Discussion.

Sir Douglas Fox. Sir DOUGLAS FOX, Vice-President, said the subject of the Paper was one of considerable and growing importance, especially when steam-engines were being used for such constantly varying loads, and he was sure it would be desired to thank the Author not only for the Paper, but for the diagrams and models submitted with it.

Mr. Richardson. Mr. JOHN RICHARDSON, after explaining the working of the apparatus exhibited, said that when the engine was used for many purposes, as in the case of comparatively large private installations at country houses, for driving dynamos, in addition to performing other work during the daytime, the mechanical governor was set at a slightly higher speed than the electrical governor; and thus it never came into action so long as the electrical governor had control, but could work quite independently when the latter was out of play. In case of accidental breakage of the electrical governing wire, the mechanical governor would take charge of the engine. On the other hand, when the engine was used for electrical purposes only, no mechanical governor was used. The automatic apparatus by means of which the engine would be slowed or stopped, in the event of the governing wire breaking when speed was being controlled by electricity, was then shown.

Captain Sankey. Captain H. R. SANKEY (late R.E.) considered, in reference to the strictures which the Author had cast on throttle-governors, that he had been misled by comparing the results obtained with a good cut-off gear with those of inferior throttle-governors. In the first place, the throttle-valves described were not suitable for accurate governing, except that shown in Fig. 9, Plate 3, which was the best form, if certain details in the design were attended to, and if the manufacture were equal to that of gauge work. In fact, it was more difficult than gauge work, because the clearance of the plug piston had to be not less than $\frac{1}{1000}$ inch to prevent sticking, and not more than $\frac{2}{1000}$ inch to prevent excessive leakage, which would be detrimental to governing at light loads. The arrangement shown in Fig. 5, in which the compression of the spring had to be transmitted, when balancing the centrifugal force, through a system of links and pins, was a faulty one. At every one of the pins there would be friction, acting either with or against the spring according as the balls tended to go in or out, and under such conditions it was clearly impossible to obtain accurate governing. The spring should be placed in direct connection with the governor balls without any intermediary. With such a governor and throttle-valve, regulation to within 3 per cent. when the load was changed from three-quarter load, as given in the Paper, to no load, was easy. This was a degree of accuracy which the Author had stated he had obtained with his cut-off gear, and which he considered sufficient for all practical purposes. It was not difficult to obtain regulation to within 2 per cent., and it was possible, although somewhat difficult, to obtain it within $\frac{3}{4}$ per cent. Captain Sankey.

Mr. Raworth. Mr. J. S. RAWORTH remarked, in confirmation of Capt. Sankey's statement, that it was unfortunate the Author had described governors of other classes, that were evidently not the best of their kind, in comparison with his own most highly organised and finished governor. The Willans governor represented a class that had been most successful in combination with the ordinary throttle-valve. Another example of the same class which he brought forward merely as an illustration of the good results obtained by a similar governor, was that made by Messrs. Browett and Lindley, of Salford. With that governor results had been obtained which were comparable to those described by Capt. Sankey. With regard to shaft-governors, that described in the Paper was an excellent one; but he thought praise was due to the excellent governors made in the United States, the efficiency of which, no doubt, resulted from the peculiar practice of building engines in large numbers to the same patterns. He referred to the shaft-governor acting directly upon a single valve. By making those governors in large quantities a degree of perfection had been attained in America which had not been readily obtained in England. The difficulty was not in the manufacture of the governor, but in designing it and in perfecting it under trial. Regulation to within 1 per cent. was attained in every-day practice, and if, therefore, the governor represented in the diagram was regarded as the best that could be made in those two respective lines, that would be to some extent misleading. He had seen the particular governor brought before the meeting at several electric-lighting installations with which he had been connected, and had been struck with the remarkable degree of perfection exhibited in the performance of its functions; it worked indeed so perfectly that he doubted if it could be much improved by adding electrical gear to it. It would be remembered that

Mr. Raworth. Mr. Willans had brought before the Institution[1] a description of an electrical governor, so perfect in theory that disappointment had been felt when expectations of it were not absolutely fulfilled. Possibly the reason for that was that there had been no demand for electric-governing, or that mechanical governors were able to obtain so near an approximation to a constant speed, that it was easy to compound dynamos to the extent of 2 or 3 per cent. above the straight line necessary to make up for the loss of speed, so that in isolated installations electrical governors were not essential. In installations in towns where many dynamos, all shunt-wound, worked in parallel, and under the control of the attendant, the complication would be too serious to be entered upon with a light heart.

