their experience was that the tapped-field motor was more difficult to maintain than an untapped-field motor. In the case of a traction motor to-day, the most difficult part of the design was the field coil and the field-coil system. To bring up a tapping from every coil and run another circuit of connexions around the motor appeared to be a very unattractive procedure when, by the simple device of applying non-inductive diverters to the field circuits a very substantial degree of field weakening and economical running could be obtained.

The Author had not brought out fully one of the points in favour of the non-metallic block. Such wear as took place on the metallic block was on the tread, and not on the flange. If the flange wore and the profile had to be restored, it was necessary to take off a large amount of the tread. With the non-metallic block a very small quantity of metal had to be taken off the flange in order to re-form the profile at the new tread-level. There was more advantage in that than in any other feature of the non-metallic block.

With regard to the Author's statement that he was experimenting with grease lubrication for his roller bearing axle-boxes, the London Passenger Transport Board used a large number of a very similar box, and had found that grease lubrication was quite satisfactory. It had been introduced for two reasons, namely, to save labour and to reduce

oil-consumption. The present practice was to use 4 ounces of grease every 12 weeks, as against  $\frac{1}{2}$  pint of oil every 4 weeks. At the same time, no difficulty had been experienced with fault currents passing through roller bearings and causing trouble.

With regard to the Author's suggestion that flats could be eliminated by putting on a cast-iron block and using that as a tool for turning the tire down, had it not been found that when non-metallic blocks were put on that tire afterwards the wheel turned the blocks down for some time? It seemed to be a comparatively expensive procedure. It would be necessary to change at least a bogie set of blocks, because they would not run mixed to that extent, as a difference in leverage was required. Mr. Graff-Baker's experience had been that a small flat would roll out. If it was big enough to require the application of a cast-iron block, the wheels needed re-turning.

Putting four electric motors on one coach was a common practice, but he considered that mechanical and electrical engineers should endeavour to raise the centre of gravity of electric railway rolling-stock, and that could not be done by attaching at axle-level from 8 to 10 tons of motor. If more axles on the train—and only one on each bogie—were motored with smaller motors he believed that the rolling-stock staff would benefit from a bogie point of view and the permanent way staff from the point of view of rail wear and battering. If the Author had put one motor on each bogie of two coaches in his three-car unit, with two equipments, and had found one equipment defective, he would have been able to push the train out, one end with the other, instead of having to bring the next train up to help him out; that was a difficult operating proposition and should be discouraged.

He did not think the Author had gone far enough with his motor-generator. A larger motor-generator was more reliable and not proportionately more costly than a 1-kilowatt one. Lighting could then be provided which was entirely free from variations due to voltage-variations on the track, which must occur even with the best regulated system. The passengers could read in comfort and the light was whiter, whilst the higher lamp efficiency at the lower voltages made up for the losses in the motor-generator.

The Author had based his failures upon motor-car miles, and that was rather puzzling, since some of the equipment on the trailers had been referred to as possibly loading up the failure figures. What was the length of the minimum delay which was brought into record for the purpose of the figures given? The London Passenger Transport Board, like the Author, had put up readily removable equipment, but they too had not had any occasion to take the equipment down. The shopmen preferred to take down the individual piece of apparatus that required attention. Even for an overhaul the whole equipment was not taken down. The Board had found, like the Author, that overhaul was largely governed by the condition of the paintwork. Four years seemed to be the right period

between overhauls, with the standard of paint that was obtainable before the war, but there was no necessity to take down every part of the equipment; many pieces would last over two overhauls, or even three. The degree of overhaul required was to some extent an inverse reflexion of the work that was done in the running sheds and the repair shops.

Had the Author worked out what the saving in weight had cost? It might have cost very little. It could be evaluated for each railway as a definite figure. On the Underground system, running a very close headway service with a very close section, the saving of 1 pound of weight was worth 15*d.*, with current at  $\frac{1}{2}$ *d.* per unit.

The doorways on the Wirral trains appeared to be very narrow. On the Underground system it had been found that the best sizes were 2 feet 3 inches and 4 feet 6 inches. The door on the Wirral trains, which was 3 feet 9 inches, was certainly not a two-passenger door, whilst it was not a one-passenger door, unless the passenger was a very fat man. On the Underground system, with the onerous conditions of traffic there and the short station stop, it had been found necessary to make 25 per cent. of the car side consist of doors, whereas the Wirral allowance was 12½ per cent. Perhaps people in Cheshire were more leisurely than those in London.

