The Author. in which the prices had been cut to the lowest limits. The Author could not accept newspaper accounts of the preliminary designs of the London, Brighton and South Coast Railway equipment as representing the best practice. The Siemens motor had what might be regarded as separate windings for forward and backward running, and consequently only needed the two contactors shown. There would appear to be no difficulty in passing under a girder-bridge 2 inches above the loading-gauge. The wire would be put to one side of the centre-line, where there was ample clearance.

Correspondence.

Mr. Kelly. Mr. A. C. KELLY remarked that *Figs. 8*, *9*, and *10*, giving data about the self-regulating long-pull magnet shown in *Figs. 7*, indicated the difficulties to be met with in designing an alternating-current magnet to actuate the contactors of the control-system. From *Fig. 9* it appeared that the "hold on" pull of the magnet was about 116 lbs. This would appear to be a very moderate pressure for switch-contacts of the size necessary when dealing with heavy currents. Tests made of similar apparatus indicated that the temperature of the contacts under a given current rose rapidly with decreasing contact-pressure. For example, a contact 1 square inch in area carrying 600 amperes continuously had a temperature-rise of about 62° F. with a pressure on the contact of 350 lbs. With a pressure of 100 lbs. on the same contact the temperature-rise was found to be about 130° F. This indicated that, in order to keep the temperature of switch-contacts within moderate limits, it was essential to maintain a fairly heavy pressure on those contacts; and he thought that such pressures were more conveniently obtained by the aid of pneumatic cylinders than by the direct action of alternating-current magnets. It did not seem desirable to introduce into the overhead construction more or less complicated tightening-arrangements such as were shown in Figs. 17, Plate 1. In general, with the type of construction shown in Figs. 13, that was, with a single catenary suspension and a single trolley-wire, it would be found that the general elasticity of the structure was sufficient to keep the dip in the middle of the catenary spans fairly constant under all ordinary ranges of atmospheric temperature. Experiments had been conducted on spans of this type and also of the type shown in Figs. 15. The centre point of a span 120 feet long had been found to move vertically through $2\frac{1}{2}$ inches under a change in temperature of 50° F. Such a variation in height was quite negligible. The trolley-bow must, of course, accommodate itself to variations of this order, and also to the much greater variations which occurred at certain bridges and tunnels. With such a variation as indicated above in a span of 120 feet, it might be calculated that the trolley-bow must rise or fall through a distance of $2\frac{1}{2}$ inches in 0·682 second when the train was travelling at 60 miles per hour. This represented a rate of change of trolley-position of about 18 feet per minute, which was so moderate that it was obviously better to allow the height of the trolley-wire to vary within these limits rather than to introduce such construction as was shown in Figs. 16 and 17, Plate 1, which must greatly increase the cost of the work and the loads to be carried by the catenary suspension-wire. About 300 miles of the construction shown in Figs. 13 and 15, namely, the plain catenary type, had already been erected in Europe and America, and it was significant that although this constituted the greater part of the single-phase construction erected up to the present time, no trolley tightening-devices of the type shown in Fig. 17 had been found necessary. Mr. Kelly.

Mr. THEODORE STEVENS observed that at p. 38, where the Author said, "It might be supposed that the periodic torque of single-phase motors would be a disadvantage because of slipping at the instant of maximum torque, and that the adhesion of a single-phase locomotive would be much less than that of a continuous-current locomotive of the same weight," he dealt with the approximately constant value of the draw-bar pull, but did not go further with the relative values in the two cases. The Author was reported to have said in a Paper communicated to the British Association in August, 1906, "The adhesion of a single-phase locomotive is not less than that of a continuous-current locomotive." Was not the tractive effort at slipping with 25-cycle single-phase current about 15 per cent. less than with equivalent voltage and continuous current applied under otherwise identical conditions? With 15 cycles per second single-phase, was this not about 33 per cent. less than with continuous current?[1] It was desirable to have such facts accurately stated to avoid inattention to this detail. The Author's list of single-phase lines did not include the following six 25-cycle equipments in the United States: Vallejo, Benicia, and Napa Valley Railway, Cal., which started in 1905 using 3,300 volts; Spokane and Inland Railway, Washington, started in 1906, 114 miles long with 6,600 volts collected; Milwaukee E. L. and Railway Co., Wisconsin, which was opened in 1906, 36 miles long Mr. Stevens.