Mr. Rigg. Mr. A. RIGG thought the Watt governor was not so bad an apparatus as many people considered, but that shown in the drawing was an extremely bad example, for its balls were not heavy enough, and the design was not in proportion. The action of the Watt governor was that of a non-sensitive governor through an extremely small space. The throttle-valve for all practical purposes might be almost entirely closed, and the engine might still run with nearly full power. So it was only the slight final movement of the governor that regulated the engine, and it should not be said that the balls at the bottom showed one speed, and in a higher position a different speed, for that did not affect the governing action. This governor acted on the engine through a very small space, and fair regulation would be obtained by such a governor of proper proportion.

The question of friction had been raised by Captain Sankey. The Porter governor had two evils in this respect, first, all the stresses of the centrifugal force of the balls were taken through the pins, causing considerable wear and tear. The momentum also of the weight A had to be overcome by the action of the centrifugal force, and that caused resistance akin to that of a dashpot and detrimental to the quick action of this governor. He offered the same criticism upon the governor shown in Fig. 4. Fig. 5 showed a better governor, for in it there was no heavy weight to overcome as in Figs. 3 and 4. The spring gave a regulation which could not be obtained with a uniform action of a load unless the links were worked, and the regulation was not nearly so good as could be secured by the action of the spring. That governor, however, had the same evil of friction in its pins

[1] Minutes of Proceedings Inst. C.E., vol. lxxxi. p. 166.

that Captain Sankey had alluded to. Fig. 17 showed a better class of governor, and one which he had used for hydraulic engines, with satisfactory results. It was not, however, made like that shown in the Fig. Instead of a spring in the box, there were two springs, one on each side, connected with the balls, so that as the balls diverged they worked the two springs directly, and there was no appreciable tension on the links and levers. It was extremely sensitive, and he knew few governors that worked better. Shaft-governors formed a more interesting subject than all the rest. Fig. 14, he believed, showed the first that had been made by the Author; but the earliest was that patented in 1802 by Richard Wilcox; and the Dods wedge motion, used by the Author in Fig. 12, dated as far back as 1839. As to throttle-valves, all of those in the Figs. had the spindles moving longitudinally, and if there was one thing that should not be done with throttle-valves it was that. The proper way of working a throttle-valve was to turn the spindle round, because the friction was infinitesimal, and it was well to remember that the only way to make a governor work well was to give it nothing to do. With regard to the indicator-diagrams, *Figs. 13* and *18*, although it had been considered that sharp corners at the point of cut-off were essential in all well-arranged engines, that idea was now modified. Sharp corners caused many irregular strains on the engines, and it was better to sacrifice a little of the sharp corners for the purpose of running the engine more easily and of making the changes less suddenly. The perfection of American governors had been attributed to the greatness of the number manufactured. The real reason why they had worked well was that they were properly and scientifically designed. There were two ways in which an engine could be governed by a shaft-governor; one, by the centrifugal force of the balls, and the other by the momentum of the wheel, as in the marine governor. The Moore governor was used by Messrs. Marshalls, of Gainsborough, and consisted of weights, like those shown in Fig. 14, with a fly-wheel, the movement of the eccentric being effected by a combined action overcoming the momentum of the fly-wheel and the action of the levers. It was somewhat complicated, but so far as it went was constructed on scientific principles. The Westinghouse governor combined that principle with the other in a much simpler and neater manner. Taking a weight like that in Fig. 15, by way of illustration, and suspending it as shown, the centrifugal action was that which moved it radially from the centre. If, instead of the weight being suspended where it was, the point of suspension were moved at Mr. Rigg.

Mr. Rigg. right angles to the position shown in Fig. 15, the weight would act by momentum, and not by centrifugal force at all. If the centrifugal force and the momentum were required to act equally, it would be hung at 45°, if not to act equally then the point of suspension would be at a different angle. All that was needed to make the governor shown in Fig. 15 into a good one, was to enlarge the diameter and move the centre about 45°. It would then act much better than that shown in the diagram.