**Mr. F. Lydall** said that he had read the Paper carefully several times, but could not understand what was the standard train. Apparently it was a three-car unit, but was the normal train in the rush period a three-car or a six-car train? One or two references had been made in the Paper to six-car trains.

The four cables from Birkenhead North appeared to be a little extravagant; but he supposed that, as a matter of fact, it was cheaper to have the four cables and bifurcate at the next substation than to bifurcate at Birkenhead North and then have two cables and then bifurcate farther on.

The use of the glass bulb rectifiers was interesting, and he supposed that they were not arranged with any kind of grid control. There seemed to be no necessity, with the substations so close together, to have any compounding. He would like to ask, however, whether it was quite a simple matter to carry on the service at the far end—at West Kirby, for instance—if the substation which was nearest to that went out, because there was no question of putting in a duplicate substation set at that point. It would be necessary, in fact, to feed all the way to the far end from the last substation but one. Further, where was the control-point situated: was it at one of the substations or at Liverpool?

He was not clear about the possibility of giving a satisfactory service if only two motors were used per three-car train. He would have thought that it was hardly practicable to get an equivalent service; in fact, surely the adhesion was not quite sufficient, with only two motors in a three-car train, to give the acceleration of 1.4 mile per hour per second.

In the motor bogies, with which some slight trouble had been ex-

perenced through cracking, the wheel-base was 7 feet 6 inches ; would it not have been possible to have a rather longer wheel-base and make more provision for cross-staying ?

The difficulty of finding suitable brushes seemed to be perennial and was quite extraordinary, after so many years. Could the Author make any suggestion as to why that trouble recurred so frequently. For every new installation the same difficulty of finding new brushes occurred.

The Author's remarks about general overhauls were very interesting. Mr. Lydall supposed that, with an overhaul every 10 years, about 400,000 or 500,000 coach-miles would be run between general overhauls. Probably it was for reasons other than engineering reasons that the whole of the stock was written off in about 30 years, but it was interesting to think that there would be only two intermediate overhauls during the whole of that period.

**Mr. S. B. Warder** said that during the 10 years preceding the present war considerable development had taken place in the art of railway electrification on the third-rail system, and the electrification of the Wirral lines was a good example of what could now be done.

With regard to the number of substations, the Author had stated that the choice lay between four, of which three would contain spare units, and six of the single-unit type. The second alternative had been chosen, and experience had shown that that choice was a sound one. It was common knowledge that the scheme of using more closely spaced, remotely controlled, single-unit substations had been first devised by Mr. Alfred Raworth, M. Inst. C.E., for the electrification of the main line to Brighton and had been used by Mr. Raworth on all the electrifications subsequently carried out on the main lines of the Southern Railway. Mr. Warder considered that the ideal single-unit substation should consist of one rectifying unit per transformer per substation ; and, having regard to the comparatively small plant capacity of 600 kilowatts, it would be interesting to learn whether the Author considered that the three-glass-bulb rectifier unit had any decided advantages over the pumpless steel cylinder type of rectifier, which was available in single-unit sizes quite capable of handling the loads depicted on the load chart (Fig. 5, Plate 1).

Mr. Warder was interested in the use of protective devices on rectifiers. From the particulars given in the Paper it seemed that the Author had installed a rather elaborate system. For instance, there were out-of-balance relays to signal bad load sharing, anode fuses for backfire protection, overload release on the alternating-current oil circuit-breaker, reverse current release on the direct-current main high-speed circuit-breaker, and forward overcurrent relay protection on the direct-current main high-speed circuit-breaker. Experience on the Southern Railway had shown that much care should be exercised in the selection of suitable protection, and that it should be based on the actual conditions of service. The ideal form of rectifier protection was still far from being achieved. For

