Discussion.

Mr. HARRISON HAYTER, President, said that there was little Mr. Hayter. doubt from what they saw going on around them, from the success already achieved, and from the inventions and improvements continually taking place, that the use of electricity as a motive power was on the increase, and would continue to increase. The subject, therefore, was one of special interest to the engineer; and it was opportune that the Institution at the present moment should have such a Paper brought before it. He would notice that the subject before them was the working, not the construction, of electrical railways. He mentioned that circumstance because, before the Session was over, the Institution was promised a Paper on the construction of the City and South London Electrical Railway by Mr. Greathead, and the members would then have an opportunity of discussing the construction of such lines. At present the discussion therefore would be confined to the working of electrical railways, unless indeed there should be any detail of construction that might have to be referred to as bearing on the working. The Author had paid considerable attention to the subject, and had been good enough to give them the results of his experience. It was therefore hardly necessary to propose, although he would do so in compliance with established usage, a vote of thanks to the Author for his practical and useful Paper.

Dr. EDWARD HOPKINSON said that there were three or four points Dr. Hopkinson. not properly forming part of the subject matter of the Paper, which were incidental thereto, and to which he should like briefly to refer. One of the first problems to be solved before considering the question of the power which ought to be provided for working such a railway, was the determination of the air-resistance to a train moving rapidly through such a tunnel. He had not discussed the question in the Paper, because the general problem of the motion of air in tubes had been fully investigated by Professor Osborne Reynolds, Professor Unwin, and others; but he might say that the air-resistance was a by no means negligible portion of the total resistance to the motion of the train. It would be seen from the diagrams that more than half the section of the tunnel was taken up by the train; consequently the air must either be pushed in front, or must pass to the back of the train through the restricted passage; in the latter case it would

Dr. Hopkinson. be retarded by the skin friction along the train and by the friction against the rough sides of the tunnel. That the velocity of the entire mass of air in the tunnel would be small could be easily proved and had been confirmed by observation. Hence the train had to maintain the motion of the air past itself in, as it were, a rough tube of less than half the section of the tunnel, consequently the resistance would be considerably more than four times what it would be were the train moving in the open. Another point which was entirely incidental, but which he thought was of some interest, was the question of the theory of the jockey-pulley. He knew it was a common impression amongst engineers, that the use of a jockey-pulley meant much loss of power in friction; but he thought that was not necessarily so. Taking the case of a stretched chain, which a link belt practically was, at rest, if they gave it a deformation transversely—say, a blow at right-angles to the chain—two waves would travel along the chain, one backward and the other forward. The velocity of those waves would depend only upon the tension of the chain and upon the mass of a unit length; in fact, the velocity was the square root of the tension divided by the mass of a unit length. Instead of the chain being fixed, suppose it to move: in the case of the belt it was moving in a direction round the driven pulley, and so back to the fly-wheel. Clearly, if the velocity of the belt was the same as the velocity of the wave caused by any transverse disturbance, one of the waves travelling against the belt would remain fixed in space, and the other would travel with double the velocity of the belt and come on to the pulley, and, by reason of the greater tension on the belt round the pulley, would be absorbed or reflected back. They would then have this condition of things: assuming the velocity of the belt to be equal to $\sqrt{\frac{T}{M}}$, if the belt were subjected to a disturbance transversely—which was exactly the action of the jockey-pulley—the disturbance would remain stationary; so that the jockey-pulley had nothing more to do than to maintain that single harmonic vibration. Of course that meant the loss of a very small amount of power. If the velocity of the belt moving in that way was not equal to the velocity of the wave, then there would be a number of vibrations set up, and the loss of power might be considerable. He had found that in some instances this condition could be approximately fulfilled. In dealing with the problem, the force of gravity on the belt must be considered. If this could be neglected, what had been said as applying to the jockey-pulley

would apply also to the driven pulley, and the belt would not drive at all. The third point he wished to mention was the question of separate locomotives, in regard to which he desired to anticipate some criticism which was sure to be raised in the discussion, because possibly if he then referred to it it might save time afterwards. It was constantly said that one great advantage of electrical propulsion was that the number of driving-axes could be increased to a large extent, and that the proper way to apply it was to put a motor upon each axle of the train, and by that means save dead weight. That advantage was great on lines with exceptionally steep grades, but in none of the practical cases with which he had had to deal had he found that there had been any material advantage in subdividing the motive power in that way. Taking the case of the City and South London Railway, the average total weight of a train might be said to be about 40 tons, and the weight of the locomotive 10 tons. Of that 10 tons the motors and electrical gear absorbed 6 tons. The motors had to be somewhere, it was therefore impossible to save the 6 tons, so that the extreme saving would be the 4 tons of the locomotive frame. But if the motors were subdivided into smaller ones, the weight would necessarily be increased. Again, supposing they were put upon the bogies, the bogies themselves would have to be considerably strengthened, and their weight would be increased, so that probably the extreme saving would be from 1 to 2 tons, out of a total of 40 tons, or from 2 to 5 per cent. That saving was very small compared with the great advantage of having the motors on a separate vehicle, and immediately under control and proper inspection. Since he had written the Paper a very important addition had been made to electric traction, viz., the Liverpool Overhead Railway. He did not refer to it, because, at the time of writing, as far as he was aware, there had been no running on the line, and now, although it had been inaugurated under high auspices, it had not yet been opened for public traffic, but he hoped, as some gentlemen intimately connected with the railway were present, they would give the members some details of the construction of the electrical plant on that line. There was another point to which he wished to draw attention, which was not included in the Paper, because he had only received the figures since the Paper was written, and he was greatly indebted for them to Mr. Jenkin and Mr. B. Mott, officials of the Company. They were given in Table I. He had been able to separate the cost of the generator-station working, that was, the cost of the production of electricity, from the cost of

Dr. Hopkinson.

Dr. Hopkinson. locomotive power, or of utilizing the electric current and re-converting it into mechanical power. In that Table he had excluded office expenses, and had simply considered the wages, fuel, water, gas, oil, stores, and repairs, given in pence per train-mile. It would be seen that the total cost of the generating power was 4·59*d.* per train-mile. Knowing the total amount of electrical energy produced, they could obtain the cost per Board of Trade unit, which was a figure of great interest to all who had anything to do with electrical engineering; and he thought it was a striking result that in the first railway of any magnitude the cost of the Board of Trade unit had been reduced to a smaller figure than in any electric station in England, and, as far as he knew, in the world, with the exception of Bradford, where the cost was 1·41*d.* against 1·56*d.*, but at Bradford they had the advantage of exceedingly cheap coal, and perhaps of cheaper labour, than was available in London. Taking another case, that of the St. James's and Pall Mall Electric Lighting Company, one of the most successful central lighting stations, the cost per unit in 1892 was, he believed, 2·26*d.* The lower part of the Table gave the cost of the locomotive working. He did not know that there was much to call attention to, except the fact that in both one and the other the item of repairs was small, and the item for wages was also small, which was of course entirely due to the excellent management of the line.

TABLE I.

City and South London Railway, half-year ending December 31st, 1892—

Train mileage	214,417
Number of passengers	3,317,602

Cost of working generator-station, excluding office expenses—

	£	d.
Wages.	1,012	1·12 per train-mile.
Fuel	2,172	2·42 " "
Water and gas	252	0·28 " "
Oil and stores	368	0·41 " "
Repairs and renewals	321	0·36 " "
	<u>4,125</u>	<u>4·59 " "</u>

Equivalent to 1·56*d.* per Board of Trade unit.

Cost of locomotive working, excluding office expenses—

	£	d.
Wages	1,776	1·98 per train-mile.
Oil and stores	89	0·10 " "
Repairs and renewals	208	0·23 " "
	<u>2,073</u>	<u>2·31 " "</u>

Mr. A. RECKENZAUN said that engineers and others interested in electric traction, himself included, were constantly referring to the progress made in the United States in electrical traction. Dr. Hopkinson had also introduced the subject of the statistics of electrical traction in that country; and had stated that in America there were upwards of 4,000 miles of electrical railways as compared with $33\frac{1}{4}$ in Great Britain; or, including Liverpool, 40 miles. Probably few engineers on this side of the Atlantic were aware of the fact that electrical traction in the United States was encouraged, primarily, by estate agents and speculators. The earlier tramways and railways were suburban lines; and they were constructed before there were roads or houses, for the principal purpose of developing certain estates where people would not live unless there were roads, and unless there was rapid transit. The estates were worth very little—probably they were only agricultural or waste land—but they had been developed by those means; and the profit derived by the speculation had, in many instances, more than paid for the electrical railway. An advantage which the Americans enjoyed was that they required no Act of Parliament to build a line; they merely had to ask the local authorities for permission to run a line through the streets, and in ninety-nine cases out of a hundred they got permission immediately; and perhaps three months after the “franchise” was obtained, the line was in operation. In that way, those 4,000 miles of electrical tramways had been established, the majority of which were new lines. Many of the lines, originally constructed for horses, had been converted into electrical lines; but there, also, the financier had done the principal part of the business. The tramway companies were not in a position to purchase the plant necessary for increasing the quickness of their service; a trust company was therefore established, which bought up the horse-tramways, or guaranteed certain dividends on bonds. By that means, capital was advanced for the establishment of electrical lines, and for the conversion of horse-lines into electrical ones. On this side the Atlantic, and particularly in Great Britain, as the Author had pointed out, progress had been very slow, although Great Britain was years ahead of the United States in the practical application of electricity to tramway working, as could be seen by the Appendix to the Paper. The Author had shown that the Portrush line was opened in 1883, the Brighton Beach line in the same year, the Bessbrook line in 1885, and several others in 1886; whereas the “boom” in the United States did not commence until 1887, but it had rapidly progressed ever since.

Mr. Reckenzaun.

Mr. Recken-
zaun.

In Great Britain, before a horse-line could be turned into an electrical one, it was necessary to get an Act of Parliament. The old tramway companies had an Act of Parliament which did not contain a clause permitting the use of electricity as a motive power; but the new Acts passed within seven or eight years had such a clause. This, however, had been mutilated by the influence of the National Telephone Company, so that the lines might be constructed in such a manner as not to interfere with the single-wire telephone, which would make the electric tramway system in use in America of single overhead conductors an impossibility. Then, besides getting the Act of Parliament, the local authorities had to be consulted, and the public in general seemed to be opposed to the use of overhead conductors. The Americans did not object to numerous poles in the streets. There were poles for telephones, poles for electric wires, telegraph poles, and poles for electric railways; indeed, some of the finest streets were nothing but avenues of ugly poles. In this country such things would not be permitted; overhead conductors were evidently at present unpopular. Then many of the British tramway companies were poor, and, even if they had an Act of Parliament and obtained permission to run overhead conductors, they had not the money to buy the plant with; and if they increased their capital in proportion, they probably would not be able to pay a dividend. They had all those difficulties to contend with, and therefore electrical traction made but very slow progress. Referring to the more technical portions of the Paper, he observed that the Author gave credit to the late Sir William Siemens for suggesting the method of putting the armature direct upon the axle of the locomotive or car. Nine or ten years ago Mr. Reckenzaun was connected with an electrical railway problem which involved locomotives of considerable power, for which Messrs. Siemens Brothers were the designers. The armature, as in the case mentioned, was placed upon the axles. Messrs. Mather and Platt were the first to have the opportunity of applying that in practice, and great credit was due to them for showing that it could be successfully done. It was his opinion, and that of many others, that an armature which consisted of more than a thousand distinct pieces of metal and insulation bolted together might not be able to stand the strain of the acute vibrations of an axle running at such a speed as those locomotives on ordinary rails. Two years' working, as the Author had pointed out, had shown that there was no fear that the armature would suffer from that cause. The Author had referred to the

amount of HP. that might be put upon a single axle, and had stated that he had succeeded in getting 100 HP. on two axles. It was a question whether more than that power should be put upon an axle on a railway 4 feet 8½ inches gauge, and he had some doubts whether it could be done. The General Electric Company of America had built a locomotive of 600 calculated HP. for the Baltimore and Ohio line. Although they used multipolar motors and large driving wheels, they were obliged to make six driving-axes, so that they could get that amount of power on the locomotive. As they increased the power they must also increase the number of axes. In connection with the question of 100 HP. of the locomotive, he wished to ask the Author how he arrived at it. He had stated that "the two motors on each locomotive on the South London line are each capable of developing 50 HP. at a speed of 25 miles per hour, corresponding to 310 revolutions of the axle per minute." Now 100 electrical HP. at a pressure of 500 volts meant 150 amperes. With 150 amperes the armature would be revolved at a very low speed. This current would only be used at starting, and at that moment the mechanical horse-power given off was nil, or very small indeed; so that if 150 amperes at a pressure of 500 volts were used at starting, probably 90 or 80 or 70 per cent. was wasted in heating the wire. Thus, at the moment of starting the locomotive could not give 100 mechanical HP. With regard to the 25 miles per hour, as the revolutions of the armature increased, so the counter-electromotive force increased and the current decreased; consequently 25 miles per hour could not give 100 HP., or even 50 HP. He had calculated that if it gave 100 HP. at 25 miles per hour and 40 tons load, the coefficient of traction would be as much as 37½ lbs. per ton, which was enormous. He believed that the Author was wrong in asserting that his locomotives were capable of giving 100 HP. either at full speed or at low speed. As to the efficiency of the motor, the Author, referring to the re-conversion of electrical into mechanical energy, had stated, "The efficiency of the motors with known electromotive force and current is easily determined, but it is of greater interest to ascertain the average efficiency of the locomotives as a whole, working under the constantly varying conditions of speed, load, and electromotive force." He would ask the Author to supply a list of the brake tests of one of the motors used on the City and South London line, which would be exceedingly interesting. He feared that the efficiency was not very high, and he based that fear on the fact that the pole-pieces compared with the rest of the magnetic circuit were very thin, and the lines of force were not distributed

Mr. Reckenzaun.