Mr. Halpin. Mr. DRUITT HALPIN asked, with reference to *Fig. 16*, in which the Author had drawn lines showing the calculated, theoretical, and actual pressures as determined by experiment, what was the difference between the calculated and the theoretical pressure, and also how that expression came to be used. Governors regulating to within 1 per cent. had been alluded to by the Author. That doubtless was a good result; but it was by no means the best result that had been obtained. In the discussion on Mr. Willans' Paper,[1] read ten years ago, he had shown the original Moscrop diagram from an electric-lighting engine subject to sudden variations of 150 HP., and the total range of variation of speed was one-third of 1 per cent., or one-sixth above, and one-sixth below the normal. That was with a double-acting Knowles governor, in which the length of the rod was changed as in the well-known system adopted by Messrs. Hick and Hargreaves. Much had been said in praise of shaft-governors, and particularly the American governors; he considered that it was good workmanship that accounted for much of their success. With regard to Captain Sankey's remarks on the admirable governor he had shown, he thought that its design tended to reduce friction to a minimum, and to eliminate it altogether as far as the pins were concerned; it was certainly preferable to the system shown in Fig. 9. In dealing with those fine adjustments, it was impossible to obtain good results with the combinations of brass and cast iron as shown. He believed that a great catastrophe had been attributed to that combination in the case of the "Thunderer." He did not see how, in fine work, the relative metallic expansions could be expected to remain proportional, and thus the governors would not always remain free. He had taken autographic Moscrop records of the American governors, and on the same day the same Moscrop recorder had been applied to an English engine that made no pretence to accurate governing, with the result that the latter records were much superior to the former.

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

Mr. W. SCHÖNHEYDER agreed as to the advisability of not using a sliding rod through a stuffing-box. It was better to have a spindle which rotated through a small angle, but it was better still not to have a rotating spindle causing friction at all. He believed he was correct in saying that Messrs. Bumsted and Chandler passed the spindles through a piece of indiarubber, so that it only was moved through a small angle, and there was practically no friction. There was no stuffing-box, as the indiarubber served as a means of packing. Mr. Schönheyder.

Sir FREDERICK BRAMWELL, Past-President, expressed surprise that, in a Paper dealing with governors generally, no mention had been made of the governors of the late Sir William Siemens, which, it would be recollected, were admirable in their power, in their quickness, and in their regularity of governing. He was sorry they had not been alluded to. Fig. 14 or Fig. 15 appeared to him to illustrate a shaft-governor which he knew as the Hartnell governor, and which he believed had been exhibited at the Royal Agricultural meeting at Cardiff in 1872. He had a small electric installation at his own house, with an engine running at 240 revolutions per minute. It was fitted, so far as he knew (he had never pulled it to pieces), with a governor of that kind. He had on many occasions tested it by throwing the whole load off the engine when in full work and putting it on again, but he had not been able, with an ordinary watch, to detect any difference in the number of revolutions. Sir Frederick Bramwell.

Mr. J. PHILLIPS observed that the Author had remarked that, "A good governor should be reliable, simple in construction, easy to drive, and instantaneous in its action, both in increasing as well as in reducing the supply of steam. It should not reduce the power of the engine to which it was applied, but should tend to economise steam." He should be glad if the Author would explain how steam could be economised and the speed left constant without reducing the power of the engine. In another place the Author had referred to the power of the engine not being reduced. He was unable to see how the supply of steam could be reduced and the revolutions maintained without reducing the power. He thought the Watt governor shown in Fig. 1 should have been shown in a different form. The original Watt governor was made with cross-arms above the point of suspension of the ball arms, and the sleeve had considerable motion. Fig. 1 exhibited an ill-constructed form of Watt governor. A properly made Watt throttle-valve should be turned. Many throttle-valves were not true, and could never work satisfactorily; and Mr. Phillips.

Mr. Phillips. some failed on account of the valve being out of balance. He was surprised that the Knowles governor had not been referred to. It had a supplementary high-speed governor, used to adjust the length of the rod connecting the throttle-valve with the governor-lever. In order to get an engine with any governor to run at a uniform speed, it was absolutely necessary that the throttle-valve should be adjusted to admit the correct amount of steam.