steel tank rectifiers the Southern Railway used, on the alternating-current side, instantaneous overcurrent relays set to trip the oil circuit-breaker at a value higher than that represented by the maximum short-circuit current that was obtainable on the track. Experience had shown that on the direct-current side, the overload settings of the high-speed feeder circuit-breakers were adequate for all conditions of track occupation. Therefore, apart from a reverse-current trip on the main direct-current high-speed circuit-breaker, there were only the instantaneous relays on the alternating-current side, which functioned purely as a backfire protection; in other words, overload protection was not fitted on the rectifier proper. For pumpless rectifiers, backfire protection was provided by anode fuses of high rupturing capacity fitted with special striker indicators arranged to trip the rectifier oil circuit-breaker. Theoretically, the correct place to isolate a backfire was in the anode circuit, because the short-circuits were removed from the alternating-current and direct-current systems simultaneously. With reliable and quick-acting fuses, the current peak was limited to one half-cycle or less, and the current was completely interrupted in approximately one cycle. Thus the oil circuit-breaker was relieved of a considerable part of its duty and the use of a main direct-current high-speed circuit-breaker became questionable. Would the Author agree on that point, and did he consider that the development of anode circuit-breakers should be encouraged?

**Mr. H. H. Swift** observed that the Author had called attention to a rather extraordinary type of wear, and his theory of the magnetic attraction of the shoe to the rail was extremely interesting. About a year ago a somewhat similar type of wear had been noticed on the North Tyneside line, again just where a train coasted into a station. Measurements had been taken by a straight-edge being laid along the crests of the waves, which were spaced about one sleeper-distance apart, and feelers had been inserted under the straight-edge. An average of twelve different readings had shown a wear of about 22/1000 inch, the maximum wear being 35/1000 inch. Measurements had been taken again in 1943, after 12 months' additional wear, and a rather curious result had been obtained. Of the twelve measurements taken, eight had shown an increase of about 3/1000 inch, whereas the remaining four had shown a decrease of about 2.5/1000 inch. Therefore, like the Author, Mr. Swift felt that, although the point should be kept in mind, it was rather early to try to diagnose the reason for the curious type of wear in question.

The rail on the Wirral lines weighed 107 lb. per yard, and its resistance, including bonds, was 0.0264 ohm per mile, whereas on the North Tyneside line the rail weighed 120 lb. per yard and had a resistance, including bonds, of about 0.028 ohm per mile. That meant that the Wirral rail had a conductivity about 10 per cent. higher than that of the North Tyneside rail, which had probably resulted in a softer rail on the Wirral.

The rail-bond shown in *Fig. 8 (a)* was apparently installed in an almost

vertical position—at all events, it was parallel to the major axis of the rail—whereas the conventional method of fixing that type of bond was at an angle of about 30 degrees, so as to give a good clearance for removing the fishplate. The sectional drawing, however, seemed to show that ample clearance was available, on the Wirral method, for removing the fishplate. Apparently the collar around the top of the ferrule of the bond had been thickened up against the rail-head, thus holding the bond farther away from the rail than usual. That enabled the strands to hang vertically, made a neater job, and reduced the likelihood of damage to the bond. It also avoided the acute angle which had to be filled in by the welder if the bond was attached at an angle of about 30 degrees. He would like to know whether his interpretation of the drawing was correct.

The steps which the Author had taken to overcome the trouble which had been experienced with the welded bogies were interesting, particularly as on the Continent, just prior to the war, one large railway had been using welding very extensively for the production of their locomotives. Mr. Swift had had the opportunity of seeing some of that work, and he had found the openings for the axle-boxes in the side frames were always cut after the frames had been welded up. That appeared to produce a very satisfactory bogie. He wondered whether the Author had tried that on his bogies, although they would naturally be smaller than a locomotive bogie.

Mr. Swift had noticed that the inlets to the ducts for the motor ventilating air were located about waist-height on the sides of the motor-coaches. The Author had stated that the ventilating system had been found to be efficient, but Mr. Swift would like to know whether, as a result of experience with the new Liverpool-Southport stock, where the duct openings were located on the roof, it was considered that the additional complication was worth while, or whether openings at waist-height provided sufficiently clean air.

The Author had expressed the opinion that the justification for the additional outlay on roller-bearing axle-boxes lay largely in the reduction in labour and material in lubrication; but in Appendix I it was stated that the axle-boxes were oiled every 25 days; that seemed to be a very short period, particularly as the motor suspension bearings were lubricated every 50 days; lubrication of the axle-boxes should be necessary only every three or four months.

