Discussion.

Mr. W. H. PREECE, C.B., President, said it was his first duty to Mr. Preece. propose a vote of thanks to the Author for the care with which he had prepared the Paper, and especially for the trouble he had taken in making such admirable diagrams. The subject was an exceedingly interesting one to all the members, but especially to those who were engaged in the electrical industry. He thought he ought to point out to the Author that while engine-makers were striving to perfect the high-speed engines, the electrician was improving his dynamos and motors so that they worked now at very much lower speeds than at the time when the high-speed engine was introduced. He did not think the nature of the liquid used in the ram was mentioned in the Paper.

Mr. DALES said oil was employed for the sake of convenience, Mr. Dales. but water or any other liquid would act equally well, if it did not corrode the parts. No difficulties had been experienced in regard to the compressibility of the liquid and the leakages which took place in working. With the proportions which were provided, the compressibility of the liquid gave a clearance on the journal of about $\frac{3}{4000}$ inch; whilst the leakages, by calculation based upon the quantity expended in a given number of strokes, amounted to no more than what would be equal to a clearance on the journal of $\frac{1}{360,000}$ inch per stroke.

Mr. HENRY DAVEY scarcely felt competent to criticize the Mr. Davey. Paper, for considerable experience in the actual use of the contrivance described was required before an opinion could be expressed. He complimented the Author on the ingenuity displayed in the design. He noticed that all the bearings were provided with hand adjustment, and he gathered from the Paper that the experiments with reference to the material and the peculiar form of the bearing-brasses were carried on simultaneously with the experiments with the peculiar kind of connecting-rod and shaft-bearing. He should like to ask if the success the Author had obtained arose entirely from the peculiar construction of the automatic adjustment of the bearings themselves. When there was a hand adjustment as well as an automatic adjustment, it was quite possible that the engineer in charge would tighten up, whenever it became necessary, by hand.

Mr. Davey. Possibly the Author, in his experiments, had left the engine entirely free to the automatic arrangement by drawing back the hand adjustment, giving a large clearance, which would cause very great damage to the engine if the automatic arrangement failed. He should like to know whether such an experiment was made, because it was obvious that if the hand adjustment was close up, it was difficult to say how perfect the automatic adjustment might be. He was struck by the remark made by the President, that electricians were working in the opposite direction; that had always occurred to him as the proper course as regarded speed of rotation. Why not make the dynamos run more slowly, and then there would not be the necessity for engines of such high speeds? Because it was evident from the great trouble the Author had taken to make his quick-revolution engine perfect that it was not an easy matter. He thought dynamos were now made of sufficient size to make it unnecessary to employ such high speeds as those mentioned by the Author.

Mr. Bryan
Donkin.

Mr. BRYAN DONKIN complimented the Author on the admirable arrangements he had devised for doing away with knock, for lubricating in a very efficient manner, and for minimizing the movement of the parts. But he thought the engine could hardly be said to be of the high-speed type; it would be more correct to call it a quick-revolution double-acting engine. The piston-speed was not high, only about 600 feet or 700 feet per minute; but certainly it was a quick-revolution engine. He was disappointed that the Author had given no indicator diagrams. There were no tests mentioned, and the consumption of feed-water, or, better still, the thermal units per HP. and B.H.P. per hour were not noted. But the Paper itself was extremely interesting, and perhaps the Author would be able to furnish this information, and some actual results of its practical work with a dynamo. The question of balancing also had not been touched upon; he would like to know particulars of these arrangements, and also the percentage of clearance, particularly the clearance-surfaces at each end of the cylinder.

Mr. Patchell

Mr. W. H. PATCHELL noticed that the Author stated that engines could not be run at the high speeds mentioned, but he had been running, for nearly $2\frac{1}{2}$ years, double-acting engines of 10-inch stroke at 350 revolutions per minute. Owing to the strike and other causes, he had been obliged to run some of the engines for rather more than 2 years without opening them. They were forced-lubrication engines, and, owing to Messrs. Belliss' system,

there was practically no wear. The Author mentioned clearance Mr. Patchell. as $\frac{1}{500}$ inch. He had ascertained the clearance of his engines, and he found the ordinary clearance was between 0.01 inch and 0.015 inch, whereas the Author fixed the limit at 0.002 inch. He would not say those engines could not be heard when running; they could if one stood close beside them. They had three cranks, and practically no vibration was felt on the platforms round the cylinders. Dr. Kennedy had seen the engines running and he thought he hardly believed, until he heard, how little noise they made. There had been various ways of overcoming the knock in an engine. One had been brought to him some time ago—a spring connecting rod, he thought. The Author of that method had a 30-HP. engine running in the West of England, and said he could not hear it running when standing with his back to it. He was afraid of anything like that, because the man in charge might forget to stop it. With regard to governors, that described by the Author was a very ingenious one. He did not think the Author was very clear in the remark he made that there were not many engines governed to 5 per cent. He thought he meant 5 per cent. variation from no load to full load, not 5 per cent. for a small variation in load. It seemed a large amount, but when actual tests were regarded it was very near the mark. Considerably better had been accomplished; tests of the Waterloo and City engines had shown less than $1\frac{1}{2}$ per cent. from no load to full load.¹ That was with forced-lubrication and throttle-governing. He hoped the Author would give more details about the expense of 5 per cent. variation, because he did not follow his meaning. The only interpretation he could think of was that the Author thought an engine running near full load and not able to work more than full load worked with 5 per cent. waste all the time, as allowance had to be made for variation if more load came on. With regard to the slide-valve being made to act as a relief-valve, with an engine working, as the Author's appeared to be, with very little clearance, and running at such high speeds, he knew that very good relief-valves would be wanted. He should like to know, with Mr. Donkin, whether any tests had been taken of the engine, especially after it had been working some time, because he was very dubious as to whether that arrangement remained steamtight. In an engine such as that shown, there would be very great danger of leakage right away to the exhaust. The

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¹ Proceedings of the Institution of Mechanical Engineers, vol. 1897, p. 256.