Dr. Preller. Dr. DU RICHE PRELLER asked whether the Author was acquainted with the Thury automatic electrical regulator which, in principle and in its mode of action, by constant rotary motion, was similar to that exhibited by the Author. The Thury regulator, of which he had given an illustration and short description in a Paper on the Mont Salève Electric Rack-Railway,[1] was extensively used in the central stations erected by the Société de l'Industrie Electrique of Geneva, notably in Switzerland, France, and Italy, where he had frequently had occasion to observe its working. This system of automatic regulation was applied in two ways. One was in connection with separately-excited dynamos, in which case a shunt of the main current passed through the solenoid, and the consequent varying rise and fall of the armature bar was transmitted by electrical contact, and then by a friction-bevel mechanism and worm-gearing to an arrow acting on the contacts of a rheostat connected with the compound-wound exciter-dynamo, the excitation being thus automatically varied. The other method was in connection with turbines and steam-engines, the solenoid replacing in this case the ball governor, while the armature bar was connected with two unequal pistons and a slide-valve in conjunction with an oil dashpot to ensure stability. This last-named mechanical direct-acting regulator was that of Messrs. Fæsch and Picard of Geneva, who had designed the hydraulic machinery for the power-station of the Niagara Falls Power Company. This combination of electro-mechanical regulation was at once sensitive and instantaneous, the variations of speed not exceeding 1 per cent. when half the load was suddenly taken off. Constant speed of the exciter-turbine or steam-engine of the Thury automatic electric regulator was presupposed for the effectual action, otherwise the regulation was liable to come too late, the more so as the pressure of the bevel surfaces against each other did not always take instantaneous effect. These two defects he had frequently had occasion to observe, and the Author's regu-

[1] *Engineering*, vol. lvii. 1894, p. 438.

lator would be equally subject to them. At all events it would be interesting to know which of these two electrical regulators was first in the field. Dr. Preller.

Mr. DAVID JOY had been working on governors of marine engines, having in view the possibility of making a governor which should anticipate the movements of a ship in the sea, and so preclude the possibility of steam being shut off too late or admitted again too early to prejudice adequate regulation. When the steam was put on as the ship fell back into the sea there was a lash on the screw, which was often the cause of the fracture of screw-blades, or even the shaft. He had taken up the matter of his anticipatory governor after the accident and terrible experience to the s.s. "Paris"; and when recently developing a new fluid-pressure reversing-gear, he had devoted his attention to the subject, because he saw that this gear was amenable to rapid and delicate control. His first efforts had been successfully made upon dynamo machines. He did not propose to dwell on the marine aspect of the question, but would refer to what had been lately done on the subject of controlling dynamo engines, so far as he had been connected with the question, and so far as his knowledge went. The governor he was about to describe was a joint invention of himself and Mr. Kadolitsch, Engineer-in-Chief of the Austrian Lloyd Steamship Company. As he had said, his fluid-pressure reversing-gear lent itself most readily to control. It acted through the interference of the movement of the fluid which actuated the eccentric to and fro. A touch of the finger against the pipe would control the fluid, and give more or less steam as desired. The engines hitherto built were single tandem-engines, compound, driving dynamos direct, and were constructed of powers up to 300 HP. on the Continent. In England some of the same kind were being commenced. The eccentric was fitted on the shaft, giving a range from full-gear to mid-gear. The fluid was conveyed into the pipe by a small pump driven by the engine, so that, as the engine was in motion, there was a continuous flow of fluid, which passed round a circuit and through a small reservoir. On that circuit was situated the connection with the pipe passing to the eccentric to control it, so that the pressure that controlled the eccentric was a differential pressure, the fluid being pumped round the circuit and through a small valve, which passed it either back into the pump, or into the eccentric, and it depended upon more or less being passed to the eccentric whether less or more steam should be admitted to retard the engine, or to give it fuller Mr. Joy.