Mr. Reckenzaun. all over the armature to give the maximum useful effect. He considered that a rather important point. The working expenses seemed remarkably moderate, and the sum for repairs and renewals was surprisingly low, especially wages and material. He hoped that there had been no mistakes made in the book-keeping. He had been a great traveller on the South London line, and in the early days the breakdowns were very frequent. Several of the armatures burned out in a week, sometimes one every day. Winding the armatures in those days was not a very easy or cheap matter. It appeared to him that the cost of repairs for the half-year ending December 31st, 1891, during which time they were, to his knowledge, frequent, was very low. Wages for six months were put down at £26 3s. 9d. and materials £193 13s., a very low sum indeed considering the experience he had had.

Mr. Parker. Mr. T. PARKER said that reference had been made in the Paper to the weight of the trains. In Liverpool the weight of the trains carrying 5-ton motors was 40 tons, when fully loaded with one hundred and fourteen passengers; while the weight of the trains described by the Author was 40 tons, and 10½ tons carrying one hundred passengers. Reference was also made in the Paper to the torque of the motor. The torque effort of a motor in starting a train was a most important factor, economy and efficiency being in a great measure secondary points. The Author stated that he had a torque effort of 1,180 lbs. with 100 amperes. In Liverpool they had a torque effort of 1,450 lbs. with 100 amperes, and that upon a diameter of 2 feet 9 inches, the wheels on the South London line being 2 feet 3 inches. With 120 amperes at Liverpool they had 1,800 lbs. torque effort. He hoped some day to be able to set those matters forth more fully. He should be glad to see some more detailed statement in regard to the motors, as asked for by Mr. Reckenzaun. With regard to the compound dynamos, working under the conditions mentioned, he thought they must be very difficult to handle, and that the conditions were not likely to give them a very long life. He should be glad to see some of the characteristic curves, and some statements of all the conditions under which they worked. They could judge but little of the motors or dynamos from the information given. He could only account for the difference by Mr. Reckenzaun's suggestion that the magnetic system was not as good as it might be. Neither did the locomotive as arranged allow of the advantages obtained under the carriages as used in Liverpool. In Liverpool they used two motors, one with each carriage, making two carriages a train, the motor being part of

the carriage. The difficulty of handling an independent loco- Mr. Parker.
motive was therefore done away with. It was not necessary to reverse the train at Liverpool, it was ready to start back immediately it arrived at its destination. They also did with two men on board the train, but it appeared that they required at least three in London. He imagined that they would be well able to deal with railway traffic without locomotives in most cases. Locomotives might be advisable under certain conditions. Where ordinary trains required to be drawn from the outside stations into the centre of London, locomotives would probably do that work with the present railway stock. He saw no difficulty in building locomotives powerful enough for that purpose as for any heavy work that might be required. He hoped to be able to show that they had made a great advance in the motors built for Liverpool. The Author had stated that he had a conductor 1 inch below the rails in the subway and wooden bridges to carry the slippers over at the crossings. He did not know what that could be done for. At Liverpool they had it 1 inch above the rails, and they needed no bridges of that kind. The slippers were continuous over the points wherever they went. The Gramme armature was used in the motors described by the Author. He thought that was the reason why the motors were not so good as they had been able to obtain in Liverpool. In further practice it would, he thought, be found that the Gramme armature was not the armature for that kind of work. The means of supporting it from the axle were mechanically bad, considering the various strains and the hammering to which the mass of the armature must continually be subjected. Although after two years no trouble had been found, still the construction of the motors would be a very important point in respect of the life, maintenance, and cost of the railway. At Liverpool they had adopted a system of insulators which were very efficient. He should like to see diagrams showing the power required to accelerate the trains in the subway. The Author had said something about air-friction in the tunnel, but unless he stated how much it was the reference was of very little value. He had often seen the Author's arrangement of the jockey-pulley, but could never learn to love it. Whatever mathematical proof might be given to show that it was a good thing, as a mechanic he could not accept it unless to meet special conditions.

Mr. GISBERT KAPP said it would have been a great advantage Mr. Kapp.
to the Institution if the Author, in his otherwise admirable Paper, had given some particulars as to the history of the failures or

Mr. Kapp. slight mishaps which undoubtedly had occurred on the line. In asking for such information he had no wish to draw attention to the fact that there had been such failures, because, in a pioneer undertaking of such magnitude where almost everything was new, it could not be expected that the different parts of the machinery and other works would be perfect from the first moment. It would have been, however, in accordance with the traditions of the Institution if the slight failures or break-downs had been mentioned, and also the means by which the difficulties were overcome. The Author had referred to the advantage of putting the armature direct on the axle of the locomotive. There could not be two opinions as to that. The question was whether there was or was not some greater tendency to break down due to mechanical shaking. The Author seemed to think that there was not. He would ask whether, in addition to mechanical vibration, there was any other reason why the armatures should have broken down more or less frequently? They did not break down at present, so that he presumed the fault had been removed. The employment of compound-wound generators was, he believed, a new departure in generating machinery for electric railways. As a rule the machines were separately excited, or shunt-excited, and he was doubtful whether compounding was a happy departure. The idea of using a compound machine was that it should adapt itself to the increase of load by raising the voltage at the generating station and so making up for the loss of voltage on the feeder. If they had to do with a small machine of 20 or 30 HP. that object would be undoubtedly attained, but they had to do with a machine of 200 HP., the field magnets of which were very heavy and massive, and such machines took a considerable time to alter their magnetic condition. There was a kind of magnetic inertia in the field magnets preventing the machines from responding readily to the change of load which happened in electric railways with alarming rapidity. It would be noticed that the period between the maximum and minimum load was a matter not of minutes, but of seconds. A machine of that massive build could not alter its magnetic condition in a short time. The result was that compounding did not fulfil all the expectations of the designer. The machines were admirable for steady loads or for loads which changed slowly; but he did not believe that with rapid changes of load they kept the voltage at the feeding points on the line even approximately constant. There was another objection to the employment of compound machines for that sort of work. The machines were not

coupled at the station, but they were coupled in a measure by the line, and it was quite possible that two compound machines coupled in parallel would come to grief by one machine sending currents through the other in a wrong direction, reversing its field. He should be glad if the Author would state whether any means were adopted to prevent such a catastrophe, for it would be nothing short of that, or whether he had never arrived at the verge of that dangerous condition. One suggestion made in the Paper, which he believed was originally brought forward by Mr. Reckenzaun, was that the very rapid variation of load should be met, to some extent at least, by the employment of secondary batteries. The secondary battery would be put in parallel with the generating machine, and would act as a kind of electrical buffer, giving out power when the machinery was heavily loaded and taking in power when there was some to spare, because the line did not take the full current. Having inquired into the question whether that could be done by secondary batteries, he obtained this result. If it were desired to use batteries and work them up to their full discharge capacity, they would in that case have to be content with obtaining only 400 volts when the load was high, and would have to apply about 500 volts when the load was light; that was, the voltage, instead of varying 60 volts as at present, would vary 100 volts, in order that the batteries might take and give power. In this way the present excess load could be diminished by about one-half if two batteries were employed, one in the City and the other at the Oval station. Each of those batteries would cost about £3,000; and their depreciation could not possibly be placed lower than 10 per cent. per annum, because they would be worked under very trying conditions. This was a very high price to pay for taking off part of the strain. There was also the disadvantage of a great variation of the voltage, because a battery when working at its full rate required for the charge $2\frac{1}{2}$ volts per cell, while it only gave 2 on the discharge. It was, of course, possible to work batteries between narrower limits of voltage; but then they must use cells which were far larger than was absolutely necessary, and the cost would become proportionately higher. The question was, could this very important object of diminishing strain, which really meant reducing the amount of steam-plant at work and coal burned at the generating station, be obtained in some other way? He thought it could. In this connection, he would like to mention a case which he had to deal with about fifteen months ago. It concerned electric power-transmission—600 HP. transmitted to

Mr. Kapp. a spinning-mill in Switzerland. The power was obtained from several motors, amongst which was one of 100 HP. nominal, driving a whole floor of self-actors. The self-actors took a moderate amount of power taking the mean; but at the moment of the carriage returning they took a considerable amount of power; and if there were six or seven of those self-actors returning at the same moment, the strain on the motor became very severe. The power was estimated from the indications of electrical instruments, which, owing to the sudden changes of load, were difficult to read, but, as nearly as he could ascertain, the mean power was 96 HP. and the maximum 150 HP. The motor would work for three or four minutes fairly steady, then on a sudden it would give a few fluctuations. The period of fluctuation was fifteen seconds, namely, the time between the forward and backward return of the carriages. This was cured by the simple application of a fly-wheel weighing 1 ton put on the motor spindle. The speed of the motor was 600 revolutions. In designing the fly-wheel, he allowed for an average variation of 5 per cent. There must, of course, be a speed-variation, so that the fly-wheel might act. That got over the difficulty completely. He thought it would show what might be done on electric railways if they were to put on in one or two parts of the line a shunt-wound dynamo with a magnet excited in a particular way, and driving a fly-wheel, but doing no other work. If the fly-wheel rim were 6 feet in mean diameter, and weighed 2 tons, then with a variation of speed from 700 to 500 revolutions, they could store in such a fly-wheel 45 HP. output from the dynamo for one minute, or in electrical measure 2,000,000 joules. This would be amply sufficient for starting three trains at once, bearing in mind that the generating station also supplied power all the time. It would in that way be possible to get over the difficulty of having heavy strains on the generating machinery, and owing to the more even flow of current, the feeders would work at a higher efficiency. The fly-wheel dynamos in themselves would waste very little power and would require no attention. They would simply run all day as long as the current was on the line. They would take power and speed up when the load on the line was light and give out power and lose speed when the heavy strain came on; and as the period of strain only extended over ten, twenty, or twenty-five seconds, a comparatively small fly-wheel would give out in that short time a large amount of power.