Mr. Patchell. Author at the end of the Paper gave the power of one of the engines, and it was a pity the results of the tests were not fuller. He said that engines with a 7-inch stroke could be made to run in a perfectly reliable manner at 600 revolutions a minute. Practically no one in the electrical world was now interested in a 100-HP. engine, for engineers naturally thought of three of such lines on one crank-shaft; but a 300-HP. engine would not be required at anything like 600 revolutions a minute, and the dynamo makers would have some difficulty in making a dynamo of that size to run at that speed. He was rather struck, on looking into the sizes of some large machines, with the fact that dynamo makers could not build them to run as fast as the high-speed engine people could now make engines to run at; so that engine makers had to come down to meet the dynamo makers. He did not understand how the continuous lubrication was kept up. If he understood Fig. 2, the Author used the top, round about the cap, as an oil-well, and the valve drew it in at every stroke. But how was that arranged for on the connecting-rod?

Mr. Stromejer. Mr. J. P. E. C. STROMEYER understood that the action of the adjustable bearings was that as the speed increased, or as the knock came on the engine, oil was pumped into the piston and pressed the brasses closer together than they would be if adjusted to run at a low speed. He did not suggest that the connecting-rod was intended for marine engines; but supposing it were applied to that type, and the engine were to race, increasing from 60 revolutions up to 200 or 300 revolutions, then the pumping action would force the piston down on to the brasses, and as soon as the engine went slow again the brasses would be so tightly jammed that he was afraid they would seize on the shaft. Regarding it again from a marine engineer's point of view, the connecting-rod, though very ingenious, seemed so excessively heavy that the side oscillation would have a bad effect on the brasses, especially as there was no brass at the side of the crank-pin. There was only a bearing at the top and the bottom, and with a side-jerk motion he would expect the shaft to wedge itself. He did not see that the arrangement intended for a relief-valve could relieve the back-pressure at all, or very little. The water would have to get between the joint—it was simply a plate with a joint—and he did not quite see that the plate would be forced off.

Mr. Druitt Halpin. Mr. DRUITT HALPIN noticed that the Author referred to variations in governing described in different parts of his Paper, his figures being 4 per cent. and 5 per cent. A Paper had been read

at the Institution many years ago by the late Mr. Willans in connection with governing, and in the discussion Moscrop diagrams of automatic governing registrations were given of a large electric-light Corliss engine, with a Knowle's double governor.¹ As was usual in those days the lights were shut off suddenly at twelve o'clock when half the load went off by pulling out a switch. It was not possible to trace from the Moscrop diagram where that took place. In fact, the maximum variation shown above and below was $\frac{1}{6}$ of 1 per cent. of the total— $\frac{1}{3}$ per cent. above and below the mean line.

Mr. Druitt
Halpin.

Mr. W. W. BEAUMONT remarked that bearings of connecting-rods which had a hydraulic cylinder, a pump, a powerful spring, and other arrangements, hardly commended themselves if they were introduced into an engine with the object of running a double-acting engine at a very high speed. If high-speed engines were required more and more every day, it might be desirable to introduce great refinements; but experience having shown how undesirable in many respects very high speeds were, every effort was being made to render them unnecessary, and they were no doubt becoming more and more so every day. With regard to the inertia effect, he was afraid that it could hardly be thought the Author had made any desirable advance when he put a connecting-rod of that kind into an engine in order to be able to run at a somewhat higher speed than others were running without such an arrangement. With regard to the bearings, he thought that with the sides of the bearings cleared away it would be found tolerably easy to keep the bearings of a well-made engine cool. At all events, the difficulties mentioned by the Author ought not to arise to such an extent as to make so complicated an arrangement of connecting-rods and bearings necessary. He could hardly understand the Author's remark: "The expansion of the source of heat overtakes that of the radiating parts." With regard to governing, it was at first strange to see that a governor which reduced the variation of speed below 5 per cent. would possibly save the whole of the coal bill of the engine which was governed by it; but it appeared somewhat more easy to understand it when it was seen that the coal bill was only $2\frac{1}{2}$ per cent. of the wages item. He understood that the variation of speed being 5 per cent. below and above the mean, $2\frac{1}{2}$ per cent. of the time that the engine was running only would be lost at a lower rate of doing work. That being the case $2\frac{1}{2}$ per cent. of the wages

Mr. Beaumont.

¹ Minutes of Proceedings Inst. C.E., vol. lxxxi. p. 198.

Mr. Beaumont. item would be saved— $2\frac{1}{2}$ per cent. being the coal bill. But the Author hardly made it clear that the 5 per cent. would be saved by the governing. If that were so, the governing would be of very much greater value than was placed upon it, even for the most favourable electrical purposes, because the gain would be very considerable. The engine was running at a speed $2\frac{1}{2}$ per cent. above and $2\frac{1}{2}$ per cent. below the mean. That was obvious, because the Author said the term variation was applied to the total range of speed, and not a deviation from the normal. But if that was the case it would appear that the machinery in the large woollen mills would be sometimes running a little higher, $2\frac{1}{2}$ per cent. higher in speed and sometimes $2\frac{1}{2}$ per cent. lower, so that it was not quite clear that the whole of the coal bill was to be saved. He was glad to know of a governor which could achieve such exceedingly close governing.