Mr. Joy. play. That control was effected by a solenoid. As the engines were connected directly to the dynamos, the engine and dynamo formed one piece of machinery. But connected with the dynamo was the solenoid, which actuated the small valve to which he had referred. If more or less electricity was produced than was required, the small valve controlled the fluid, and either admitted more fluid to the eccentric, so as to cut off the steam, and so the power, or let the fluid pass away back to the pump, and the eccentric falling to full gear, the speed of the engine was increased. The results obtained from the arrangement showed that with the engines running at 210 revolutions per minute, full power might be reduced to one-fifth of the power, with a variation of only one revolution either way—that was, $\frac{1}{2}$ per cent. in the total revolutions. That was found, however, to be too quick, and was too sensitive to be useful; and now the governors were speeded so as to take 5 revolutions, or $2\frac{1}{2}$ per cent., to pull the engine up to mid-gear; but it could be set for anything between $\frac{1}{2}$ per cent. and $2\frac{1}{2}$ per cent. The details of the engines were upon the table and could be examined by the members.

Dr. Hopkinson. Dr. JOHN HOPKINSON remarked that the first point he wished to raise had reference to the results shown in *Fig. 16*. A discrepancy or a difference had been found by the Author between the theoretical results which his calculation gave for the strength of a certain spring in one of his governors, and those which he realised in practice. The recognised laws of centrifugal force were of course nothing less than a particular department of the recognised laws of motion; and a discrepancy between those and the results of observation would either imply some incompleteness in the method of applying the recognised laws of centrifugal force or some errors of observation. He considered that the point was one which required a little further elucidation. The other point to which he wished to refer related to the electrical control of steam-engines. It had rightly been pointed out by the Author that electrical control could be such as to give a constant potential at the dynamo-machine, or, if it were preferred, a constant current delivered by the machine. For a constant potential at the dynamo-machine a high resistance solenoid was used, connected between the two terminals of the machine. For a constant current a low resistance solenoid was used, and the whole current, or a definite portion of it, was passed through. It had further been pointed out by the Author that the speed of the engine could be regulated by the difference of potential at various parts of an extended system, and he proposed to do that by bringing back the pilot wires in the well-known way from the more distant parts. He would merely point out that that was not necessary. It was possible to compensate for the loss of pressure by the resistance of the leads in other ways. Use should be made of the high-resistance coil connected between the terminals and the dynamo, and another coil should be wound round that coil to carry either the current or a proportional part of it a definite number of times depending upon the resistance of the circuit. It was taken in that direction to demagnetize in part the effects of the first coil. If those two coils were proportioned aright, a definite action of the electromagnet would be obtained at the time when the potential at the far end of the conductors exceeded or was less than a certain assigned value. Dr. Hopkinson.

Mr. HERMANN KÜHNE observed that the Author had set himself the task of describing a number of governors that met the demand for close regulation, some as types to be avoided, others to be imitated. Dealing exclusively with mechanical regulation, he found that the Author had mentioned ten governors. Two of them, the Watt and the Porter were well known, and of the remaining eight five had been designed by the Author. It had been stated by the Author that a governor should have great lifting-power, forcing-power, and stability, and that the Watt, Porter, and Buss governors had not sufficient stability, while, for instance, the stability of the governor, Fig. 5, was very great. Again, with regard to the same governor, the Author had stated that with only 4 per cent. increase in speed it overcame a pressure of 200 lbs. He thought there was some confusion in terms, as the stability of a governor was quite distinct from its power. A governor of great stability might be deficient in power, and a powerful governor might be devoid of stability. The meaning of "stability" should therefore be explained, or the term should be eliminated and replaced by others that conveyed a distinct meaning. The Watt governor would require, as the Author had correctly observed, a great increase in speed to open it through a large angle. Nevertheless it had very little power. That resistance to follow the increase in speed the Author had called stability, and thus ascribing to it stability which, in other parts, he denied the governor altogether. He thought it would be well to adopt the term "static" as descriptive of the sluggish behaviour of governors, as adopted by eminent writers on the subject. A governor was called "static" if it only answered after a great increase of speed. That was a very convenient term, as there Mr. Kühne.