Was the high-tension transmission-line, on wooden poles, an earthed or unearthed system, was an earth wire used, or were the cross-arms and metal fittings earthed at each post? Further, were lightning-arresters installed at each substation-in addition to the 50 yards of cable mentioned by the Author, or had that cable connexion alone been found sufficient to protect the substation apparatus from the effects of lightning storms?

\* \* **Mr. A. W. Woodbridge** observed that on two of the lantern slides

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\* \* This contribution was submitted in writing.—SEC. INST. C.E.

shown by the Author the telegraph wires appeared to be carried on poles on one side of the track whilst the power transmission-lines were carried on poles on the other side. Thus the wires were paralleled by the power lines for long distances. In those circumstances inductive interference with the communication circuits was generally considerable, and it would be interesting to know what steps had been taken to reduce such interference to the minimum.

Apparently the Wirral lines were not track-circuited throughout, and since on many lines it had been the practice for the Signal Department to maintain the track bonds, would the Author say who was responsible for the bonds, both in the track-circuited areas and on other sections ?

From the Signal Engineer's point of view the fourth-rail system had many advantages over the third-rail system, but it was rather surprising to hear Mr. Graff-Baker's statement that the cost of impedance bonds per mile of track was higher than the cost of the fourth conductor-rail. Presumably that applied only to lines with signalling laid out for very close headways.

On overhead and third-rail electrified lines with track-circuiting one great problem had been the transmission of traction currents of the order of, say, 1,000 amperes in the running rails at the same time that the Signal Engineer had the track-circuit connexions to the rails carrying a few milliamperes. A slight unbalance in the return rails immediately caused trouble for his department. Such difficulties were practically eliminated by the fourth-rail system, but in that case the signalling system was sensitive to faulty trains, causing traction current to flow in the running rails. Therefore, it was disturbing to hear from Mr. Graff-Baker that trains could run for a long time with either pole earthed. Surely that would be a rare occurrence in practice !

**The Author**, in reply, observed that he welcomed Mr. Wallace's comments on the maintenance of the track, and his statement about the reduced wear of the rails with the new electric services was particularly interesting. Although the new services were more frequent, the light-weight stock and the absence of locomotives had considerably reduced the total ton-miles passing over the tracks, but it must be remembered that schedule speeds were now somewhat higher. War had been waged on the question of systems of electrification as long as he could remember. He had now completed his fiftieth scheme, which had included many different systems, and it was clear that no hard and fast rule could be given to meet all circumstances. He could say, however, that unless some radical technical change occurred—and that was not to be expected—the 1,500-volt overhead system would probably win the day on the London, Midland and Scottish Railway. He held no brief for the third and fourth rail system and he had every sympathy with Mr. Wallace in the difficulties experienced in maintaining the track where that arrangement was employed, but existing installations which were to some extent the legacy of the past could not easily be changed.

In reply to Mr. Fletcher, the Wirral scheme was too small to bear the cost of development of any major departure from usual practice. There were certainly alternative arrangements which might well repay investigation, both as regards the starting of trains and stopping them, but it was obvious from its almost universal employment that the series motor would not easily be displaced. It hardly seemed to be just to state that electricity was not good for stopping trains since the braking arrangements in actual use on almost all traction systems, whether electrified or not, were entirely mechanical. Mr. Fletcher had had a long and successful connexion with the traction motor, and any concrete proposals he might put forward would deserve the most careful attention. As a matter of interest, the motor used on the Wirral line was an existing standard design which, with slight modifications, happened to suit the system. It had a peculiar feature, so far as Great Britain was concerned, in that the fan was at the commutator end. That was the practice in some countries on the Continent, and the Author thought it was possibly right. It had given no trouble on the Wirral lines, and much could be said in its favour.

On a large system of electrification there might be an economic case for the use of transportable substations for emergency working, but such a provision would not be justifiable on a small line such as the one in question. Transportable substation plant had been very successfully used in Sweden and Italy, but conditions in Great Britain were appreciably different.