Mr. Harris. Mr. GRAHAM HARRIS was fairly baffled by the statement to which Mr. Beaumont had referred on pages 95 and 96. He presumed the Author understood it, but he did not. Since hearing Mr. Beaumont speak, he presumed that gentleman understood it, but he (Mr. Harris) understood it even less than before. If some further information might be afforded he would be much obliged.

Sir Frederick Bramwell. Sir FREDERICK BRAMWELL, Bart., had in 1854 made an engine to work directly a circular saw for sawing iron. It ran at a speed between 600 revolutions and 800 revolutions per minute. It was a trunk-engine, with the top side always in connection with the boiler, and the bottom side alternately in connection with the boiler and with the exhaust. The valve was D-shaped in section, but in plan it was an entire circle, running the whole way round the cylinder, cut at one place, and capable of being adjusted to the exact diameter. It floated upon the cylinder, and did not require any back-plate, or anything of that kind, and was absolutely frictionless. That engine ran between 600 revolutions and 800 revolutions per minute with perfect quietness. Then 25 years ago he had experimented with one of Thornycroft's very early quick launches, the "Miranda." He read a Paper¹ on this boat, from which it would be seen that the engines ran 600 revolutions per minute. There was no knocking or trouble of any kind or description, and it had not any of the very ingenious, but somewhat complicated arrangements described by the Author.

¹ Transactions of the Institution of Naval Architects, vol. xiii. p. 263.

Mr. W. W. MARRINER said it was impossible not to be struck Mr. Marriner. with the very clever and ingenious method the Author had described of overcoming the trouble he had found with his fast-running engines, but his experience was not quite similar with regard to the clearance or knock in brasses and bearings. In some small fan-engines that were running at 1,000 revolutions per minute, it was found impossible to run them successfully unless they had a $\frac{1}{32}$ -inch clearance in the connecting-rod brasses. In some larger fan-engines, running about 400 revolutions, the clearance was about $\frac{1}{64}$ inch, and the same applied to some larger torpedo-boat engines which ran 400 revolutions and indicated about 2,000 HP. The whole question of running engines at high speeds was one of lubrication, and any attempt to run engines successfully at high speeds must be in the direction of forced lubrication similar to the means adopted by Messrs. Belliss. He thought that if the Author in his engine had put the extra weight into increasing the bearings, and adopting improved methods of lubrication, he would have obtained even better results than he had. In the high-speed engine there was also another point, and that was, if the number of working parts were increased, the liability of the engine to a breakdown was much greater.

Dr. A. B. W. KENNEDY was sorry the Author did not state at the Dr. Kennedy. commencement of his Paper—as was certain he knew quite well—in bringing forward two novelties in the construction of high-speed engines, that, after all, those novelties were only one pair of methods out of many others which were at work at the present moment, for rendering high-speed double-acting engines practically successful. He did not wish to join in some of the unfavourable comments which had been made on the Author's plan. It was quite true that the arrangement with the hydraulic cylinder for keeping the bearings in contact looked more or less complicated, yet he thought it was perhaps a little cheap criticism to lay great stress upon this until it was seen in existence, and experience was obtained of how it was going to work. If it was, as he thought very probable, an exceedingly good way of at the same time preventing knock and allowing of forced lubrication, then he was content to believe that the little additional complication might be got over; at any rate it was a matter for practice to settle. In the matter of the governor, he was in the same position as Mr. Harris and other speakers; he thought there must have been a mistake. He did not see how the governor could possibly effect economy in steam, unless it was to be interpreted

Dr. Kennedy. as suggested by Mr. Patchell. Quite on the contrary, an absolute alteration of speed might be very economical, because if an engine had to work at very varying loads at different times, it was better to work it slower when working at lower speeds, in order that so much work might not be expended in engine friction, the engine friction being more or less constant per revolution. Therefore, if an engine was run at full load at 400 revolutions and at light loads run only at 300 revolutions, the efficiency at the lower loads could be made proportionally higher and the economy of the engine correspondingly improved. He had specified engines to be made so that they would be employed in that manner, but he never found that the drivers would so run them, and he had therefore discarded the clause in his specifications, but it was undoubtedly to a certain extent a source of economy. In reference to other systems which were in use, he could fully endorse what Mr. Patchell and others had said as to the working of the Belliss double-acting engines. They made practically no noise, they ran at extremely high speeds, and their lubrication was absolutely perfect. With regard to their governing, he could not pretend that he knew anything that attained the governing Mr. Halpin had mentioned; but in the engines which were used on the Waterloo and City Railway he had seen the whole load—when the engines were driving a dynamo working at full load on resistance—thrown off suddenly and again thrown on, and he did not think that a casual observer looking at a couple of ordinary glow-lamps in the circuit would be able to tell that anything had happened. In throwing off load especially he could hardly tell that anything had happened, and that was, after all, governing closer than was ordinarily wanted. The governing was of the throttle-valve type, and was made specially close in this case simply because it was wished to run the lights in the trains off the same circuits as the motors. If any of the members present travelled by that most luxurious and modern method of travel, the Waterloo and City Railway, he had no doubt they could read quite comfortably all through the tunnels, and did not find that the lights varied sensibly, although the power upon the motors was varying enormously from minute to minute.