Mr. Kühne. was also the corresponding term "astatic" used to describe opposite behaviour of the governor, as the Author had used it in regard to Fig. 4. The term "astatic" for that behaviour would be more suitable than the term "isochronous," used by him, because the latter word indicated that the angular opening of a governor would be the same for every equal increase in speed. As the Author had correctly observed, the astatic governor, was useless as it flew through its whole range at the slightest provocation. The proper behaviour of a governor, so far as sensibility was concerned, was called "pseudo-astatic," or very nearly astatic; the nearer a governor approached "astasy," the smaller would be its regulating interval, viz., the increase in speed required to bring the governor from its lowest to its highest position. That static or astatic behaviour of a governor was, however, quite independent of its power, or, as he preferred to call it, energy. The energy of the governor was dependent on the masses held in suspension, whether those masses were represented by dead weight or spring load. That accounted for the smaller energy in the Watt governor, in which the balls themselves were the only masses in suspension, and at the same time explained why a loaded Watt or Porter governor developed more energy. A spring load was more effective still, because it permitted of a great power in a comparatively small space. The power required to compress a spring was also confused with the regulating power or energy of a governor. It had been stated by the Author that the governor, Fig. 5, with a change of 4 per cent., had a lifting- and a forcing-power of 100 lbs. That was an impossibility for a governor having balls revolving at a radius of 4 inches and 8 inches respectively. If a spring governor were revolved at a constant speed, the balls would diverge, and the centrifugal force would balance that of the spring. Although there might be at such a moment a pressure of hundreds of pounds upon the spring, none of it was available for regulating purposes except when the speed varied, and then it only amounted to the balance between the two forces. With regard to the governor, Fig. 17, the late Dr. Proell had made calculations from its dimensions, and the result had been that at the lowest position, with a variation in speed of 2 per cent., the governor developed an available regulating energy of about 6 lbs., in the mean position about 11 lbs., and in the highest about 15 lbs.; also the governor would begin to open at 266 revolutions per minute, would take up its mean position at 295 revolutions, and its highest position at 312 revolutions; so that there was a total regulating interval of 17 per

Mr. Kühne. cent. in the governor. As compared with the Author's statement, that the governor overcame a further pressure of 200 lbs. with a variation of 4 per cent., there was a wide discrepancy. Returning, however, to the governor shown in Fig. 5, he had been astonished to find it stated in the Paper that the Author had introduced not only that form, but the straight path of the balls in 1869. Perhaps the Author would indicate where that particular form of governor had been introduced. The other form, Fig. 12, was the only approach to it which had been published; but no reference had been made in any description of it to a straight path. Under those circumstances, it could not be said that the Proell weight-governor was a variety of that shown in Fig. 5. He considered that the Author's statement that the action of the balls was similar was erroneous. With reference to the date of the introduction of the Proell weight-governor, showing that it was 1871 and not 1884, he had placed on the table a signed patent drawing bearing the former date. With regard to the lifting- and forcing-power, these seemed to the Author to be two distinct qualities of a governor, whereas they were identical, seeing that every governor exerted the same power in rising at 2 per cent. increase of speed as it did in falling on the same decrease of speed. He preferred to call that lifting- and forcing-power energy. The form of governor which the Author had illustrated was a special one, used in connection with the Proell expansion apparatus, and comparatively few had been made. Tens of thousands were, however, in use of the form shown in the patent drawing, or a slight modification of it. He wished to append the following Table of performances of the Proell governor:—

LIGHT WEIGHTS.

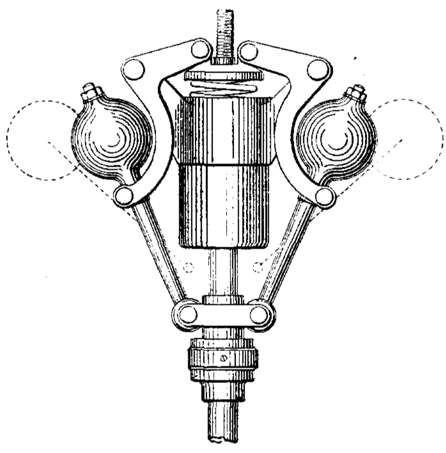
Weight of governor . . lbs.	43	72	120	170
Lift of sleeve . . . inches	$1\frac{5}{8}$	2	$2\frac{5}{8}$	$2\frac{3}{4}$
Energy at 2 per cent. alteration of speed . . lbs.	1	2	3	4
Revolutions per minute . .	120	100	90	80

HEAVY WEIGHTS.