[1] See tests by B. G. Bergman, *The Electrician*, vol. lviii (1906-7), p. 144.

Mr. Stevens. and collecting at 3,300 volts; Philadelphia, Coatesville, and Lancaster, Pennsylvania, 22 miles; Anderson, South Carolina, 35 miles, 3,300 volts; and West Shore Railway, Frankfort to Herkimer. There were 30,000 nominal HP. of motors under 75 N.HP. each, 40,000 N.HP. of motors from 75 to 150 N.HP. each, 30,000 N.HP. of motors over 150 N.HP. each, in service and under construction for a total of over 800 miles of single-phase railways in the world.

Mr. Thrupp. Mr. EDGAR C. THRUPP remarked that the Paper was an interesting sequel to that by Messrs. Mordey and Jenkin in 1902, and bore evidence of similar ability and enthusiasm for the realization of the ideals set up. Those who had been concerned with the battle between alternating and continuous currents which began in London about 17 years ago, and continued for a long time with diminishing vigour, would remember that one of the principal arguments put forward by the "alternating" side was that the continuous current involved the use of machines with commutators, which were declared to be troublesome and costly articles. It was amusing that the boasted triumphant conquest of single-phase traction over other systems should now be dependent upon the adoption of the much-abused commutator. It was admitted that there was twice as much waste of energy in the single-phase as in the continuous-current motor, and engineers would require some strong inducement to adopt a second-best article when the best was also available. Mr. Thrupp would admit at once that where there was no fuel-bill to pay, and only a moderate traffic to deal with, the single-phase system might often be the best to adopt, as, with ample water-power, efficiency was not very important, and with small traffic there would be plenty of opportunities for dealing with repairs to the overhead equipment; but he thought that the proposition to use single-phase current for British main-line traffic was based upon several fallacious ideals. The first of these fallacies was the idea expressed by the Author in 1902 in the discussion on Messrs. Mordey and Jenkin's Paper, that a main-line electric railway "should be something like a bucket conveyor: instead of a few heavy trains at long intervals, there should be, at short intervals, a large number of small trains running at a high and almost uniform speed." Suppose that, instead of a train of six cars running half-hourly, six distinct cars were run at intervals of 5 minutes: that plan would be impracticable for three reasons:—(1) It would block the line for 30 minutes instead of 5 minutes. (2) It would require six drivers in place of one. (3) It would require 60 per cent. more power to drive the six cars separately at high speed (say 75 miles per hour) owing to the wind-resistance having to be completely overcome six times, and

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losing the benefit of the leading car screening the other five. The comparison would really be more appropriate if based upon the case of a twelve-car train, when 73 per cent. more power would be required by separate cars. A twelve-car train would require 11 per cent. less power than two six-car trains at 75 miles per hour. Another fallacy was the idea that high-tension transmission was an absolutely essential condition. This assumption might be readily conceded where the average power required was under 100 kilowatts per mile of line, but that was rarely the case on main lines, and the matter assumed quite a different aspect when the average demand was upwards of 100 kilowatts per mile. The trains which were likely to be required would want 400 to 1,000 kilowatts each, and therefore an average of over 150 kilowatts per mile of double line was quite a normal case in England. This meant upwards of 1,500 kilowatts on every 10 miles of line, and in many cases it would be more than 5,000 kilowatts. Now the continuous-current lines at present working were fed from sub-stations serving sections up to about 10 miles in length, and the outputs were found to be in accordance with the figures given above. In his opinion there was no justification for the existence of a sub-station of 1,500 kilowatts capacity, unless a generating-station on the same site was likely to be a nuisance. On main lines there was no difficulty in finding sites for engine-houses about 6 to 12 miles apart. He had recently made an elaborate study of the statistics of power-stations, with a view to arrive at a correct comparative estimate of the cost of working stations of various sizes, and he had arrived at a simple broad conclusion as regarded fuel-consumption. He found that with a load-factor of about 15 per cent. the fuel-consumption per unit generated was roughly inversely proportional to the logarithm of the maximum load in kilowatts. There was of course a variation with the load-factor as well, and the improvement in fuel-economy with an increase of load-factor was much more rapid with small powers than with large powers. Consequently there was less to be gained in this respect by large power-stations for railway purposes than for electric lighting. The disappointing position of certain electric power-distribution companies at the present time was due to misapprehensions by the promoters on this important question. He believed that the assumed necessity for high tension on main lines was due to the same kind of exaggerated idea of the economy of very large generating-stations as compared with smaller ones, and also as to the possible improvement in the load-factor by serving more than 10 miles of line from one point. The single-phase system with the transformer on the train was to his mind simply a repetition of the old mistake