Mr. Dales. MR. DALES, in reply to the Discussion, expressed his obligation for the manner in which the Paper had been received. It had been his intention to confine it to an investigation of the mechanical action only of steam-engines, as a suitable preliminary to further enquiries as to the possibilities of generally increased

economies which might accrue from very high rates of rotation, Mr. Dales. considered both relatively and actually, that was to say, from increasing the speeds of engines of any size, both large and small. A method was first necessary of making relatively high rates of rotation practicable, and that had been accomplished. The second condition necessary was running very closely to any normal speed, and this had also been accomplished to a point which appeared to fulfil all practical requirements, the possible running being to within 1 per cent. This amount was the extreme oscillation of speed which could be brought about by absorbing the full power of the engine by a brake applied to the fly-wheel, and by the instant release of such brake, leaving nothing for the engine to drive but its own friction. This was the most extreme variation of work which can be put on an engine, and much greater than any which could be effected by manipulating a dynamo. The variation was not a deviation from the normal speed, but the total difference of speed which was brought about. In most ordinary cases considerable deviations were brought about not by a change of work but by a regular oscillation of speed in the engines, which was caused by the friction, inertia and other defects of the governors and expansion-gears applied, and which, in performing their functions, were always either behind the requirements of the engine or over-acting, and there was a rise and fall of the speed indicator line which was due to change of work, in addition to the broad mark of friction deviation made by the pencil. This regular oscillation of the engine speed might be easily observed by watching the action of a common governor and throttle-valve. The balls ran a few revolutions in a low position; they then rose and ran a few revolutions in a higher position; then the reverse action took place and went on indefinitely without any change of work having taken place. The same thing occurred in a greater or less degree with any governor; but in one which would run an engine to a total variation of 1 per cent. it was imperceptible and, for practical purposes, did not exist. To prevent racing, the setting or adjustment of the governor could not be nearer than about four times the friction variation of the governor. Where so fine governing was required the friction and inertia must be so very low that only correct principles of design could accomplish the desired end. If, however, such correct principles were applied fine governing was just as easily obtained as any other, and the governing element in engines so provided was a great deal less trouble than ordinarily. The application of the methods referred to in the Paper had been made both on a test engine for extreme

Mr. Dales. speed and also in engines doing regular work, at unusually high rates of rotation, during 4 years, and the results had shown that neither extreme speed nor time had had any detrimental effect upon the appliances, and that they were in fact amongst the most permanent parts of the engines, and which for running purposes were practically always perfect in their mechanical action. The parts which in the hydraulic adjustments were extra to ordinary fittings were all practically fixed, and did not partake of the nature of mechanism as ordinarily understood, and they did not require skilled labour for the maintenance of their efficiency. The packings of the rams would last 12 months or more, and they could be renewed by any ordinary engine-tenter in a few minutes. The men who had had charge of the engines fitted in the manner described (and which were all of one size, indicating up to 85 HP. on 80 lbs. to 90 lbs. steam, and running up to 480 revolutions per minute), had performed the combined duties of fireman, shaft-oiler, engine-tenter, and, in one case, electrician, and received 25s. per week as wages, where they had only one engine to attend to. The speed trials made with single-acting engines by the late Mr. Willans showed conclusively that a very large saving in cylinder economies was effected by running at comparatively high rates, and it was likely that, with similar clearances and steam distribution, at least equal steam economies might be obtained from double-acting engines, in addition to some of the undoubted mechanical advantages of the double-acting type, not the least important being their very much smaller engine friction, which amounted to not more than 5 per cent. of the full load, whilst the friction of single-acting engines was about double that amount. Although it was not possible in double-acting engines to have the true Cornish steam cycle in the high-pressure cylinder, a close approximation to that might be obtained, and the double weight of steam which passed through the cylinder in a given time there was little doubt reduced the proportion of the cylinder losses; so that, taking the cylinder losses and friction together, there was probably a balance of engine efficiency left in favour of the double-acting type. He thought it was agreed that the double-acting type was mechanically superior to the single-acting. In regard to the ordinary rates of revolution in steam-engines of the double-acting type fitted with fixed bearings the extreme rates in current practice were 500 revolutions at 100 HP. and 380 revolutions at 350 HP.; these were respectively two- and three-crank engines; the average practice was very much lower. The speed test with the 6-inch-stroke engine had shown that no such speed

as 600 revolutions could be maintained for any time with a fixed bearing. A test for the establishment of this point was easily made by screwing down the hydraulic cylinder-top until the bearing was fixed and solid without putting any nip on the bearing. This had been done experimentally on several occasions and the bearing speedily heated whatever the lubrication. The bearing had also been run with sufficient knock to prevent its seizing, but at such a speed as 600 revolutions the hammer of the journal both generated heat and drove out the lubricant, and the bearing became hot. The results of these speed trials had sufficiently established that there was a very large difference in the possible rates of revolution of fixed and expansible bearings; and, also, that extreme speeds such as had been attained were only practicable with close-up bearings of some such design as those described. Experimentally a speed of over 800 revolutions per minute had been attained by 8-inch-stroke engines, but it was found that crank-necks, 5 inches by $3\frac{1}{2}$ inches, such as were provided, were insufficient to stand the speed, and they gradually warmed. Presumably the necks were too short. All the stationary bearings, however, stood the speed perfectly well. Longer crank-necks provided on the 6-inch engine remained perfectly cool at 600 revolutions; in fact, the whole of the trials had shown that for very high speeds very long crank-necks were necessary. The difficulties of high speed increased very much more rapidly than the rate of revolution. The friction item due to the revolution of the shaft and the viscosity of the lubricant increased directly as the speed; but both the inertia of the piston-line and the centrifugal force generated on the crank-journal increased as the square of the speed. At some of the trial speeds the centrifugal force on the crank-neck was about eighty times the weight of the material; it was thus easy to see how the lubricant would be thrown off the journal. As the friction increased directly as the speed and the inertia as the square, the limit of speed for any given clearance with fixed bearings would be pretty clearly defined, and when the extreme maintainable rate had been reached it was very difficult to increase it by ever so little. He had experienced this in ordinary practice, especially in high-speed ordinary practice. With 16-inch stroke engines having fixed bearings he had been able to run 225 revolutions with tolerable certainty under certain circumstances; but it was not easy to maintain 250 revolutions with an adjustment which was satisfactory in regard to knock. It did not appear that a large quantity of lubricant was of special value at high rates of

Mr. Dales.