Mr. Greathead. Mr. J. H. GREATHEAD said he was not sure whether he ought not to apologise for not having before presented a Paper to the Institution descriptive of the City and South London Railway. He

regretted that it had not been done, because if it had been a great Mr. Greathead. part of the Paper might have been left unwritten, and the Author might have added some other facts in reference to his particular part of the work, such as those to which Mr. Kapp had referred. He hoped to be able to prepare a Paper on the subject during the present session, and that it would be published in the same volume as that which contained the present memoir. He hoped that he should not be considered hypercritical if he began with the first words of the Paper, namely, the title, which seemed to him to be a mistaken one. He thought it ought to have been "Electrical Traction," or "Electrical Traction on the South London Railway," or "Electrical Traction on Railways and Tramways," not "Electrical Railways." It was to all intents and purposes a Paper upon electrical traction, and not upon the railways themselves. Referring to the historical part of the Paper, he might be permitted to refer to the statement in reference to the consulting engineer. The Author had said that Sir John Fowler and Sir Benjamin Baker were the consulting engineers at the commencement of the undertaking, whereas, as a matter of fact, Sir John Fowler became consulting engineer two years afterwards, when the company was launched. He thought that some tribute was due to Mr. Mott, the Chairman of the South London Company, for his action in reference to the question of electrical traction. It was due to him that electrical traction was employed upon the line. He first of all took great pains to satisfy himself, and then his co-directors, and finally his shareholders, that electrical traction had made such advances that it offered attractions superior to those of the cable system, upon the satisfactory working of which Parliament had granted the powers for making the railway. Among the enquiries which were made were invitations to a number of firms in England and America to send in proposals to the Company for working the line by electricity. The first proposals were of a general character, and were so divergent that it was almost impossible to compare them. Accordingly, tenders upon a specification were invited from the same firms, and the result was that the Company received from about half-a-dozen firms in England and from one in America proposals for constructing electrical plant, and working it in some cases. He thought it right to make that statement as showing that at that time there were in England a number of firms who were prepared to undertake that very important work, novel as it was, without at all wishing to detract in any way from the skill and enterprise of Messrs. Mather and Platt, who had carried out the work. Very important

Mr. Greathead. modifications were made in the proposals of Messrs. Mather and Platt, and one of the conditions was that they should, within a very short period, run one of their locomotives upon the line with two of the actual carriages that were to be run upon it finally. Experiments were made upon the line with those carriages for about nine months before it was opened, and consequently they had a full opportunity of estimating exactly what had to be done. He made that statement because it might be inferred from some of the remarks in the Paper that Messrs. Mather and Platt had been left in ignorance of what they had actually to do. He might add that the experiments were made upon the most difficult section of the line, viz., the City section where the gradients were steep and the curves sharp. He proposed to confine his remarks exclusively to matters connected with the traction, some of which he thought were of importance. It was stated in the Paper that there was no duplication of the steam-pipes. That was the case when Messrs. Mather and Platt had to do with the line, but since then a duplication of the steam-pipes had been introduced, and the works were perfectly safe in that respect. The chief reason for not employing condensing-engines was the difficulty of disposing of the hot water, which it was not allowed to discharge into the sewers. The Author had suggested that in the larger tunnels that were now contemplated in connection with electrical railway schemes there would be an opportunity of placing the conductors overhead instead of between the rails as had been hitherto done, both on the South London line and on the Liverpool Overhead Railway. He might observe that that was not his intention in proposing those larger tunnels. The intention was to give the power of putting in larger and more roomy carriages, and a better system of permanent way. He saw no reason why the conductors should be placed overhead. Dr. Hopkinson had stated that the system used on the South London line had worked well, and he did not see why it should not work equally well on all other lines. The Author had discussed the question of geared as against direct-action motors. One of the great arguments against direct-action motors to which the Author had not referred was that, on account of its larger size, it took, at the present time at least, a much greater current at the start. That meant a very great and sudden load upon the dynamos and engines, and it was an important matter, not so much on account of the actual loss of power as on account of the effect at the generating-station. The effect was that the generating plant must be very much more powerful than would otherwise be necessary.

Figs. 3 would illustrate that, showing, among other things, the horse-power taken by the locomotives from the conductors in taking a train from the City to Stockwell and back again. It would be seen from those diagrams how very large the current was, and the corresponding horse-power at the commencement of each run. The greater part of the large spikes represented loss. That loss was not peculiar to electrical working; in cable working very much the same thing occurred. When the grip was applied to the cable before the carriage or train reached the velocity of the cable, the cable itself must have travelled twice as far as the carriage, consequently the loss in power was equal to that necessary to overcome the inertia of the train. That was a considerable loss, although in that case it had not the same serious effect upon the engines in the generating station, because there was the inertia of the cable assisting the engines. Starting with the diagrams in *Figs. 3*, he had constructed two others, *Figs. 4* and *5*, one for a service of nine trains with intervals of four minutes, and the other for a service of seven trains with intervals of five minutes between the trains. It would be seen that the variations in power were very considerable. The shaded spikes which he had added indicated the power taken by the turnover locomotives at the terminal stations. That was interesting as showing the effect of the starting even of a locomotive of only 10 tons upon the machinery at the generating station. *Fig. 6* showed the actual effective power that he estimated to be required for the line when electricity was first talked of. They showed the power required on the rails for a service of ten 30-ton trains with three minutes intervals, and it corresponded very closely with the others when account was taken of the difference in speed and in the weight of the trains. The great objection to a geared locomotive, at any rate in connection with tunnel-railways, was the intolerable noise it made. The Author had said that a geared locomotive was constructed for the South London Railway. That locomotive was very seldom used, the principal reason being that it made such a noise that it could be heard three-quarters of a mile away, from one station to another. Directly it started the hum of it was distinctly heard. Another objection to a geared locomotive was the difficulty of hauling it. When it got out of order it had to be hauled, and it was more difficult to haul a geared locomotive than a direct-acting one. The Author had given four reasons in favour of gearing. He did not think that there was any force in the first in regard to separate locomotives, because it was found already that separate

Mr. Greathead.

Mr. Greatehead.

Figs. 3.

Fig. 4.

NINE TRAINS RUNNING. INTERVAL BETWEEN TRAINS, FOUR MINUTES.

Fig. 5.

SEVEN TRAINS IN RUNNING. INTERVAL BETWEEN TRAINS, FIVE MINUTES.

Fig. 6.

TEN TRAINS RUNNING. INTERVAL BETWEEN TRAINS, THREE MINUTES.

Mr. Greathead. locomotives had not the adhesion corresponding to their power ; on steep gradients the wheels would skid, showing that the power of the locomotive was greater than its adhesion, consequently there would be no object in reducing the weight of the motors. Of course in a separate locomotive there was plenty of space for the motors. Number two did not apply, because, as the Author had shown, the vibration had no bad effect upon the motors. The other two points were at least doubtful. The Author had given the torque of the motor at 100 amperes and 226 amperes. He did not know what the effect of 226 amperes would be upon the motors ; but he did know that 150 amperes, which was the current always used in starting the trains, had been the cause of some trouble. At first a great deal of trouble and loss had been occasioned the company through the damage to the armatures, resulting, he believed, entirely from the rush of current through the motors at the start. The remedy was found by Mr. Basil Mott, the resident engineer on the line, who wound a number of the armatures with square wire instead of round, and there had been no trouble since with those armatures. For many months the locomotives had been running without giving any trouble at all ; but it was only by the exercise of the greatest vigilance and care that that end could be obtained where the armatures were constructed with an insufficient section of wire. The next point was as to the brakes. He had been asked " Why do you not use electric brakes in connection with your trains ? " To begin with, when they started the work, there had been no electric brakes tried in which they could place confidence ; and, in the next place (which was the most important reason), he thought that it was very much safer not to depend upon electric brakes upon an electric railway, where, possibly through the failure of the current, they might want to put on powerful brakes exactly at the time when the current failed ; consequently, they adopted the Westinghouse brake with a reservoir upon the locomotives. That had been found to answer so well on the South London Railway that they had adopted it on the Liverpool Overhead Railway. In reference to one passage in the Paper, he thought it was only fair to Messrs. Siemens to state that their locomotives, which were supplied subsequently to those of Messrs. Mather and Platt, were upon a design which they had themselves submitted with their proposals sent in to the company, and that they were not copied from those of Messrs. Mather and Platt. The Author had made some remarks on air-resistance on railways of that kind. He (Mr. Greathead) did not think that air-resistance was a very

important element. He went into the subject very carefully, and Mr. Greathead. he regarded it thus—taking the area of the train as equal to half the area of the tunnel, and, assuming as an extreme that the ends of the tunnel were completely blocked up, the locomotive, in passing towards the blocked end, would have against it the air which would have to pass at the same velocity in the opposite direction; and, consequently, in those conditions there would be an air-resistance equal to that due to twice the velocity of the train. That, of course, would be four times the resistance that there would be from still air in the open. But the ends of the tunnel were open, and there were connecting passages between the up and down tunnels, and on an average it might safely be assumed that the air-resistance would not be more than double that of still air in the open. He had taken the trouble to calculate from the current taken by the locomotive what would be the average resistance on the line, and he found that from one end to the other, taking the average current, the average resistance would be 13 lbs. per ton for those small trains, and that the maximum resistance would be 20 lbs. at twenty-one miles per hour, which corresponded very closely indeed with the amount he had estimated originally, which was from 13 to 21 lbs. With reference to the question of separate locomotives as against motor-carriages, no doubt where motor-carriages could be used, as on the Liverpool Overhead Railway, where there was plenty of head room and they could be put on the bogies under the carriages, and where the trains were short, motor-carriages were the right thing. There could be no question about that because the weight hauled was reduced, and the terminal shunting was avoided. He had shown on the diagram the effect of terminal shunting at the generating station. In addition to that it was always necessary to keep two locomotives with their drivers and assistant drivers, who were half their time not running. Then a very important matter was the first cost. He had looked into the figures and had found that on the South London Railway the cost for about the same seating capacity was about £1,000 per train more than on the Overhead Railway; and the chief difference was on account of the separate locomotive. Of course, on the South London line, there was no room under the carriages; the curves were too sharp to admit of the carriages being lengthened, and therefore it became a question of multiplication of vehicles in any case, and it was decided, and he was sure quite rightly, that the locomotive should be separate and not a part of the carriage.

Sir FREDERICK BRAMWELL, Past President, said he had only one Sir Frederick
Bramwell.

Sir Frederick Bramwell. observation to make. Mr. Greathead had remarked that the main reason for not having condensing engines was the difficulty of getting rid of the hot water, which was not allowed to go into the sewers. He desired once more to repeat, that which he had so often said at the Institution and elsewhere, that they could in every instance, where there was a sufficient supply of water to feed a non-condensing engine, have condensation with the respectable vacuum of 26 inches without sending any water away at all, by the use of the evaporative condenser delivering simply a "reek of steam" into the air; and further, from what he had seen at Stockwell, he should say there was ample room there to have an ordinary injection-water pond. At all events, he thought that no mechanical engineer would be at all troubled to apply condensation to those engines on the ground that he could not send hot water through the sewers. He might mention that on the Surrey side of the river, and just to the west of Charing Cross Bridge there were two engines which had been working, one for twenty years and the other for thirty years, where the vacuum was made entirely by evaporative condensers such as he had mentioned.

Mr. Greathead. Mr. GREATHEAD said that they had not abandoned the idea of using condensing engines, and they hoped that they might be able to send the hot water into the gravel.

Mr. Cowper. Mr. E. A. COWPER said that Sir Frederick Bramwell had taken the words out of his mouth. If they were short of water they ought to use the condensing engines, because they could do with less water than with high-pressure engines. That he most distinctly maintained. There was no question of sending the hot water down the sewers or elsewhere, because the water that was used with a surface evaporative-condenser disappeared, taking with it the latent heat, and thus keeping the temperature of the pipe low enough to produce a good vacuum, namely, $28\frac{1}{2}$ inches inside the pipes, which were connected to the engine. The important practical point in favour of condensing-engines was this, that the steam did so much more duty in an engine with a good vacuum that only about 220,000 lbs. of water would be required to do the same work as 330,000 lbs. in a high-pressure engine, and only two-thirds as much coal would be necessary. A little hard water should be mixed with the soft, distilled water for feeding the boiler.