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Mr. Thrupp. of single-phase distribution with the transformer in the house for lighting purposes, only the waste was not so serious owing to the higher load-factor. Nevertheless the transformer on the train must be made to suit the "train load-factor," which was only about 25 per cent., and not the "line load-factor," which might be about 45 per cent. With a load-factor of 25 per cent., the transformer would average about 5 per cent. loss of energy. The extra power required to carry the heavy transformer might be about $1\frac{1}{2}$ to $2\frac{1}{2}$ per cent., and the single-phase motor was admitted to be about 10 per cent. less efficient than a continuous-current motor. The aggregate of these losses at a modest estimate was 15 per cent. He had made two approximate estimates of the relative cost of working a British main line by the single-phase system with one generating-station for 50 miles, and by continuous-current direct-feed generating-stations situated 10 miles apart, and having intermediate battery sub-stations. In one estimate he had taken the demand at 150 kilowatts per mile and in the other at 300 kilowatts. The efficiency of distribution was taken at the same figure in each case, so that the loss of 15 per cent. on the single-phase train represented the difference in total efficiency between the two systems. In capital outlay the single-phase system came out about 25 per cent. more than the continuous-current system (with two insulated conductor-rails, one being earthed at certain points), and in working-expenses per unit generated the continuous current came out about 3 per cent. cheaper, excluding interest on capital, and about 5 per cent. cheaper after allowing 4 per cent. interest on capital. The final results showed that the single-phase system (allowing for its 15 per cent. loss on the train) would be about 20 per cent. dearer than the continuous-current system. His estimated costs of power-supply per train-mile might be of interest. For a service of twelve-car 400-ton trains to travel 75 miles per hour, the cost per train-mile was 11·4*d.* on the continuous-current system and 13·7*d.* on the single-phase system. These figures included interest on the new capital outlay, and liberal allowances for maintenance and depreciation of power-stations, but did not include the corresponding items for rolling stock. The results given had surprised him as regarded the low cost per train-mile for such a service, and had convinced him that the electrification of main lines was now a matter worthy of close attention where the traffic was becoming congested or where there were four lines in use. Large railway-companies would never scrap all their locomotives at once, but they might find that electrification of their trunk lines for high-speed long-train service would be an advantage, whilst

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the branches could continue using steam to wear out the locomotive stock. The idea of imitating tramway-traffic was quite out of the question. The trains might have twelve or even twenty-four cars, and long goods-trains could also be dealt with quite easily. The multiple-unit system throughout long trains was also unnecessary. One locomotive or two to four motor-cars would probably be found most satisfactory. Existing rolling-stock could do the rest. Electric locomotives might be relied upon to do a far larger mileage per annum than steam-locomotives and to require much less expenditure in repairs, and therefore the use of two motor-cars on a train did not necessarily mean requiring two electric locomotives for one steam locomotive, the ratio being more likely to be the reverse. The argument that single-phase current should be adopted because it would be cheaper than continuous current on branch lines with small traffic seemed to him untenable, because in such cases steam railway motor-cars would always be able to beat any electrical system that was not driven by water-power. The Zossen experiments had yielded valuable information, and had proved the extravagance of single-car high-speed traffic. One thing they had not tested was the question of the difficulty and danger of maintaining, or repairing, or renewing high-tension overhead wires without stopping the traffic, which, on main lines, was practically continuous day and night. These difficulties were practically non-existent on the continuous-current system, and it was hard to see any sound reason why a more expensive and more dangerous system should be adopted.

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20 November, 1906.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President, in the Chair.

The discussion upon Mr. C. F. Jenkin's Paper, "Single-Phase Electric Traction" occupied the evening.