Mr. Dales. revolution, the great centrifugal force generated throwing off any bulk of oil fed to the wearing-surfaces, only such as clung to the surface of the metal being actually useful for lubrication. All the results referred to had been obtained without forced lubrication, an ordinary drop-feed having been used. The quantity of oil required for the 85-HP. engines was about 1 pint per working day, which cost $1\frac{1}{2}d.$ (1s. per gallon). Certainty of action in the lubricating arrangements was of more importance than either quantity or quality of the lubricant. The governor shown on the diagram had thoroughly proved the soundness of the principles on which it was designed and had developed no weaknesses, but, on the contrary, had shown that it was as permanent as any other part of the engine, and also that, as the sliding parts became easy by wear, the quality of the governing improved. The governor proper had only two moving parts, or, rather, one which was duplicated, and there was absolutely nothing to get out of order. If a spring broke it simply dropped the speed of the engine so very slightly as to make no perceptible difference. Such a thing had occurred only once with a spring made by strange men during the strike. The governor could be regulated from the switchboard when running by applying a small motor in the wheel for screwing up the load-springs, the necessary current being carried by two contact-rings on the outer surface of the wheel and suitable brushes. It should be noted, however, that any centrifugal governor which would work throughout its entire range with a variation of speed of only 1 per cent. could not be screwed up more than about 2 per cent. or racing would occur, and that if the speed were much lowered by unscrewing the springs the fineness of the governing would be spoiled. There was very little margin either one way or the other. Referring to the action of the governor upon the expansion-valve motion, the eccentric-rod, valve, and parts were driven by the engine through the governor, and the force required for this formed a permanent load on the centrifugal parts. Experiments made for the purpose of ascertaining this quantity without the load-springs showed that a speed of about 100 revolutions per minute was required to balance the driving-force. The normal speed of the same engine was 450 revolutions, so that the squares of these two speeds would give the difference between the driving power of the valve motion and the total centrifugal force of the governor. Worked out this was 1 to $20\frac{1}{4}$, say the driving power was 5 per cent., and it would be seen further that the length of the governor-slide was to its width about $2\frac{1}{2}$ to 1, which would cause a side friction of the guide-rods

due to 2 per cent. of the total centrifugal force. The actual friction would then be, if the rods were dry, 10 per cent. of 2 per cent. of the total centrifugal force, or $\frac{1}{5}$ per cent. of that quantity. This would partly explain the comparative absence of friction in the arrangement. In regard to the necessity for high speeds it was always advisable to derive the highest service out of any given appliance. High speed, if it gave commercially increased value, was not any matter of choice, but a necessity. No user could afford to run his engine at any slower rate than the fastest which could be maintained. He could not agree that engines used for electric light purposes had been ahead of the dynamos driven in the matter of speed. A 100-kilowatt alternator ran at 500 revolutions, and required about 170 HP. indicated at the engine. He knew of no single engine or single pair of engines which would do this direct driving. A 200-kilowatt dynamo was easily practicable at 500 revolutions, and a 300-kilowatt machine was given by an eminent authority as running at 400 revolutions. This latter would require nearly 500 HP. He was acquainted with recently-built engines by one of the best firms, which indicated 500 HP., with three cranks and three tandem compound cylinders, and they did not run at nearly that speed. He had received a letter from an eminent builder of dynamos, in which he stated, "the question is one largely of design. I don't think it impossible to design a 300-HP. dynamo to run at 600 revolutions. Mr. Parsons runs his machines at 3,000 revolutions; but, nevertheless, there are few if any dynamo-builders who have patterns, &c., for such a machine. The tendency has undoubtedly been of late to bring down the speed of dynamos, partly because the engines available have a slower rate, but also because the multipolar design is coming to the front with its largely-increased diameter of armature. The multipolar type of dynamo is necessary for large powers because (1) there is a great saving of weight in the magnets; (2) the armature reaction in two-pole dynamos of large output is too great; (3) the introduction of carbon brushes necessitates larger commutators with a number of brushes in parallel at several points round the commutators." Both dynamo- and engine-builders preferred to make large machines, but the principle of making more expensive appliances than were really necessary for any given purpose was obviously unsound, and both contractors and consumers would always buy those appliances which were best for their cost. In regard to uniformity of rate of rotation, it had been found that with first-class governing, say $1\frac{1}{2}$ per cent. total variation of

Mr. Dales.