In reply to Mr. Harrison, all track equipment such as cables and switches was maintained directly by the Electrical Engineer's Department, but conductor rails and bonding were maintained by the Civil Engineer's Department in consultation with the Electrical Engineer. It would seem that the basis on the London and North Eastern Railway was now very much the same as on the London, Midland and Scottish Railway. Corrosion of the third rail was a factor of some importance, but it could be exaggerated, and he thought that the new rail section adopted on the Wirral line, which reduced the surface area by 11 per cent. in comparison with the previous section, was about as much as could be done. It would take many years to find how much it saved, and anything further seemed likely to introduce difficulties greater than the evil it was intended to rectify. Painting of the rail had been tried, but the saving did not justify the cost.

Regarding the anchoring of the conductor rail, on welded sections it was the practice to put five anchor insulators close together. In theory, those would all bear on the rail simultaneously, but in practice that did not happen, and the slight tilting of some of the anchor insulators which occurred was therefore an advantage, as it distributed the load substantially evenly between them. The felt packing shown in *Fig. 7a* inside the clip permitted that tilting to occur without damage to the insulator.

The figures concerning the respective weights of the North Tyneside stock and the Wirral stock given by Mr. Richards were somewhat misleading, as the North Tyneside stock was articulated. It had at first been

intended to use articulated stock for the Wirral scheme, but when questions of clearances were gone into it was found to be hardly practicable. If that were taken into account, it would be seen that the North Tyneside stock was not what was usually regarded as normal, and that the weight saved on the Wirral stock was actually more than 10 per cent. in comparison with the usual heavy type of stock in use on electrified lines. The maintenance costs for the Wirral stock were, so far, the lowest of any on the London, Midland and Scottish system. It was true that that stock had not yet had many years' service, but all the evidence available suggested that the present low costs would be maintained. Therefore, the question of setting off saving in energy against higher maintenance cost did not arise, and all the savings obtained could be regarded as net figures.

The term "service fault", as used in the Paper, might be defined as any fault which resulted in a reported delay. All delays except, perhaps, short ones not exceeding 1 or 2 minutes were reported. It seemed, therefore, that the figures given by Mr. Richards for faults on the Tyneside lines were not on a comparable basis. Actually in 1942 there were only three occasions on which trains were taken out of service. The Author welcomed Mr. Richards' remarks about the interchange of information between the two Companies, and he felt that he should record that exchanges which had already taken place had been of definite interest.

Several speakers had discussed the question of system, and he had given his views in reply to Mr. Wallace. Mr. Graff-Baker had admitted that he was almost alone in advocating 650 volts, and one of his main arguments in favour of the third and fourth rail system had been questioned by Mr. Woodbridge. The Author, too, was not at all happy about the idea of running trains on that system when an earth had occurred, as it was undoubtedly likely to interfere with the signalling system. The bending down of the end of the current rail instead of fixing a separate ramp had not proved unsatisfactory. It was, of course, a minor point so far as the cost of the track system was concerned, but at the moment he had no evidence to warrant a reversion to the more expensive method.

He had had manufacturing experience covering thousands of traction motors and extensive operating experience, but he had never found the tapped field a source of weakness. It was true that the design of the field coils was the most difficult part of the motor, but it did not seem that the introduction of tappings made it any more difficult and the use of non-inductive diverters did lessen the ability of a motor to withstand current-surges without flashover.

If Mr. Graff-Baker's figure for the consumption of grease and lubricating oil referred to the quantities used per axlebox, they seemed high. Actually the Author had maintained plain sleeve-pad lubricated bearings with about half the oil-consumption mentioned.

He could not agree that the use of cast-iron blocks to remove flats from the tires was not a useful procedure. Admittedly there were certain small

flats which might roll out, and occasionally large flats necessitated returning the tires, but in between there was a wide range of cases where the cast-iron block worked very well. Only the blocks on the axle concerned were exchanged; the loss in braking effort was negligible and the whole job was much simplified. The polish on the tread was, of course, destroyed and when non-metallic blocks were restored there was increased wear for a time, but that again was not important.

Regarding the number of motors on a motor coach, it did not seem to the Author to matter much, from a mechanical point of view, on which axles of a train the motors were placed. With a given motor, a certain amount of dead weight had to be carried on the axles and the total effect on the track was not reduced by distributing the motored axles over a greater number of vehicles. Nor would that step have helped him in dealing with a disabled three-car set unless he had gone to the considerable expense of doubling the number of control units fitted. The motors on the Wirral line were relatively small and a single control equipment could deal with the currents required by four of them, and such duplication would be of value only very infrequently. It should be remembered that there were switches to cut out either pair of motors, so that a single motor failure did not render a three-car train immobile and, in fact, it had not yet been necessary to rescue any train with another.