Dr. Hopkinson. Dr. JOHN HOPKINSON thought it only justice to Messrs. Mather and Platt to explain the slight discrepancy existing between the weight of the cars, as specified in the first instance, and the

weight which they were afterwards found to be. Mr. Greathead Dr. Hopkinson, had said that Messrs. Mather and Platt should have found out that difference at the time at which they made their somewhat lengthened experiments when the railway was opened with their single pair of locomotives. The purpose of those experiments was threefold. First, they wanted to ascertain what kind of commutator and what kind of brush were the best. Secondly, they wanted to see whether the better plan was to use series-dynamos or shunt-dynamos; and thirdly, they wanted to compare the direct-action dynamo with the geared dynamo. Those three points they did pretty satisfactorily ascertain. They did not go into any considerable examination of the question whether the size of the wires of the dynamos was adequate. The runs upon that railway were hardly long enough to ascertain that point, and Messrs. Mather and Platt relied upon their general experience of what the wires were calculated to carry, and what would cause them to give way, rather than upon the experiments themselves. For his own part he never dreamt of the carriages weighing more than the weight specified, and he was sure that if Messrs. Mather and Platt had anticipated anything of the kind he should have heard of it. Fortunately in the result the difference did not cause much trouble. Undoubtedly at first a certain number of armatures gave way owing to the greater load to which they were exposed compared with that which they were designed to carry, but, as Mr. Greathead had stated, a very slight alteration was found to be sufficient to make the same motors do the increased work. Consequently, owing to the fact that there was a margin and that it was possible to increase the output of the motors to that slight extent, no serious trouble had resulted. Reference was made in the Paper to the existence of earth currents from the tunnel. Those currents could be detected so far away as Greenwich by the wires used there for the purpose of investigating earth currents. He believed at no time had they been so considerable as to cause serious disturbance either to the telephones or to the telegraphs; but of course from the telegraphs they could hear of their existence. They had been materially diminished by the expedient referred to in the Paper, viz., that of connecting successive sections of the tunnel by means of a conductor. That, however, did not completely obviate the inconvenience, no doubt from the fact that the segments of cast-iron, of which the tunnel was composed, were separated from each other in a greater or less degree by a comparatively non-conducting layer of oxide of iron. He believed that if the trouble were still found to be serious, it

Dr. Hopkinson. could be almost completely prevented by annihilating any metallic connection between the rails and the shell of the tunnel. That would be some little trouble, but it would not be impossible. If it were done, they could interpose between the rails whereby the current returned and the shell of the tunnel, a considerable resistance, possibly of some hundreds of ohms. In that case the earth current would be diminished in something like the ratio of the actual resistance of the shell of the tunnel and the earth surrounding it to the interposed resistance between the shell of the tunnel and the rails. The next point to which he desired to refer was the method, which he believed he was the first to propose, of diminishing the great strain upon the locomotives in traction by means of a switch which should put two motors, if there were two, upon the car in series or in parallel at pleasure. He did not agree with the Author that the economy to be realised in that way would be insignificant. The actual power saved by the mere saving of that which was a loss would be material. But that was not all. Mr. Greathead had already referred to the fact that owing to those very great currents and strains at starting, it was necessary to provide a greater plant—heavier conductors, and that that plant had to work with a more variable current than would be the case if those heavy strains were diminished. For that reason it seemed to him that there would be a very material economy indeed resulting from an arrangement whereby the two motors could be put in series in starting and switched into parallel when the speed was got up. The addition would be slight. Instead of having a reversing switch, they would require a switch for putting them in series and parallel, and possibly two switches for reversing. On the other hand, they would be able to diminish the resistance upon the car which was needed to take up the excess of pressure at the moment of starting. Reference had been made to the question whether the conductor should be placed overhead in the tunnel or between the rails. The Parliamentary Committee last year recommended that the conductor should be placed overhead, on the ground that it was safer for the public. As far as his own experience went, on the City and South London Railway, there was no danger to the public; he had never heard of any member of the public receiving so much as a shock from that system. Probably one would have heard of it if they had received a shock, for those shocks, though not very severe, were disagreeable. He had received shocks on the railway from the 400 volts, and though they were disagreeable, they were by no means dangerous.

The public had two lines of protection; first they had the Dr. Hopkinson. certainty that they would not get any shock at all, and, secondly, that if they did get a shock it would not hurt them; but he agreed with the Author that there were other reasons which would induce them to place the conductor, if the conditions were favourable, overhead. One of those was the greater simplicity of arranging points and crossings. If points and crossings were at all complicated they would find a difficulty in placing the conductor between a pair of rails; if they were overhead they had nothing to deal with except the conductors themselves, and that was comparatively a simple matter. For that reason he should strongly advocate, where he could do as he pleased, the placing of the conductors over the cars in the tunnels. He did not know whether the discussion was to be strictly limited to the question of railways, or whether he could be permitted to refer to the question of tramways. With regard to the working of tramways by electricity in America, they had carried their experience very much further than in England, at all events they had carried their schemes on an enormously greater scale. But he thought that English engineers had yet to learn that it was their duty to copy precisely what was done either in America or anywhere else. They had their own conditions to meet, and they were willing to learn what they could from all the world, but they had to consider how it would apply to the conditions in this country, and to adopt what appeared to them to be the best. What was the reason why electrical tramways in England had made such comparatively slow progress? Partly, no doubt, it was the objection which the public felt to the idea of having multitudes of conductors strung over their heads through streets, interfering with fire-escapes and creating annoyances, which, if not very serious, certainly amounted to something. Whether they liked it or not, the British public would object very seriously to carrying the conductors of tramways overhead, and if they were not to be carried in that way, they would have to be carried in some other way, or accumulators would have to be used. Accumulators had been tried very extensively for tramway purposes, but, as far as he knew, they had never been a commercial success. Fortunately there was another method, viz., that of conductors made in a trench underground and communicating with the car by a slot. He believed that plan was first introduced at Blackpool, but it was now in use on a much larger scale at Buda Pesth, where the work had been carried out by Messrs. Siemens and Halske, of Berlin. They had there a tramway of about 11

Dr. Hopkinson. kilometres (7 miles) in length; it was a double line, therefore being about 22 kilometres, and they had running upon it about sixty-three cars, all of which were sometimes at work. They carried a very considerable number of passengers, and made a profit. They charged a low rate, and the cost was something like 4d. per car-mile, including all charges, taxes, and everything. They were extending the line upon the same system. What were the objections to that system in this country? Surely, only two. First, there was a certain objection to the existence of the slot in the road. The slot at Buda Pesth was about $1\frac{3}{8}$ inch wide, and he believed that no objection had been taken to that width. He did not, however, think that such a width was at all necessary. He should not hesitate to undertake to arrange an electric tramway with a slot not exceeding 1 inch in width, with the exception perhaps of a fractional increase at the points, and such like. The other objection was the cost. The cost of a culvert would be probably somewhat over £1,500 per mile in excess of the cost of an overhead conductor. If the pavement were costly, it would be something more, making an additional cost perhaps of £2,000 per mile. In this country, corporations could borrow money at less than $3\frac{1}{2}$ per cent., so that the additional cost, exclusive of maintenance, if there were any—he did not believe there would be, having regard to the possibility of breakdowns by snow, and so on, with overhead conductors—the additional cost of using the culvert system would be confined to about £70 per mile per annum. That was not a very large matter. In populous districts where cars were frequent, he had no doubt that the general public would be content in one form or another, whether out of the rates or out of the fares, to pay that amount rather than have the annoyance of overhead conductors. His view was that if one had to put up a tramway in any of the large towns, the proper system to adopt would be that of the culvert, with a narrow slot, as narrow as convenient—certainly not more than 1 inch—to connect the car with the conductor.

Mr. Preece. Mr. W. H. PREECE said he wished to supply one omission in the Paper, which had been slightly referred to by Dr. John Hopkinson, viz., the disturbance that had been occasioned by the South London Railway upon the telegraphs and telephones of London. The line was opened in November 1890, and immediately it commenced to work there was scarcely one telegraph circuit in the South of London that was not violently disturbed. Every single line was subjected to a fluctuating current of a peculiarly distressing and errant character. Not

Mr. Preece.

only did this extend as far as Greenwich, where it was observed upon the delicate instruments of the Observatory, but it extended as far as North Walsham in Norfolk, a station not very far from Norwich. North Walsham happened to be a very important station for telegraphic purposes to the Continent; it was the point where the most important German cables end, and where the connection between the submarine portion and the land line was made. Here the currents were observed, and the clerks in charge of the apparatus were able to distinguish the motion of every single train upon the South London Railway. It was a most remarkable fact that the disturbance produced by that railway on the currents working the railway in the earth in London should extend to such enormous distances, and he had not the least doubt that if instruments sufficiently delicate were installed, they would find the same currents evident in Manchester, Liverpool, and perhaps even Glasgow. However, in North Walsham this was studied, and in order to get records that would give some idea of what they were, he had established at Tottenham, on the North Walsham line, instruments that enabled him to record curves which he had the pleasure of sending to Mr. Greathead and Mr. Mott, as an indication of the watchfulness maintained on the correct traffic returns of that railway. Although these currents had been observed, he did not think any one had seen a case in the Law Courts of any action brought by the Postmaster-General against the South London Railway. It fortunately happened that the responsible officer of the Postmaster-General was deeply interested as an electrician himself in the progress of the application of electricity to the working of railways. He took every possible opportunity to bring these facts to the notice of the responsible officers, and he was bound to say those responsible officers of the railway did all in their power to reduce these disturbances. The effect was diminished, and although they could still see the motion of every train in the General Post Office in London, it did not disturb the telegraphs, and they did not care about it. It would also disturb the telephones, if, fortunately for the railway company, those telephones were not shielded by an iron tube. It did not affect the telephones of the Telephone Company; if it did, no doubt the law would have been brought to bear before this. The principal reason of the non-interference was that the South London Railway adopted the gearless motors, and not motors either with single or with double-reduction gear. Where reduction gear was at work there were pulsations due to the passage of the brushes over

Mr. Preece. the commutators of very high frequency indeed, and the result was a very distressing sound. If any one had been down to Leeds and listened to the sound of the disturbance produced by the Leeds tramway in starting, they might be strongly tempted to throw away the telephones pretty quickly. It was not so in South London, because the number of pulsations produced by the gearless motor were so few that the sound produced a very low and deep note and one which did not annoy the ear. The cause of these disturbances was bad insulation. The Author said, "The return circuit is through the rails, which are practically uninsulated. In such a system high insulation from the earth is neither aimed at nor required, provided the power lost in leakage is inconsiderable." He (Mr. Preece) contended that was not true engineering. Insulation was necessary, and if it was not maintained the power of the law would certainly one of these days be evoked against those gentlemen who were breaking the law. He did not think that such proceedings would be taken against a tramway company, but he was strongly tempted to believe that the electric light companies, who were using very powerful currents, increasing in magnitude, and whose disturbance to the telephones and telegraphs of the country were increasing every day, if they did not look to their insulation, would hear something very unpleasant one of these days, either from the legal authorities of the Telephone Company or the legal authorities of the Post Office. No reference had been made in the Paper or the discussion to the growth of this industry, not only in its application to railway purposes, but to the dimensions of the works of railways. At first it was a mere tramway, now the City and South London line had become a railway. The Overhead Railway at Liverpool was on a still larger scale, and he hoped soon to hear of Great Northern coaches being carried from Finsbury to the City in trains weighing 180 tons by locomotives, up a gradient of 1 in 30, with an expenditure of from 400 to 500 HP. The Americans had gone far ahead of the English in this direction. On the Baltimore and Ohio Railway they were going to use locomotives weighing 80 tons, which were competent to draw freight trains of 1,200 tons up an incline of 1 in $12\frac{1}{2}$, and exerting a HP. equivalent to 1,600.

Mr. Siemens. Mr. ALEXANDER SIEMENS said that the locomotives at Baltimore referred to by Mr. Preece were not yet in existence. The Americans had merely invited tenders.

Mr. Preece. Mr. PREECE said that his information had been derived direct from the firm that had the order, and was now executing it.

Mr. A. SIEMENS said that Mr. Greathead had referred to the design of the locomotive supplied to the City and South London Railway Company when the invitation to tender was sent out. But the Author was perfectly right in saying that there was a very great general resemblance between the two. That was because the company particularly requested that the arrangement of the switches should be exactly the same as those of Messrs. Mather and Platt, the reason being that the drivers, when transferred from one locomotive to the other, might know what handles to move in stopping and reversing. But the essential parts of the locomotive were really different. That would be evident when he stated that the resistance of Messrs. Mather and Platt's armature was 0·3 ohm; that of Messrs. Siemens was 0·18. The resistance of the field magnets of Messrs. Mather and Platt was 0·087; and the resistance on each of the bobbins of Messrs. Siemens was 0·96; but they were all four in parallel, so that for the current the resistance was 0·24. The reduction in the resistance of the armatures had the great advantage that the heat developed in the armatures was much less in Messrs. Siemens' locomotives than in the first ones, and consequently the consumption of the current was very much reduced, although the actual size of the motors was very much greater than that of the first fourteen.