Mr. Dales. speed, a two-pole dynamo might be driven by belting on glow-lamps by an engine speed of 170 pulsations per minute (85 revolutions double-acting) without any perceptible variation of the intensity of the lights, and it was clear that the better the governing the less the necessity for a multiplication of cranks and cylinders became. In the test case above mentioned the maximum pulsation possible was $12\frac{1}{2}$ per cent. per stroke, that was to say, the speed of the engine running light was, by full steam and latest cut-off, accelerated $12\frac{1}{2}$ per cent. toward the full speed per stroke. With a single-cylinder double-acting engine running 450 revolutions per minute, perfect driving could be obtained with very light fly-wheels, with wheels made from pressed steel plate (like boiler ends) for the sake of safety. The maximum pulsation possible in this engine with 90 lbs. steam is $4\frac{1}{2}$ per cent., or nearly three times better than what was proved to be good enough. Carrying this point further, the maximum pulsation per stroke possible in the 6-inch stroke 600-revolution engine was only $1\frac{7}{8}$ per cent., or six and two-third times better than what was good enough and sufficient in turning quality for the very best class of work. As regards uniformity of torque, no appreciable betterment could be obtained by the employment of three-crank engines over a single piston line at high rate of rotation when it was provided with first-class governing; and perfect balancing, with consequent absence of vibration, could only be had by placing one large cylinder on one centre between two small ones of an equal weight of piston line and cranks collectively on the opposite centre. This arrangement would appear to be the best possible, and could be either compound or triple. Messrs. Braithwaite, of Elstree, had in hand a twin-cylinder compound engine to indicate 300 HP. at 450 revolutions per minute with one pair of cylinders of $21\frac{1}{4}$ inches and $15\frac{1}{4}$ inches by 10 inches stroke on 120 lbs. steam condensing, and it was intended with this type to make exhaustive trials of the steam results which might be obtained by different speeds in double-acting engines, and also of the relative merits of cut-off and throttle-valve arrangements as regards both steam economy under varying loads and the possible governing qualities of each method. The trials would be made with the same valves and valve motion and the same governor, the design lending itself in such a manner for the purpose that it was expected the results would be conclusive and that the data obtained would be valuable. The total cylinder clearances in this engine amounted to $6\frac{1}{2}$ per cent., of which $2\frac{1}{2}$ per cent. consists of $\frac{1}{4}$ -inch piston clearance at the cylinder

end, leaving less than 4 per cent. for the port and piston-valve clearances. The latter were the smallest clearances possible with a side port and piston-valve to give $\frac{1}{24}$ and $\frac{1}{12}$ of the cylinder area respectively for steam and exhaust thoroughfares, and were about the same as Willans' single-acting engine with central valve. This engine was being built on a guarantee to run 140 hours a week regularly without stopping, that was, from 2 A.M. on Monday morning to 10 P.M. on Saturday night. It was fitted with both the hydraulic adjustments and the governor as shown on the diagram. In regard to the commercial value of high speed, it had been found that at a sale price of about £2 10s. per indicated HP. on full load and normal speed, engines of the highest class could be provided in sizes over 200 HP. and down to 100 HP. at about £3, whilst the difference in cost of dynamos running 350 and 450 at 200 HP. output would be about 12 per cent. to 15 per cent. Long-stroke engines of the power named would cost about twice as much as stated, with a proportionate outlay for buildings. In making the trials of the bearings every care was taken that the adjustable plugs were properly set with sufficient clearance to prevent the bearings seizing, and for an increase of temperature which would melt out the white metal. The object of the plugs was to make the packing adjustments of the rams more convenient than if any exact quantity of packing was required; and also they were for the purpose of following up the wear of the brasses, so that in case of any breakdown which might release the liquid taking place no destructive knock in the bearings could occur. In one instance of an engine fitted as described, which was now working close to the sea-shore, and the bearings of which were supplied with very fine sand by every breeze, the wear on the crank-pin, gudgeon, and the four brasses, eight surfaces in all, had caused a clearance of $\frac{3}{8}$ inch behind the ram in a space of 18 months, but the engine worked perfectly well. A re-adjustment was made by taking out washers under the big end cap which were provided for the purpose. In such a place decent running in an engine fitted with fixed bearings could only have been secured by letting the four brasses up about once a week, which would have cost in time a very great deal more than the total cost of all the adjustments together. The piston-speed mentioned was high for a 6-inch stroke engine, being 600 feet or 700 feet per minute, the latter being about the rate of some of the highest speed long-stroke engines, and as it was always easier to get piston-speed by stroke than by rate of revolution, he thought the piston-speed attained was perhaps an achievement. The methods of attaining speed

Mr. Dales.

Mr. Dales. and economy were such as could be applied to any type or design of double-acting engine, and the steam economies would be according to such type or design. Very satisfactory work on dynamos had been done by engines fitted in this manner up to 50 kilowatts output, the extreme steadiness of the speed being much appreciated by the electricians. The cranks and connecting-rod end were balanced fore and aft; some of the later engines were somewhat overbalanced in this direction to partially balance the piston-line. These seemed to run best. A 10-inch stroke fitted with close-up adjustments as described would run comfortably at 450 revolutions per minute, and the difference in the inertia of the piston-line between 350 revolutions and 450 revolutions would be as 12.25 : 20.25, or roughly as 3 to 5, and with the $\frac{1}{1000}$ -inch clearance mentioned by Mr. Patchell there would be a very great knock at 450 revolutions. In referring to quiet running, he meant no knock whatever. He thought the Paper was quite clear on the percentages of governing. It stated that average governing was not nearer or so near as 7 per cent., and that there were very few engines indeed which run so near as 5 per cent. total variation, and that it was evident the best quality of governing, 1 per cent., would produce on the average 4 per cent. more work, which would in most cases pay for the whole of the coal bill, and that therefore good governing was of greater importance than small steam economies taken by themselves. The saving was really more than the 4 per cent., because the engines run slow on the heaviest load, so that it would not be stating too much to say that the saving, or rather extra saving, would be 6 per cent. He did not know of any method for avoiding knock other than the one submitted, which both took up wear and allowed for expansion. Taking up wear alone could be done in many simple ways. There was no slide-valve as referred to by Mr. Patchell, but a valve-case which was kept in position against a scraped port face by the pressure of the steam in the chest, and which in case of priming was forced off the port face in the same way as an ordinary slide-valve. This joint had kept good in a remarkable way. It was thought when it was first applied that it might require re-bedding every few years, but in one engine after $3\frac{1}{2}$ years' work the joint was found to be perfectly good, the cylinder oil having entirely preserved it from corrosion. There never was any intention of making 300-HP. engines to run 600 revolutions, although that did not appear to be at all impracticable. Dynamo makers were recently asking for engines