Regarding the use of a larger motor-generator set, the decision turned largely on the question of weight, as he agreed that there was little difference as regards cost; but it should be remembered that the direct lighting system was used on the great bulk of multiple-unit stock and there seemed to be little complaint. Faults were based on motor-car-miles because that was the established practice of the Company and it was desirable to have the figures relating to all lines on the same basis. Admittedly, that basis might not be quite accurate for the Wirral stock where there were air doors, etc., on the trailer coaches, but the error introduced was small and far outweighed the inconvenience of using more than one basis for the Company's lines as a whole. The question regarding the definition of "service fault" had been dealt with in connexion with Mr. Richards' comments.

The arrangement of demountable equipment adopted had added nothing either to the weight or the cost of the stock, and the Author was convinced, from a long and varied experience, that when attention was necessary it was far better to take the equipment as a whole on to the bench, where the work could be carried out under the best conditions. It might be true that when one of the equipment cases was removed for overhaul all the items of equipment in it would not need attention, but as everything came away together, that made no difference to the total work involved. The arrangement did not, of course, preclude the occasional removal of a single piece of apparatus if that course offered a saving of time.

Mr. Graff-Baker had suggested that the saving in weight on the stock might have cost very little. Actually, the first cost of the stock had been

lower than that of stock of the heavy construction previously used. The question of maintenance costs had already been discussed in reply to Mr. Richards, but the Author would like to re-state his view that in order to obtain a successful electrification of the multiple-unit type, the stock should be made as light as could be reasonably be done.

The 3-foot 9-inch doors suited traffic conditions in the area quite well. Although two people could not step out abreast, movement was appreciably quicker than it would be with doorways only 2 feet 3 inches wide, as the passengers automatically took up what might perhaps be described as a staggered formation. Wider doorways would not have been worth the sacrifice in seating entailed.

In reply to Mr. Lydall, the standard unit was a three-car set, which was used for light traffic, and two sets were used together for heavy traffic. Unfortunately, in the advance proofs of the Paper, the caption under *Fig. 9* was incorrect. Regarding the four high-tension circuits from Birkenhead North, *Fig. 2* might be amplified by explaining that two feeders went direct to Morton and the other two independently to Bidston and Wallasey. The site for Birkenhead North substation and the adjoining control-room was selected according to its general convenience and the availability of ground. All four circuits happened to lie on the opposite sides of the same length of track for a few hundred yards, but the layout adopted was undoubtedly the cheapest.

The rectifiers were not compounded by grid control or any other method. Arrangements were made for parallelling conductor rails at the ends of the system if the end substations were out of commission. The arrangement had not yet been needed in service, but tests had shown that satisfactory services could, in fact, be maintained with any of the end substations out of commission.

Regarding the statement made at the beginning of the section headed "Electrical Equipment of the Rolling Stock" (p. 27, *ante*), it was not intended to imply that an identical service could be obtained if the motor-cars had only two motors, and an acceleration of 1.4 mile per hour per second could not be obtained. It would, however, be possible to get sufficiently close to that to give a service which would meet the needs of the line. There were various ways such as the ones suggested by Mr. Lydall, in which the rigidity of the motor bogies could be improved if an increase in weight were not objected to, but such an approach to the problem would be clumsy, and the Author had no doubt that a completely satisfactory bogie of about the same weight as the present bogie could be built once the teething troubles inherent in a change from a riveted to a partially or wholly welded design had been overcome.

The difficulty with motor brushes seemed to arise mainly from the lack of any adequate method of testing them when a motor was built. At present their performance could be discovered only by running the motor for a considerable time. If some method of assessing their performance

and rate of wear accurately on test could be devised, he had no doubt that their characteristics would soon be much better understood and satisfactory grades would be installed from the start.