Mr. LLEWELLYN ATKINSON said that the Author had expressed an opinion as to the use of high-speed engines in connection with the work, where the load was as variable as it was in the present case, to the effect that the lower-speed engines were more likely to give satisfactory results in point of wear. As he happened to have some experience of the Willans engines driving machinery working underground traction, hauling machinery where the load of course was as variable as in the case described, he might be permitted to give the results of the wear of the engines. It was true that the engines were not coupled in the same way that dynamos were coupled, directly to the engines. That had not been done for quite a different reason, a reason which he thought might have been considered in regard to the railways concerned. With reference to the output of the dynamos, it was stated in the Paper that they were each capable of giving 450 amperes. He presumed that each was capable of working a dynamo to 450 amperes. None of the curves in the Paper and on the wall, as far as he could see, showed any load exceeding 450 amperes. It would, therefore, appear that one dynamo in the station would be sufficient to supply the maximum current used. There were, however, in the station no

Mr. Atkinson. fewer than four complete sets of machinery, and he understood from the Paper that the fourth was supplied at the instance of the Board of Trade, who thought that there was not enough spare plant. His adaptation of the Willans engine for driving traction-work had been partly with the view of diminishing the amount of spare plant necessary. In the arrangement shown, if one dynamo or one engine broke down, the complete plant was at a standstill. By having two Willans engines, and placing them facing one another with a shaft between them, geared in a couple of independent bearings, and providing clutches at each end, not necessarily friction-clutches, two dynamos might be put down in a similar way, and then the engines and dynamos were working in pairs, and if one dynamo broke down, the other could be used with either of the two engines. The engines might also be thrown in and out; although the clutches were only pin clutches, it was possible to throw the engines in and out without stopping them. They ran them up steadily. They could drop the clutches in without the slightest check, and change from one engine to the other without stopping the dynamos or the plant. That was the reason why he used Willans engines for driving underground shafts not direct-coupled. By that means they could greatly save the haulage plant, and decrease the capital expenditure in duplicates. The engines had been running with that class of plant for more than two years, and in some cases there had been absolutely not a penny spent in repairs on that high-speed engine driving with quite as variable a load as in the other case. He had been able to make some measurements, not as complete as he could wish, to give a general idea of the amount of power which was lost in using an extra shaft and belting, as compared with the figures given by Mr. Thompson in a Paper where he stated that a direct-coupled Willans engine dynamo would give an efficiency of 86 per cent. between the indicator diagram and the electrical output. He found that from 4 to 5 per cent. was the outside loss by using an extra shaft and the belts, over what would be the effect of absolutely direct coupling. They had to take into account that 5 per cent. extra loss. He did not think it would be a serious item, looking at the amount of fuel and so on, and it would probably be more than covered by a decrease in the capital expenditure and in water-consumption.

Mr. Smith. Mr. HOLROYD SMITH said he wished to congratulate the Author on the fact that he had been associated with those who were prepared to take the onus of the conditions imposed

upon the contract, and that they had so ably supported him Mr. Smith. through its experimental stages. Only those who had worked out an undertaking of that kind could fully appreciate what he had had to endure and achieve before he brought the work to a success. He desired also to congratulate Messrs. Mather and Platt on the fact that they had succeeded in getting such modifications made to the terms of the specification upon which the competitive designs and estimates were formed, to enable them the more easily to deal with the details of the work, and further that they had had the good fortune to have so skilled and able a man as the Author to carry out the undertaking. The Paper dealt with a very interesting subject and one which, if thoroughly threshed out in all its details, would not only require an entire evening for the discussion, but all the evenings at the disposal of the Institution during the Session. He feared that an outsider, guided by a paragraph on page 211, would suppose that the proposal to work the City and South London line by electricity originated with Messrs. Mather and Platt, and that they were the only firm in treaty with the Directors of the Company. He was sure that the Author would not wish to convey such an impression, but Mr. Greathead had to be thanked for his remarks which removed any doubt upon the subject. The title of the Paper covered a wide field, but the Author had wisely concentrated his attention upon the particular work in which he had himself been most actively employed. Mr. Holroyd Smith would also confine his remarks mainly to the City and South London Railway, although, as Dr. John Hopkinson had introduced some questions relative to tramway work, he might be excused for making brief reference to that subject. In all engineering, the first principles must, of course, be sound, but successful work usually consisted of a host of details carefully thought out and executed. The Author, however, had favoured them with very few such details. Referring to the relative progress made in America and England, he wished to endorse all that Mr. Reckenzaun had said, which, no doubt, was the result of his own personal experience and observation and long intimacy with electric traction. On the subject of jockey-pulleys he wished to express some doubt as to the soundness of the Author's conclusions. The direction of a mass moving in one direction could not be changed without the employment of force. Further, if it took power to bend a belt one way it took power to bend it the opposite way— $\theta \pi \mu$ notwithstanding. He left that question to be dealt with by the mathematicians of the Institution. The explanation of harmonics was very

Mr. Smith. pretty, but he doubted very much whether the continuance of the harmony, which he admitted was perfectly possible upon particular occasions, could be relied upon throughout the whole of the conditions that would occur in the employment of a jockey-pulley under such varying loads. As mechanics they could scarcely rely upon the poetry of motion. With regard to the generating dynamos, the Author wound his dynamos as compound ones. Mr. Holroyd Smith would not say that the Author was wrong in so doing, but he emphatically asserted that he should not venture to do it himself. He had laid it down as an axiom for his own guidance, that generators for traction-work should be separately excited. He had found in the Paper itself an element of doubt upon that very point, for the Author had stated—"The field-magnet coils are wound on both shunt- and series-coils, but the latter can be half short-circuited, or entirely so, at will." With reference to switch-boards the Author had said that automatic cut-outs were employed, but he had not given any details as to their construction. Knowing what those automatic cut-outs were, Mr. Holroyd Smith ventured to predict that they could not be relied upon for efficiency. They were constructed on the principle of being actuated by culminating weight. As soon as the current exceeded a certain amount it released the catch, the catch released the weight, the weight began to fall, and swung round, and when it had attained a velocity it struck a pin, and the pin knocked off the electrical connection. He had taken some little time to describe it, but not much more than it took the weight to think about it when it had the work to do. It was obvious that when dealing with a current of that magnitude when there was a short circuit, the break, or the interposition of resistances, must be made immediately. With regard to the question of conductors, he had no doubt others would feel obliged if the Author would give them the benefit of his experience as to some simple rules for easily dealing with a problem of that kind. Those who had to do with the distribution of electrical energy knew that the question of mains was no light matter. They required to be carefully considered and calculated, and a host of figures had to be gone through. The Author would be doing a service to electricians, especially those who had to deal with such matters, if he would state some simple method, at which he had no doubt arrived, of approaching that somewhat complex problem. The Author said that in distributing the electric energy over the line, automatic cut-outs were used to separate the main supply from any particular section of the line

where short circuits might occur. He was very much interested Mr. Smith. to find that that was so, and he ventured to think that it might be further extended and made more complete by an automatic system that would not only cut out a given section of the line when a short circuit occurred, but would also act as an automatic block system for trains.

He was pleased to find that the Author admitted that an overhead conductor would be preferable to the conductor upon the rails. He took exception to an expression that the Author had used—"but it was found impracticable on account of the exceedingly limited space available for such a conductor above the carriages." He wished to show that it could positively be done. The carriages were provided with longitudinal seats, and were entered from the ends; the roof therefore need not be of the railway type, but could be formed similar to those usually adopted in tram-cars, viz., hollowed along the side, and the space so obtained, instead of making room for roof-passengers' feet (as in tramcars), be utilized for the overhead-conductors fixed in the tunnel. The electricity could be gathered by a trolley or slipper connected to the locomotive by a metallic cord, which, being flexible, would allow the slipper to follow the conductor when outside the tunnel, where it would be sloped upwards to a higher level beyond the reach of passengers entering or leaving the carriages at the stations. These overhead conductors could be provided with points and crossings, and be worked by the levers that operated the rail points without detriment to the electric circuit. He had by experimental demonstration proved this to be possible. On the question of locomotives the Author, referring to the absence of the gear, had said, "Although the principle of direct drawing was suggested many years ago by Sir William Siemens, it has not previously been applied in practice." This statement would be more correct if the words "on so large a scale" were added. As to gearless locomotives the Author had based his conclusions apparently upon the fact that a certain occasionally-used locomotive fitted with gear had been tried, but he had failed to state what constituted that gear. They could form no opinion on the question whether a gearless or a geared locomotive was best on the statement in the Paper unless they knew what the gear was like. The Author had coupled Mr. Smith's name with that of Mr. Reckenzaun as having made certain experiments, and advocated the use of worm-gearing. He pleaded guilty to that charge, and he still advocated it; indeed, his experience

Mr. Smith. led him, the more he knew it, the more strongly to advocate it. If there was no gearing at all they must take advantage of a high ratio of difference between the motor and the axle to be driven. If it only went down to a single reduction 3 to 1, it was better to have direct driving. He might say that tests made by others of worm-gearing, for the design of which he was responsible, showed that with a load of 4 HP., at an axle-speed of 55 revolutions per minute, there was an efficiency of 72·25 per cent., and when the speed increased to 112 revolutions with 7·43 HP., the efficiency of the gearing alone was as high as 94 per cent. These results he knew would seem extraordinary to those who had not specially studied the subject, still they were obtainable. He certainly thought that gearing of any sort should be dispensed with wherever expedient, and had worked out a method of lessening the vibration of the armature when it drove the axle direct. Still the question of gear or no gear could not yet be considered as definitely settled, especially when dealing with tramcar work, in which he held that worm-gearing could be most advantageously employed. Respecting working motors in series, multiple and parallel, he had had satisfactory experience in so doing in the steep-hill-climbing demonstration he had recently conducted in Bradford, in conjunction with Messrs. Easton and Anderson. The practical difficulty lay in constructing a switch which would, with one continuous movement, change from one couple to another without interruption of current or temporary omission of one or more motors from the circuit. It was a totally different thing from dealing with variable resistances, and he should like to have known how the Author proposed accomplishing this. Dr. John Hopkinson in his remarks proposed designing a slotted conduit for street tramways with a slot 1 inch wide and employing insulated supply and return conductors; he would remind them that the first underground conduit he constructed contained separate insulated conductors positive and negative; in the various ones he had made, including that at Blackpool, no slot exceeded $\frac{5}{8}$ inch in width. Having regard to the important question raised by Mr. Preece, as to the effect upon telegraph- and telephone-wires of the strong currents from dynamos when the earth was used as a return, it occurred to him that a probable solution of the difficulty might be found in the combination of cable haulage and electricity for tramway traction, and he would suggest distributing the power from the generating station by insulated electric mains to drive electric motors, located at intervals throughout an extended tramway system, and employ-

ing these motors to actuate short lengths of cables running in Mr. Smith. slotted conduits for hauling the cars.