to run 600 revolutions and indicate 100 HP. The engine illustrated was made solely to demonstrate the efficiency of the hydraulic adjustment and its independence of speed. The arrangement of bearing shown was not intended as a method of forced lubrication; the liquid in the hydraulic cylinder was intended to act as a stop or filling to keep the brass in position without pressure. The lubrication was by the ordinary drop feed. The leakages (not the lubrication) from the connecting-rod cylinder were supplied from a spring piston reservoir, the charge in which would last, when the packings were good, up to 2 months in regular work. Forced lubrication was not necessary to get a double-acting engine fitted as shown to run any speed. Oil was not pumped into the cylinders, but was drawn in after the manner of the suction-valve of an ordinary pump, and it then remained as a stop. The arrangements were eminently suitable to marine engine-work, and no difficulties could arise even if the valve were to stick, or any other unlikely thing to happen, as the hydraulic cylinder ends would be adjusted to the same clearance as ordinarily necessary to allow the engines to work, but by the action of the adjustment the usual thud of all the bearings would be stopped. For very fast craft with high rates of revolution much better running than ordinary could be obtained. In regard to racing, such a governor would prevent it if applied to the stop-valve. No more severe test could be applied than that of the brake referred to. In regard to the weight of the hydraulic connecting-rod as it was usually constructed in small sizes, the weight of the piston-line was increased from 5 per cent. to 10 per cent. In large sizes the weight was about the same as an ordinary arrangement. This arose from the high compressive strength of the cylinder. The tension bolts were about the same in weight as the big end and small end bolts combined ordinarily. No such wedge action as Mr. Stromeyer mentioned took place by reason of the easing of the brasses, the inclines being 1 in 1. Also the adjustment held the upper and lower brasses in close contact. He thought Mr. Druitt Halpin held an erroneous idea of the figures quoted in regard to governing. In the case he quoted it was not possible to trace from the Moscrop what took place. He doubted that the centrifugal governors which he had seen used in these machines some years ago would change position with much less than a 2 per cent. variation from the normal, or a total of 4 per cent. He thought they had a regular "race" of their own. Also their driving-bands, as he had seen some, were not at all

Mr. Dales.

Mr. Dales, calculated to transmit the exact motion of the engine to the pencil.

He had run an engine, fitted as described in the Paper, without oil until the white metal was melted out and thrown all over the engine-house, but the engine did not either knock or pull up. By "the expansion of the source of heat overtakes that of the radiating parts," he meant that when a bearing began to heat, the journal and brasses expanded quicker than the outer parts of the bearing, for the reason that they were the source of heat and hotter than the outer casing. Mr. Beaumont had formed a clear view of how the coal bill might be saved by good governing. It would perhaps be more correct to say that sufficient extra money could be earned to pay for it. In all manufacturing processes there was a limit of speed which the material operated upon would stand without damage, and, consequently, engines which varied widely had to be speeded lower than they should, so that they might not overrun such limit, and if the highest rate was, say, 100 revolutions, 1 per cent. governing would vary from 99 revolutions to 100 revolutions, giving $99\frac{1}{2}$ revolutions as the average. If, however, a governor varied 7 per cent. (which was under the mark rather than over) the speed would be from 93 revolutions to 100 revolutions, and the average $96\frac{1}{2}$ revolutions, or a loss of $3\frac{1}{2}$ per cent. against a loss of $\frac{1}{2}$ per cent. But the actual loss was really more than the $3\frac{1}{2}$ per cent., because the bulk of the work was done at the lower speed. It might be said that an adjustable governor could be regulated, which was perfectly true, but if the full speed was run with the full load on, and part of the load suddenly dropped off, the engine overran before the governor could be let out again and the damage was done. He had known 400 glow-lamps to be smashed in about 2 seconds by such a thing. It was well known that many engines had to be governed by hand when the full load was on on account of these difficulties. He was sorry to hear that Mr. Graham Harris was fairly baffled, and was afraid he had stated that good governing saved the coal bill instead of earning it. The result would be about the same to the man who had to pay. With reference to the clearances mentioned by Mr. Marriner, he had never been able to run engines quietly with $\frac{3}{32}$ inch of slack. It was possible to run the connecting-rod of an engine pretty quietly, or at any rate with no heavy knock, if the inertia of the piston line and steam-pressure exactly corresponded, with considerable clearances; but an engine seldom ran on work with the conditions so well balanced. Possibly the centrifugal force of the big end of the rod was sufficiently above the effect of