Mr. Warder's comments regarding development of the single-unit substation might be amplified. Firstly, it was necessary to have a clear idea of what was meant by the term and, in fact, the phrase "single unit" was generally used wrongly. The "single-unit" feature of the arrangement was incidental. What the phrase actually implied to-day was a substation in which all the plant was in use during normal service, that was, a substation where there was no spare or standby plant. A substation coming within the true meaning of the phrase might have a single 2,500-kilowatt steel tank rectifier or a number of glass bulb rectifiers capable of the same output. It was difficult to know what phrase would be best; what actually was meant was a "no standby plant substation," but so long as it was understood that that was what was actually implied, the actual phrase used might not seriously matter.

Regarding the conception of the idea of the single-unit substation, it was certainly well known on the Continent, more particularly perhaps in France, as early as 1923-24, and installations were projected in the United States some time before 1930. For example, the extensive construction of subways in New York undertaken in 1925 was originally intended to have substations with rotary plant on the then conventional lines, but during the course of construction a very substantial proportion of the supply system was changed to the single-unit arrangement with closely spaced supervisory controlled substations, each containing a single water-cooled rectifier.

When the Wirral scheme was undertaken, there had been little actual experience with air-cooled steel tank rectifiers. The glass bulb rectifier had proved adequate for the job, and the Author would not be likely to change to the air-cooled steel type unless some positive advantage seemed likely to be gained. The three-bulb arrangement had the additional advantage that routine maintenance could be carried out in one cubicle at a time during light-load periods.

Careful consideration of the protection provided would show that it conformed to Mr. Warder's precept that it should be based on the actual conditions of service and that the various relays provided did give protection against the contingencies which might arise. The economics of protective equipment were always difficult and the majority of the relays provided had not yet had to justify their existence. The load-sharing relays which operated alarms in the control-room had been dispensed with in later installations. One of the quantities that governed rectifier capacity was the integral of  $I^2dt$ , and in the Author's view a single relay was not adequate for rectifier protection. Certainly, the correct place to isolate a back-fire was in the anode circuit, but for economic reasons it was obviously desirable to reduce the number of circuit-breakers to the

minimum and, as anode fuses were cheap and reliable, there seemed little reason why anode circuit-breakers should be adopted. The rectifier output circuit-breaker was certainly a second line of defence, but general practice, with the support of rectifier manufacturers, was in favour of retaining it.

It was very interesting to learn from Mr. Swift that the North Tyneside lines exhibited the rather curious type of wear observed on the London, Midland and Scottish Railway. The running rail bond used was a standard commercial product very similar, the Author understood, to those used by other Railways in Great Britain. *Fig. 8a* had been reproduced from the standard working drawings, and whilst in practice the bond might sometimes be installed with a rather greater inclination to the vertical than that shown, it was not as great as 30 degrees. Occasionally, too, a bond might be bent as the fishplate was removed, but in general little difficulty was experienced in removing the fishplates with the bond attached to the rail in a position not far from the vertical.

Regarding the position of the inlet ducts for the motor ventilating air, the arrangement on the Wirral lines had proved quite reasonably satisfactory and was a decided improvement on the conventional arrangement. The Liverpool-Southport line ran close to the sea shore for the greater part of its length and there was a lot of sand about; therefore it was decided to put the inlet on the roof as a further protection. The Author had no data to show whether that change would be worth while on an inland route. The 25-day oiling of the axleboxes was admittedly rather frequent, and it was hoped to extend that period or, alternatively, to use grease. The economic margin in favour of roller bearings was admittedly fine.

The high-tension transmission system was earthed at Liverpool through a resistance and a continuous earth wire was mounted underneath the line wires on the overhead routes, to which all metal fittings on each pole were bonded. This earth wire was itself earthed every quarter of a mile. Horn-gap arresters had been installed at each terminal pole, but they presented too great an attraction as a roosting-place for birds, and lines were shut down on several occasions. Their value was doubtful and it was decided to remove them and rely entirely on the length of cable mentioned in the Paper to protect the substation plant against lightning.

In reply to Mr. Woodbridge, the high-tension lines were transposed wherever a cable break was introduced at bridges, etc. Otherwise no precautions to avoid telephone interference were taken and no troubles had been experienced with properly installed telephone circuits. The line was, of course, relatively short and similar good results would not necessarily be obtained on a long line.

As stated earlier, the track bonds were maintained by the Civil Engineer, but any bonds installed purely for signalling purposes were maintained by the Signal Engineer.