Captain R. SANKEY (late R.E.) said that under the head of efficiency Capt. Sankey. the Author had remarked that "probably no tests have been previously made on engines working under the abnormal conditions of a load constantly varying at very short intervals from one-fourth, or a less fraction, of the full load up to the maximum, and averaging a little more than one-half the maximum." He therefore thought it might be interesting to ascertain the consumption under somewhat similar conditions. The trial had been made with a G G size Willans compound central-valve engine capable of indicating 80 HP., and coupled direct to a Crompton dynamo, which happened to be under test at the time, and in order that the consumption at half-load should be in fair agreement with the figure stated by the Author (viz., 27.5 lbs. per indicated HP.), the cut-off was arranged so as to give the full load with about 100 lbs. gauge-pressure. The engine was governed by throttling. The load was altered by switching resistances in and out every half minute; the electrical load was observed, and the water consumption was measured by the well-known method devised by Mr. Willans, which enabled accurate results to be obtained in a very short time. The mean electrical HP. was found by calculation to be 25.6, and the total water-consumption was at the rate of 1,099 lbs. per hour. It was not, of course, possible to indicate the engine with such rapidly changing loads; but from previous trials the mean indicated HP. would be about 38.6, so that the water per indicated HP. would be 28.5 lbs. per hour. No consumption-trial had been made with this set for a steady load at 38.6 indicated HP.; but the consumption had been obtained at 76.4, and at 44.3 indicated HP., and by the application of the straight-line law, discovered by Mr. Willans, the consumption for a steady load of 38.6 indicated HP. was found to be 28.2, or sensibly the same as for the rapidly varying load as given above. The mean load of 38.6 indicated HP. was rather less than half the maximum load of the set under trial. In the case given by the Author, the mean load was $230 \div 400$ of the maximum load, which corresponded with 46 indicated HP. in the trial set, and at this load the water per indicated HP. would be 26.7 lbs., or rather better than the figure mentioned by the Author. It should also be remembered that with the smaller engine the result was obtained with 110 lbs. boiler-pressure as against 140 lbs. with the larger engine. The Author had said that "it is doubtful, or at any rate remains to be proved,

Capt. Sankey. whether a high-speed engine driving direct will give as relatively satisfactory results without undue wear and tear, and liability to accident when working under the abnormal conditions of load obtaining in traction work." Now, with regard to the engine itself it was difficult to see how loads suddenly and continually changing were likely to affect a high-speed engine more injuriously than a low-speed engine. The piston-speed was practically the same, and in either case the stresses produced in the moving parts, by changes of speed consequent on sudden changes of load, were but a mere fraction of the inertia stresses to which they were exposed at every revolution while working under a perfectly steady load; the advantage, however, being with the high-speed engine, in that the moving parts were very much lighter per HP. than those of the low-speed engine. Hence, if high-speed engines were as reliable as low-speed engines for steady loads, which they now had been abundantly proved to be, they would be at least equally reliable for suddenly and continuously changing loads. The effect of a short circuit on the dynamo would, however, affect a high-speed direct-driven set somewhat differently from a low-speed belt-driven set. When a short circuit took place, it was clear that it was not the engine, but the dynamo armature which was exposed to injury, the principal destructive power being the energy stored in the fly-wheel, the dimensions of which were of course determined, so that the fluctuations of speed should not be greater than some specified percentage of the normal speed. As an example, the fly-wheels of the three Willans engines, each indicating 200 HP., now being erected at Hobart, Tasmania, for an electric tramway, were arranged to weigh 1 ton each with a radius of gyration of 1 foot $9\frac{1}{2}$ inches. In a speed-trial with one of these sets (the engine being coupled to a Siemens dynamo), the energy stored in the fly-wheel at 350 revolutions was 140,000 foot-lbs. To get the same results, as regards evenness of speed, with a similar (Willans) engine indicating 375 HP. at 300 revolutions, it would be necessary to store 300,000 foot-lbs. in the fly-wheel. Turning now to the Stockwell engines, it was stated that the fly-wheel of each engine weighed 14 tons, and was 14 feet in diameter, so that the energy stored was about 2,400,000 foot-lbs., and it was believed that, in the last engine supplied, the weight had been increased to $15\frac{1}{4}$ tons, bringing the energy up to 2,600,000, or no less than nine times that required for the equal-powered Willans engine. One would suppose that with such a fly-wheel the fluctuations of speed would be less than those shown in Hobart tramway engines; but it had been stated

that such was not the case; it would therefore be interesting if Capt. Sankey. the Author would give some figures, so that a comparison could be instituted. On more than one occasion the dynamos of Willans combination sets of 200 I.H.P. had been short-circuited without any damage, and there was no reason to doubt that a Willans engine of 375 I.H.P. could have its dynamo short-circuited with equal impunity. It seemed likely, however, that with a low-speed engine, in the fly-wheel of which it was necessary to store 2,400,000 foot-pounds, as against 300,000 foot-pounds only, the result would be very different. If it drove by belt, the belt would be likely to break. It was evidently better to have a direct-driven high-speed plant, subject to no such danger, than a low-speed plant, in which such danger could only be guarded against by means at once expensive and troublesome.

Mr. W. SHELFORD understood Dr. John Hopkinson to advocate Mr. Shelford. the use of an underground conductor for electrical tramways in this country as against an overhead conductor, and to say that the additional cost would not be very great; also that he thought he could reduce the width of the slot which had been adopted on the electrical tramway at Buda-Pesth, from $1\frac{3}{8}$ inch to 1 inch. He need hardly say that the width of the slot was a very important point, especially in London. Those who had followed the development of street tramways during the last thirty years, knew well that for many years the great difficulty had been to devise a construction which would not make the wheels skid, or a groove in which the wheels would not catch, and so cause accident to life and limb, and it was not until that groove was reduced to 1 inch as a maximum that a satisfactory result was arrived at. Then again, quite recently, cable-tramways had come into successful operation, particularly in Edinburgh and Birmingham, and still later in South London. The width of the slot in those cases was $\frac{3}{4}$ inch, and he could not but think that the large experience that the tramway companies, especially cable-tramway companies had had in the construction of what was adapted to street traffic as well as to haulage, would serve as a precedent for the electric companies, and that they might, with great advantage, consider whether they could not also adopt the $\frac{3}{4}$ -inch slot in preference to the 1-inch. He should be glad to know from Dr. Hopkinson whether that reduction to $\frac{3}{4}$ inch was possible or not. With regard to the cost, it should be remembered that street tramcars were the poor man's vehicle, and would not bear heavy expenses; and for that reason undoubtedly the companies would adopt the most economical method, whatever it might be, whether in regard

Mr. Shelford. to first cost or the working. What the London County Council would do in regard to tramways in London he could not say; nor could any one tell. They knew, however, that in Glasgow, where the Corporation had for years owned the tramway system, they had lately invited tenders for electrical tramways working on the overhead plan. It was certain that everywhere people wanted to improve upon horses; that they wanted to run more quickly, and to have a more prompt and efficient control of the vehicle, and the system which would do that in the cheapest way was the one that would succeed the best.

Mr. Beaumont. Mr. W. W. BEAUMONT thought the Paper was important, especially with regard to the great question of the cost of haulage on the City and South London Railway, and on other lines. The Author, Mr. Greathead, Mr. Kapp, and other speakers, had referred especially to the curves that were given at pages 224 and 225, and to those prepared and given in a similar form by Mr. Greathead, *Figs. 3 to 6*. Mr. Greathead had prepared them especially to draw attention to the great loss arising from the demand for power for starting the electrical locomotive; and the same demand and the same loss occurred, so far as he knew, on any electrical railways or tramways. The Author, in referring to the questions bearing upon the origin of that demand for power, had touched upon the relative advantages of geared and direct-driving motors, and had arrived at the conclusion that for railways, at all events, direct-driving was the better expedient, though possibly the geared motor was the better form for tramways. All the advantages that he had mentioned on page 218 undoubtedly did and would probably for a considerable time, remain with the geared motor for tramways; but, as far as he could see, it would remain also a matter of importance for the railways too, because the whole of the power referred to by Mr. Greathead as a loss would remain a loss until some means were obtained for starting the motor and its train, without that demand shown by the spikes in the diagram. It had been stated that the difficulty with regard to starting could be overcome electrically; that it was possible to overcome it, either by using a couple of motors in series or more motors, so that it might be overcome by using motors so arranged as to give a very large torque. That was true in regard to overcoming the difficulty of starting at a tolerable speed; but it did not overcome the difficulty that a very great deal of power was required to do that; and that in tramcars, for instance, of quite ordinary weight, it was necessary, or at all events, it was the practice now, to use motors of as high

as 30 HP., the cars not running at a very much higher speed than Mr. Beaumont. those ordinarily drawn by two or sometimes three horses. It was, then, necessary to arrive at some arrangement, by means of which the great demand for current at starting could be avoided; and various proposals had been made with that view. If the car could be started by some mechanical means which would enable the relation between the speed of the motor and the speed of the car to be for a few moments reduced—that was, that the ratio of speed of the motor to the speed of the car should be increased, that would get over the difficulty; and instead of requiring 30 HP. to start a moderately heavy tramcar, they might do with much less in proportion to that ratio—say 12 or 15 HP. The subject was one of the greatest importance in connection with the cost of working electrical railways. *Figs. 7 and 8* indicated how the difficulty might be overcome. In *Fig. 7*, A represented a motor-shaft, and A² a car-axle, arranged as for single reduction gearing. On the motor-spindle was fixed a double-faced disk-magnet B, current being sent into either of the two energising coils, C or C¹, through the medium of the conductors + + and the return conductor —, according to which side of the magnet it was desired to use. On either side of the double magnet were pinions J and J¹, connected to the armatures H and H¹, the pinions running loose upon the shaft of the motor and gearing with the wheels K and K¹, the one or the other as might be desired. In starting a car current would be sent through the coil C by the conductors + —, and a brush E resting upon one of the collector-rings D. The armature H would thus be drawn to and held by the magnet, the frictional bed being increased by the use of the pole-pieces or rings G, with annular projections fitting into grooves in the armature. The small pinion J would thus be fixed to the magnet and thereby to the motor-shaft, and the car-axle A² would be driven at a speed corresponding to the ratio subsisting between the diameter of the pinion J and the wheel K. This in the diagram was a ratio of 4 to 1. The car having been started or having ascended a hill by this means at low speed, the motor running at full speed might now be driven at the higher speed due to the larger pinion J¹ and smaller wheel K¹ by cutting the current out of the coil C and sending it through the coil C¹. The armature H was thus allowed to run loose upon the motor-spindle, and the armature H¹ was fixed to it, and the car would now be driven at the higher speed. This in the case shown would be double the lower speed. An arrangement of gearing for attaining the same end with direct-driven car or railway-axles

Mr. Beaumont.

Fig. 7. *Fig. 8.*

was shown in the other diagram, *Fig. 8*, partly in section. In this case the maximum speed was that of the motor, the shaft of which A was hollow, and was mounted and ran upon the shaft to be driven A², namely, the car- or railway-axle. Upon the motor-shaft A was fixed a pinion J, gearing into an idle wheel K, carrying a pinion J¹ which geared into the wheel to be driven K¹ fixed to the shaft A². Fixed upon one face of the idle wheel K was an annularly-grooved disk-armature H, into which the rings G G on the pole-pieces of the disk-magnet B fitted, forming a magnetic clutch. Two such clutches were employed in the arrangement shown. Current for energising the coils of these magnets was supplied through the conductors + -, the brushes E, and collector-rings D. By means of these magnetic clutches so formed, the idle-wheel K and the connected pinion J¹ might be held fast, and when this was done the shaft A of the motor, the whole of the gearing and containing case were locked together so that the speed of the driven shaft became that of the driving-shaft. For starting an electric car or locomotive, current was cut out of the coils of the magnets B B, and was instead directed into a magnetic clutch-brake not shown in *Fig. 8* (except in so far as the clutch-brake band was shown in section) at F, upon a part of the case M, which is made circular for the purpose. When this clutch-brake F was in action, the case M was held fast, and the idle-wheel K, revolving with the spindle P, drove the car-axle A² at a speed which was proportional to the dimensions of the gearing. In the example shown the motor-shaft A would make two and a half revolutions to one revolution of the car- or locomotive-axle A². It would be seen that for ordinary running, that was to say, after starting and when not climbing a hill, the whole of the gearing was inactive.

Mr. NORMAN SCOTT RUSSELL said he agreed with Dr. John Hop-kinson that the method that was most likely to receive acceptance in this country for tramways was the conduit system, but Dr. Hopkinson did not seem to be well posted up in what had been done with regard to the conduit system, when he mentioned a groove of $1\frac{3}{4}$ inch. He hardly thought that the groove was so wide. At any rate in this country it had been done with a much smaller groove. At Blackpool he understood the groove was only $\frac{5}{8}$ inch. At any rate it was not more than $\frac{3}{4}$ inch at Northfleet. He did not cite either Blackpool or Northfleet as presenting the perfection of underground systems, but there certainly was no difficulty experienced in carrying the electrical current in a groove of only $\frac{3}{4}$ inch. The electrical conduit had this great advantage

Mr. Beaumont.

Mr. Russell.