the steam-pressure to keep the crank-pin in contact with the eye Mr. Dales. of the rod, whirling round it as it were. But the stationary bearings could not be kept quiet by any such means, and $\frac{1}{32}$ -inch clearance would mean ordinarily what would be termed a "steam-hammer knock." In none of the cases mentioned, he supposed, was there any pretension to silent running. He was glad Mr. Marriner corroborated his statement that a clearance which was out of reach of the expansion of heating was inadmissible in ordinary work; and he could assure him that no such speed as 600 to 700 revolutions could be run with a 6-inch stroke with any clearances at all, as the hammer caused the bearings to heat. As regards the possibility of running dynamos on variable loads with constant or very closely approximate constant voltage, without any alteration of the governors of the driving engine whilst running on the work, there appeared no difficulty in arriving at such a desideratum with engines which would run to a total variation of 1 per cent.; seeing that continuous-current dynamos could be made to give constant voltage to within 1 per cent., and can be made to give a higher voltage at the same speed on full load than on light load, if desirable. Assuming that voltage in such dynamos varies directly as the speed for a sufficient range about the normal for the purpose referred to, a fall of speed of 1 per cent. at the engine would give that amount of difference in voltage at the dynamo, and if the voltage at the dynamo fell 1 per cent. for increased resistance on full load, the total fall of voltage would amount to 2 per cent. Now an engine governor adjusted to a 1 per cent. total variation could not be screwed up in speed more than about 2 per cent., or racing would occur, but this amount would about make up for a 2 per cent. combined fall of voltage due to increased load both in engine and dynamo. In the case of an over-compensated dynamo, no fall of voltage would occur even without any alteration of the governor. The risk of overrunning in case of sudden reduction of load could be limited to 2 per cent. in the first case, whilst in the second there would be none in any circumstances. He referred to results obtainable at the dynamo; which would be such as would make no ordinarily perceptible difference in the light, nor would they cause any damage. As a comparison with an engine varying 5 per cent. (a moderate estimate of ordinary governing) there would be in such a case a fall of voltage of 5 per cent. due to the full load on the engine, in case of non-interference with the governor, and a further fall of 1 per cent. voltage, due to the full load on the dynamo, or a total of 6 per cent. loss; while in the case of screwing up the governor the

Mr. Dales. risk of overrunning would be to the extent of 6 per cent., which would make a very perceptible difference in the light by either the fall or rise of voltage. The governor mentioned in the Paper could be manipulated from the switch-board, by means of a small motor placed in the fly-wheel and suitable contact rings and connections. Variation of voltage due to difference of load was due much more to the bad governing of engines than to the imperfections of dynamos, and with engines running to a 1 per cent. total variation of speed practically constant voltage could be obtained under any variation of load whatever, and ordinarily no alteration of governors whilst running would be necessary. Such results would, in central station work, effect a large saving in the attention ordinarily necessary to preserve approximately constant voltage in the mains, and at the same time increase the output from any given plant. There was a further point in favour of direct driving of dynamos by high-speed engines which was not generally taken into account, namely, the loss of speed on the dynamo by the elasticity of the driving belt or ropes—between light load and full load. The extent to which voltage, and, consequently, useful effect might be lost, was much greater from this cause than at first sight might be supposed. As a case in point, he had one of his engines driving 85 HP., at 480 revolutions per minute, through a 9-inch by $\frac{3}{4}$ -inch link belt on to a dynamo running 600 revolutions, which absorbed that amount of power. The belt was put on as tightly as it could be got on, and on light load (about 6 HP.) the belt ran with both sides about the same curve, but when the full load was applied, the length of the slack side became 5 inches greater than the tight side, between 17 feet centres of the pulleys. There would be no stretch on the slack side when running on full load, and there would not only be double the initial stretch on the tight side, but also 5 inches more, and for every 17 feet of belt which went on to the driving pulley, 17 feet 5 inches, plus the original stretch, would come off, and the belt would continually creep the extra length. The mere stretch of the belt in this case diminished the speed of the dynamo 3 per cent., without any fall at the engine being reckoned, and the latter being 1 per cent., made 4 per cent. altogether from these two causes. Added to this the increased resistance of the dynamo of, say 1 per cent., there would be a loss of voltage of 5 per cent., instead of a total of 2 per cent., by direct driving of the same engine and dynamo. The loss by stretch of ropes would probably be greater. In short, it was necessary to carefully watch all the points and causes of loss if close running

must be made, and it was of little use having one point excellent Mr. Dales. if the others were bad. To obtain good driving of dynamos by belt or rope, a very large margin of strength must be allowed, and excellent driving could be obtained only by direct coupling.

Correspondence.

Professor M. F. GUTERMUTH found it difficult to judge the value and practicability of the design of the Author's engine only by the description and the drawings. He had no doubt the method shown in the Paper avoided knock in the driving parts of high-speed engines as long as they were new, but he could not believe that the complications employed would prove in the long run very satisfactory; and he had the impression that the advantage of smooth running was paid for too dearly by the great disadvantage of too many parts, which would cause in time difficult and costly repairs and shorten essentially its durability. The type of engines constructed by the Author was not fit to be used everywhere, but only where skilful hands would manage them. For high-speed engines the greatest simplicity in the construction of all their parts ought to be observed. The smooth running could be ensured by giving sufficient compression of steam, ample surface and thorough oiling to the bearings, and by using for the latter that accuracy and care of make which the Author required for the whole construction of his complicated driving parts and bearings. As to the governor, it could be said that many similar types existed already which had proved very satisfactory, and which allowed the same small variation of speed of 1 per cent. to 1.5 per cent. between full load and no load. But present experience showed that such steadiness in the speed was not at all suitable for most or all the purposes in which these high-speed engines were used.

Professor T. A. HEARSON considered the device described by the Author for eliminating the knock in the bearings of a high-speed engine very ingenious and probably effective, but the result he aimed at was capable of being achieved more simply and probably more effectively by means of forced lubrication. The Author's explanation of the advantages which he claimed for his automatically-adjustable bearing was just that which was wanted for a full appreciation of the very great merits of forced lubrication. His design was for the purpose of providing an adjusting enlargement

Prof. Guter-
muth.

Prof. Hearson.