Mr. Russell. over the cable, that a third groove was not required. The conduit should be placed under one of the rails so that practically the groove in the rail was a slot. The losses in electrical traction were so many and so great that everything should be made as light as possible. He thought, therefore, that a mistake was made in making the motors for the City and South London Subway on the ends of the cars. Both Mr. Greathead and the Author had said that it was not possible, but Mr. Scott Russell could not conceive why it could not be done. In that way something like 5 tons or $12\frac{1}{2}$ per cent. of the weight would be saved. That would be increasing the efficiency. The coal consumed on the South London line was stated to be 28 lbs. per train-mile,¹ and he might mention that for an ordinary locomotive the consumption would only have been one-fourth, drawing the same weight of train. That showed that where economy only was the object to be attained, electricity was by no means to be preferred. He thought that the Author had done well in adopting the gearless motor. Mr. Scott Russell would advocate that for tramways upon somewhat different reasons from those mentioned by previous speakers. He advocated it because in all mechanical traction, whether by steam, or cable, or compressed air, one of the most serious causes of expense was that of repairs, and he would therefore say "Give me the simplest motor you can—disregard the efficiency." The Americans had adopted with increasing frequency that principle. They began by having duplicate gearing, but they had mostly come to single gearing, and all the great makers—Short, Westinghouse, and Thomson-Houston—were all trying to get a gearless motor. There were, no doubt, difficulties in regard to tramways. There was the difficulty of starting owing to the very low velocity at which the tramway axle ran, about 100 revolutions per minute. In regard to electrical traction on tramways, they must all be glad that the London subways were offering a field for which it was so admirably suited.

Mr. Sellon. Mr. STEPHEN SELLON said he wished to correct the Author in reference to his statement on page 210 that New York was still without a trolley-road, and the implied inference that it was because the trolley system was inapplicable to so large a city. That, perhaps, might be expected after the attitude which the Author assumed in

¹ Mr. Scott Russell has since ascertained that on the Underground Railway the weight of train is 150 tons, and the consumption of fuel 34 lbs. per train-mile; so that for a train of 40 tons the consumption of fuel would be 9 lbs., or less than one-third of what is done on the South London line.

the well-known telephone case ; but it seemed scarcely consistent Mr. Sellon. with the statement made in the Paper that the only reason that the overhead system was not adopted in the City and South London line was the lack of room. There were at present eighty or ninety cars in operation in New York, which number, although small as compared with other American cities, was about double the number operated in the whole of Great Britain ; and that number would shortly be very greatly increased. In Philadelphia concessions had been granted for the trolley on over 100 miles of streets ; and if the system was not at present in use, it would be so within a few weeks. The total mileage was also understated. The Thomson-Houston Company alone had 4,700 miles in operation ; and the Westinghouse and other systems had about 1,000 miles in operation. He should be glad if the Author would state the name of the conduit road which he had mentioned now running in America, as one of the few, if not the only conduit road, viz., the Love, in Chicago, had now ceased running, due to mechanical defects. He thought that the opposition to overhead wires in England was exaggerated, and that the backwardness in electrical traction was more to be attributed to the deplorable financial condition of nearly all tramways that were not operated under specially favourable conditions. That was largely due to unwise legislation, and, it might also be added, to absurd local clauses. And in many instances the opposition of the Telephone Company, strongly championed by the Author, had prevented the adoption of electricity. In fact, electric tramways would have an uphill struggle until they were accorded the same privileges as railways, viz., carrying all the passengers that they could get, regardless of seating capacity. In fact, the City and South London would not have been able to pay even the small dividend that they had done, had they been compelled to furnish seats for all passengers. The Author had stated that the Buda-Pesth system was a success. For a line to be a commercial success, it was necessary to know what was the original initial cost of the installation, what its earning capacity was, and what was the dividend paid. He was able to supply its earning capacity ; that item he had no difficulty in obtaining at Buda-Pesth. He had, however, been unable to obtain any figures as to the initial cost, or as to the dividend paid ; and he presumed that the Author was in a position to supply those details which enabled him to state that it was a commercial success ; and he hoped the Institution would be supplied with those figures. He thought he had a just cause of complaint when he discovered that the Author stated that there

Mr. Sellon. had been no interference, due to the use of a trolley-wire system, with the telephones on the City and South London Railway; as, in the lecture which he had recently delivered before the Royal Institution, he stated that there had been a considerable disturbance to telephones by the City and South London Railway, and that he considered that legislation should step in and prevent the use of the single trolley-wire system. That appeared to him rather strange when he remembered that in certain evidence which Dr. John Hopkinson had given in the great telephone case, he had stated, "I think there is no doubt that the one of the two systems in which there was no connection to earth the whole system insulated, would be not only the cheapest, but the most satisfactory in working." That appeared very strange, remembering that the Author had adopted, in every case in which he was responsible, the single-wire system. Dr. John Hopkinson had stated that a conduit for the purpose of electrical traction could be built for £1,500 or £2,000 a mile, and along with that statement he coupled the success of the Buda-Pesth system. He presumed that Dr. Hopkinson did not intend them to understand that the Buda-Pesth conduit cost £1,500 or £2,000 a mile. He wished to make one remark with regard to the Buda-Pesth slot. He had himself measured it upon the ground, and he found it to be $1\frac{1}{8}$ inch. One point, he thought, had been forgotten, viz., that the system at Buda-Pesth had a metallic return—this necessitated the great width of slot in use there, as provision had to be made for insulating the return wire from the other. Mr. Shelford had stated that at Glasgow they had agreed to adopt the overhead system. They did agree to it, but unfortunately it had all fallen through.

Dr. Preller. Dr. DU RICHE PRELLER said that having had a good deal of experience of electrical railways, worked both by locomotives and by motor-cars, he might be allowed to refer to one or two points in relation to the Paper. Had there been time, he would have compared the electrical part of the South London, more particularly, with two lines which he knew very well. As it was, he would confine himself to the tractive force of the motors. One was the steep-grade electrical railway from Florence to Fiesole, with which he had been connected up to last year, and which he had described in a Paper in the Proceedings of the Institution in 1891;¹ and the other was the electrical mountain railway at Mürren, in Switzerland, opposite the Jungfrau, at an

¹ Minutes of Proceedings Inst. C.E., vol. cvi. p. 248.

altitude of 5,000 feet above the sea-level, both being worked by Dr. Preller. the overhead-wire and trolley system. The Florence line was worked by motor-cars with double gearing, and the Mürren by locomotives which weighed $7\frac{1}{2}$ tons, with single vertical gearing. With regard to the maximum tractive force of electrical motors, that of the Florence motor-cars, weighing 7.5 tons, was 1.5 ton, or one-fifth; that of the Mürren locomotives, weighing 7.2 tons, was as high as 1.8 ton, or one-fourth, and it had been tested up to 2 tons, or one-third, while that of the South London locomotive, weighing 10 tons, was stated to be 1.5 ton, equal to only one-sixth. He would, therefore, ask the Author if, in the figures given in his Paper, viz., 3,000 lbs., or about 1.5 ton maximum tractive force, there was not some inaccuracy, because in hauling a train of, say 30 tons, including the locomotive, up the steepest grade section of 1 in 14, with sharp curves at the Monument end of the line, the resistance the locomotive had to overcome—in other words, the tractive energy the motors had to develop, worked out at $2\frac{1}{2}$ tons, equal to a coefficient of adhesion of one-fourth, such as must be expected from a good electrical locomotive as compared with the coefficient of adhesion of steam locomotives of one-sixth to one-seventh. That brought him to the question raised by Mr. Reckenzaun as to whether the South London locomotives really developed 100 HP. The Author gave the total weight of a normally-loaded train at 40 tons; and, if so, the locomotive would have to develop on the 1 in 14 grade at only 7 miles per hour, not only 100, but 130 HP., equal to 96 kilowatts, or 190 amperes at 500 volts. As a matter of fact, the total train-load was, he believed, only 30 tons, viz., 10 tons for the locomotive, and 20 tons for the three cars with about one hundred passengers. That, at a speed of 7 miles per hour, and taking the coefficient of traction at 13 lbs. per ton, gave 100 HP., or 75 kilowatts, equal at 500 volts to 150 amperes. That agreed with the figures given by the Author, but the discrepancy appeared to be in his train-load of 40 tons and in his maximum tractive force of only 3,000 lbs., and that discrepancy he would perhaps kindly explain. With regard to the remark made by a previous speaker, "Give us simplicity before efficiency," he wondered whether the speaker was aware that in gearless, axle-wound motors repairs were much more troublesome than in single-gearing or in double-gearing, because whenever a motor required cleaning or repairing one axle-wheel had to be entirely dismounted, whereas geared, suspended motors could be much more easily removed or replaced. With reference to the differences in the statements as to the width of

[Dr. Preller. the slot at Buda-Pesth, he thought it must be owing to the circumstance that one speaker measured the width at the ordinary line, where it was 25 millimetres, or rather less than 1 inch, and that another measured it at the points and crossings, which required an extra width.

Dr. Hopkinson. Dr. EDWARD HOPKINSON, in reply, said it was with considerable diffidence that he had brought the subject of the Paper before the Institution, because he was well aware that such an undertaking, in many respects entirely novel and carried out on a large scale, involved much of an experimental nature, which would, nevertheless, in the criticisms to which the Paper would be subject, be treated in the light of subsequent knowledge. But it was for that very reason that he thought that the discussion of the subject might be of special interest, and perhaps not altogether devoid of utility. He joined with Mr. Greathead in regretting that the latter had been unable to bring before the Institution his Paper upon the construction of the railway itself, which was a more weighty matter, and not less novel than the form of traction employed; but he thought the two subjects were so distinct that there had been no inconvenience in the separate discussion of them, or in the circumstance that the Paper now discussed was the first to be read. He would refer to the different points that had been raised in the order of the various parts of the complex machine of which the traction plant of the railway consisted. In regard to the generating-station, he thought that the most interesting remarks on that part of the subject, especially with reference to the loss of efficiency due to the extreme variations in the load, had been those of Mr. Kapp, who had brought forward an important proposal deserving serious consideration, viz., that the excessive load at the moment when several trains were starting together should be met by what he called "fly-wheel motors" placed at suitable points of the line. The proposal had the advantage that it secured the supply of extra power required close up to the work that it had to do. A motor would be fixed at each station or at those stations where the greatest starting-power was required, and so, as it were, in front of the conductors and of the generating dynamos, so relieving not only the engines, but the generating-dynamos and conductors, thereby materially increasing the efficiency. He hoped that Mr. Kapp's proposal would be tried on some future occasion, but he thought that it was worth while for him to consider whether the "fly-wheel" motor should not be put on the locomotive itself, so as to be available whenever it was required.

Such a system had two disadvantages in comparison with the use of accumulators. It did not meet what might be called the diurnal variation in load—the variation between a heavy morning or evening and a light noonday load; it also involved the objection of moving mechanism at places where it could not be easily supervised. They were all much indebted to Captain Sankey for his remarks upon what had been done with the Willans engine; he had thereby added one more favour to the many others which his firm had conferred upon the engineering profession generally, in relation to the theory and practice of the steam-engine. He had shown that the consumption of steam in an engine with a varying load would be approximately the same as the consumption in the same engine working with the mean load. That was a point that Dr. Hopkinson had no opportunity of trying himself, and he thought it was an important point and one of great interest. Much had been said in connection with the use of compound-generator dynamos. He thought there could be little doubt that compound dynamos were the right thing. They were connected through considerable external resistance; the load was seldom entirely off, and there was practically little risk of reversing. To provide against what risk there was, an electro-magnetic arrangement was provided which rang a bell if the current began to reverse, and gave ample warning to the attendant to short circuit the series coils of the dynamo by the switch provided for the purpose; but he believed that that seldom occurred, so that really there was no disadvantage from the use of the compound dynamos. On the other hand, there were very great advantages, inasmuch as it tended to keep the electromotive force on the line much more constant than it otherwise would be. Mr. Kapp expressed some doubt as to whether the generating dynamos really did compound, inasmuch as, on account of the great mass of iron in the field magnets, some appreciable time elapsed before they attained a magnetic state corresponding to the current passing through the coils at the moment. He thought that anything which had led Mr. Kapp to that conclusion was not due to the dynamos themselves, but due to the governing of the engines. No doubt the engines did not govern as satisfactorily as they might do. Any lagging of the electromotive force behind the current was not due to the dynamos, but was due to the engines not adjusting themselves to the load as quickly as they ought to do. Mr. Holroyd Smith had remarked that he (Dr. Hopkinson) was evidently afraid of using compound dynamos because he had provided switches to short circuit the series coils.

Dr. Hopkinson. The object of the switches was that the dynamos might be properly adjusted to the work they had to do. The dynamo coupled to the near end of the line was worked either shunt or half-compound, but that coupled to the far end was full compound. In regard to another point in connection with the generating-station, Mr. Greathead had drawn attention to a remark in the Paper that there was only one system of steam-pipes, desiring apparently to infer that that was some fault in the original design. As a matter-of-fact he had urged the Company for years to duplicate the pipes, and he was glad to say they were now in such a prosperous condition that they were able to do so. Mr. Holroyd Smith had referred to the switch-board and to the system of cut-outs there employed. He was mistaken in assuming that the current was broken; the current was never broken, but resistance was thrown into the circuit. With reference to the conductor, Mr. Parker had expressed some surprise that he had put it 1 inch below the rail-level, and stated that in Liverpool it had been placed 1 inch above. Mr. Parker was right in the case of the Liverpool Overhead railway in putting it above, because there he had plenty of room; but in the case of the City and South London line the room was exceedingly limited, the clearance below the lowest part of the locomotive being only $1\frac{3}{4}$ inch. It was, therefore, obvious that the conductor must be fixed at the lowest level possible. Much had been said in reference to the effect of the earth-currents upon the telegraph and telephone systems. It was stated in the Paper that experiments had failed to reveal any disturbance. That statement was made on the authority of Mr. Preece himself, the best possible authority in such matters, and was quoted from evidence which he had given on one of the Railway Bills before Parliament. He supposed that in his evidence Mr. Preece referred to the present conditions, and not to those obtaining when the line was first started. That there had been some trouble in the first instance was undoubted, but it had since been entirely obviated. When Dr. Hopkinson referred to the same question in his recent lecture before the Royal Institution, he was not referring to the City and South London line, but to tramway systems in general, and no doubt the disturbance to the telephones had been very serious in many cases. Mr. Preece had taken two sentences in his Paper and put them together, separated from their context. In the one he referred to the return through the rails, which were practically uninsulated, and in the other he said that high insulation was neither

aimed at nor required in the conductor. Mr. Preece took exception to the two statements; but he wished to know to which statement Mr. Preece referred? If he referred to the first, that the rails were uninsulated and the return was through them—practically in that case through the earth—he quite agreed with him that valid objections might be urged against the use of such a system, but of course it could only be prevented by legislation, because the use of an insulated return entailed considerable outlay, which would be avoided unless obligatory. But if it was to his second statement that Mr. Preece objected he could not agree with him, for, given an earth-return a little leakage from the conductor could not in anywise affect the telegraph or telephone systems in the neighbourhood, and therefore from that point of view was immaterial. Mr. Holroyd Smith had asked what was the rule to be followed in determining the size of the conductors. There was only one rule in all such questions which every engineer must follow where possible, viz., Lord Kelvin's, enunciated ten years ago, which he need not repeat. Of course there were instances in which it could not be followed by reason of considerations of first cost; otherwise it was the only canon applicable. With regard to the motors, the most important question of all, he would refer first to the comparison made by Mr. Parker of the motors of the Liverpool Overhead Railway with those of the City and South London line. He thought that Mr. Parker was hopelessly confused between the words "torque" and "tractive force." He had stated that the Liverpool Overhead Railway motors, which weighed $2\frac{1}{2}$ tons each, gave a torque effect of 1,450 lbs., the diameter of the wheel being 2 feet $8\frac{1}{2}$ inches. That corresponded to a tractive force of 1,055 lbs. The motors on the South London line, which weighed $2\frac{1}{4}$ tons each, deducting the wheels, which Mr. Parker did not include in the weight of the motors on the Liverpool line, gave a tractive force of 1,180 lbs. In both cases the current was 100 amperes, so that the City and South London motor gave greater tractive force. Mr. Parker, therefore, instead of having made a great advance in the Liverpool Overhead line had, he thought, taken a retrograde step. Mr. Reckenzaun had asked why Dr. Hopkinson had not given full details of efficiency brake-tests made upon the motors. One reason was that there must be some limit to the length of his Paper. Another reason was, that the theory and construction of motors was well understood by the leading manufacturing firms and did not call for special discussion. There was, however,

Dr. Hopkinson. one point that he conceived to be very important, namely, the actual efficiency of the locomotive as a whole, taking into account the loss in resistance, and by reason of the low efficiency at starting. That he had determined, he believed, for the first time, and the result of 70 per cent. as the efficiency of the locomotive as a whole was, he thought, one of considerable interest. Mr. Reckenzaun had expressed some fear that the motors must be of low efficiency on account of the shape of the pole-pieces; but of all the things to which to attribute low efficiency that was the most unfortunate. It would be seen in the Paper that the resistance of the magnet-coils was 0·16 ohm. With a mean current of 70 or 80 amperes the loss would be 12 volts in the magnets out of 500, or about 2 per cent. As the motors were wound with wire of small section, any loss of power due to the shape of the pole-pieces would appear in the amount of magnetizing force required for the magnets. He had shown there only 2 per cent. of the total amount of energy passing through the motors was absorbed in the magnets, so that there was no great margin to turn upon there, whatever the shape of the pole-pieces might be. He would now refer to another point which he was not responsible for introducing into the discussion, but, as it had been introduced, it was necessary to state the facts with some completeness. Mr. Kapp and Mr. Reckenzaun had both referred to the breakdowns which had occurred upon the South London line during the first six or twelve months of working. They did right in referring to them and asking for some explanation. The explanation had been given in general terms that the motors were overloaded; but he agreed that something more definite than that was required, because mere overloading of the motors, although it might reduce the efficiency, ought not to lead to breakdown in an unreasonably short time. When Messrs. Mather and Platt first inspected the tunnels they were in an exceedingly moist and damp state; and they naturally expected that one of the difficulties to contend with would be a damp atmosphere. They accordingly introduced an innovation in the insulation of the wire used for winding the armatures: and between the ordinary two covers of cotton they put a layer of india-rubber. It was well known that india-rubber was an excellent insulator, but that it would not stand any excessive heat; that if it was heated it would sooner or later perish. If the load had been what Messrs. Mather and Platt had been instructed to provide for in the first instance, there would have been no heating of any moment in the motors; but with the materially increased load

there was considerable heating in the wires, and the result was Dr. Hopkinson. that the rubber insulation was destroyed. Consequently the wires became slack; and where wires were slack sooner or later there must be vibration, and vibration meant the wearing out of the insulation and final breakdown. As soon as he knew that the load was greater than was anticipated, he knew also that every one of the motors would certainly break down, as every one did in due course. But the cure of that had not been what Mr. Greathead suggested—the winding of the motor with a larger section of wire, although that was a proper thing to do from the point of view of efficiency. Mr. Greathead, he thought, could not be aware of what had transpired. Of the thirty-one motors supplied by Messrs. Mather and Platt for working the line, only six had been rewound with a larger section of wire. Yet the other twenty-five worked daily with entirely satisfactory results, simply because they had been rewound with wire without rubber insulation and well shellacked. That was the complete explanation of the breakdowns which had occurred. Mr. Greathead appeared to desire in his speech to give the impression that Messrs. Mather and Platt were aware from the first of what the load would be. Although the point had been referred to in the course of the discussion, he thought that a more specific explanation was necessary. The weight of the carriages originally specified by Mr. Greathead was $4\frac{1}{4}$ tons, and Messrs. Mather and Platt were instructed to provide locomotives of sufficient power for such carriages. Experiments were made about six months after the contract was arranged, not, as Mr. Greathead said, as a condition put upon Messrs. Mather and Platt by the Company, but as an express condition made by Messrs. Mather and Platt with the Company, that they should have the opportunity of making certain tests at an early date. Those experiments were made not with a view of ascertaining what power was required for working the line, because that was a matter of easy calculation, but with a view of testing the novel system of direct-acting motors and other points of detail which it was important should be tested practically before all the locomotives were constructed. Two carriages were supplied for the experimental run, but after the experiments considerable alterations were made in them. The carriages actually supplied for working the line were not those which they had to do with in the experiments, and weighed 7 tons instead of $4\frac{1}{4}$ as originally specified. But whether the experiments were to be directed to the determination of the amount of power required for the line, or whether the carriages

Dr. Hopkinson. had been the same then as at a subsequent time, he submitted that so important a change in the fundamental conditions ought not to have been left for chance discovery, but ought to have been announced to the contractors at the first possible opportunity, so that they might have the means of rectifying a calculation which had been made on wrong data supplied. He wished also to refer to what several speakers, including Mr. Reckenzaun, had said with regard to the power of the motors. He entirely agreed with Mr. Reckenzaun that it was a mistake to describe traction motors as of certain horse-power. Traction motors could only be properly described by a statement of the tractive force they would give at various speeds. He had stated that the motors were of 50 HP., not with any object of defining exactly what they could do, but simply with the object of giving a general idea of their capabilities. If they were worked off a 500-volt circuit they would give continuously 50 HP. on the brake at 310 revolutions, corresponding to 25 miles per hour, and in that sense might be described as of 50 HP. He would only refer to one other point: the cost of working per train-mile in lbs. of coal, alluded to by Mr. Scott Russell, who had made a comparison between the 28 lbs. on the City and South London line, and the coal used on large railways. Dr. Hopkinson thought the comparison, although interesting, was not a fair one, because, of course, the conditions of working were entirely different. On such a line as the City and South London every effort was directed towards giving as frequent and rapid a service as possible, and the cost of the coal per train-mile suffered in proportion. Indeed Sir Benjamin Baker had just said to him that it was like comparing a hansom cab with an omnibus, which put the matter more fairly than any words of his own could do. [Mr. SCOTT RUSSELL said a fair comparison might be made with the Underground Railway.] In conclusion Dr. Hopkinson desired to refer to one point in which Mr. Greathead had forestalled him. It had been a pleasure to him to mention the prominent part which Mr. Mott, the chairman of the company, had taken in the substitution of electrical traction for cable-traction, and his confidence in its success. He had referred to it in his Paper; but such matters, like all not directly relevant, were subject to editorial excision. He regretted that the discussion had not been upon the lines that he thought might have been most usefully followed. It appeared to him that those parts of the scheme which were most susceptible of improvement and open to criticism had been but briefly discussed or altogether avoided; but he thought that the South

London Railway had at least proved that electrical traction could be applied to railways on a large scale with economy, safety, and convenience to the travelling public. Dr. Hopkinson.

Correspondence.

Sir BENJAMIN BAKER, Vice-President, thought that, in order to appreciate the degree of success attained on the South London Railway by Messrs. Mather and Platt, and to give full credit to the directors for their enterprise in adopting the electric system of traction, it was necessary to recall the popular view held on the subject only three years ago. At that time, the general manager of the Metropolitan Railway told a Parliamentary Committee that his company had been negotiating for two years with electrical companies, as they were anxious to get rid of sulphur and other disagreeable concomitants of steam-locomotion on their line, but the results had been so disappointing that he had visited America himself to see what had been done there in the direction of electrical traction. The only really practical experiment, he said, that had ever been made either in the United States or Canada in the direction of substituting electric motors for ordinary locomotives was on the Manhattan Railway in New York. The experiments there cost £20,000, and the electric motor had been at once withdrawn and was lying on the rails rusting and rapidly decaying. According to the official report, he said, the electric motor, at a speed of about 12 miles per hour, cost five times as much as a steam locomotive. Referring to the Report itself, Sir Benjamin Baker found that "the four cars, weighing 59 tons, travelling at a rate of 9·4 miles per hour, excluding stoppages, required a pull of 26·7 net HP.; and to produce this the large generating-engine exerted an average of 175·8 I.H.P. Of this, 149·1 HP. was lost in friction, counter-currents, resistance, leakage, transmissions and conversions of power—leaving 26·7 HP. as the net result available for pulling the train. That made the average loss 85 per cent., and the efficiency 15 per cent." He had happened to be in New York shortly after the preceding experiments were made, and his conversation with the Chief Engineer of the Manhattan Railway led him to believe that there was no particular anxiety on the part of that company to attain success with electric-traction, as public pressure might have been exerted to make them withdraw steam-locomotives from their "elevated" lines through the streets of New York and substitute costly electric motors. Nevertheless, Sir Benjamin Baker.