Weight of governor . . lbs.	80	108	170	240	260
Lift of sleeve . . . inches	$2\frac{1}{4}$	$2\frac{1}{2}$	3	$3\frac{1}{4}$	$3\frac{1}{4}$
Energy at 2 per cent. alteration of speed . . lbs.	2·6	4·0	5·0	6·8	8·6
Revolutions per minute . .	145	130	115	107	120

Mr. Kühne. The above governors had also been made with four balls, having an energy as great as 56 lbs. at 2 per cent. variation. As an advantage of those governors, it should be noted that that energy was developed at a moderate speed. For an alteration of speed of 4 per cent. the energy was doubled, and for 1 per cent. halved. He did not think that for a weight-governor that regulating power should have been called "practically nothing." For equal size the Proell weight-governor had about twice the energy of, for instance, a Porter governor. It had been further stated by the Author that the Proell governor required a dashpot. Apparently he meant an air- or oil-brake, as by a dashpot was usually understood a cylinder with a piston to prevent shock. First of all, the Proell governor needed a brake only under special circumstances where its sensitiveness would be too great. He did not think that 10 per cent. of all the Proell governors were provided with a brake of any kind. He could not agree as to the purpose of a governor brake. Let a governor having a total regulating interval of 2 per cent. be considered to be applied to an engine that was not quite balanced or that had a light fly-wheel, then the inherent differences of turning the engine might be larger during every stroke than 3 per cent., and the engine would cause the governor to hunt. At the beginning of the stroke there was the full impulse, at the end the momentum was spent, but in the meantime the sensitive governor had passed through its whole range. As the Proell expansion apparatus had been originally designed for application to old engines, such occurrences had to be guarded against, and that was the reason why its governor was once for all supplied with what the Author had called "something in the nature of a dashpot," which, however, experience had proved to be the most efficient air-brake that could be devised. With good workmanship air-brakes of that kind would almost prevent the governor from rising with any increase of speed if the air-screw were quite closed. Between that and the air-screw quite open, it was easy to find a medium position, such that the governor was prevented from following the impulses of the engine too quickly, and was kept in position until a new impulse could be given. A perfect governor should, the Author had said, require no dashpot. That statement conveyed no meaning, as no governor would answer every condition. To place a governor with 1 per cent. regulating interval on an engine, driving, for instance, stone crushers, would not be proper. The finer the regulation was intended to be, the more astatic the governor must be made, but the greater was the need for an efficient brake. A static governor, such, for instance, as had regulating intervals of 17 per cent., could regulate a badly-balanced engine without a brake, because it was indifferent to slight variations. He could not agree in the statement that air was a less effective medium for governor-brakes than oil. The brake should not stop the freedom of the governor, but only restrict it. A spring had even been interpolated, as in the Buss governor, between the governing lever and the oil-brake to produce an elastic motion at that point, and the finest regulation was the result as nearly astatic governors could be used without fear of hunting. It was evident that a brake that used an elastic medium like air, and that did not require such spring, was preferable. If the Author had used Mr. Kühne.

Fig. 29.

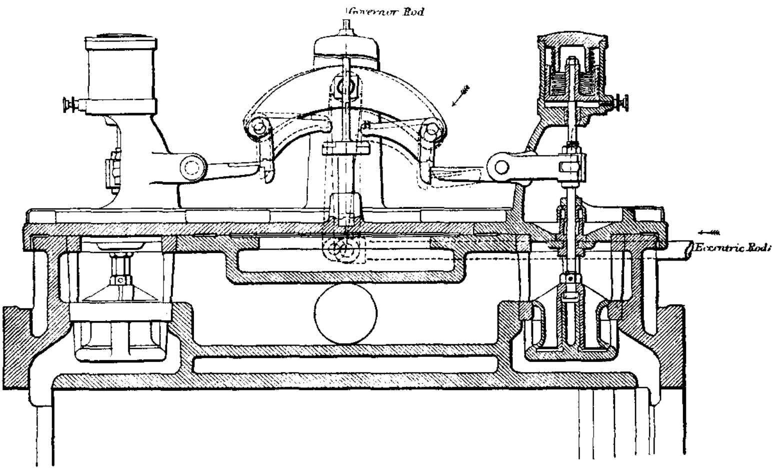


oil-brakes, such as he had illustrated, with stuffing-boxes at the top, he could understand why he had such a bad opinion of dashpots. The stuffing-box was useless, as the oil displaced on the top would be drawn in by the pipe to the bottom. He would, however, mention that the Proell weight-governor was no longer used by Dr. Proell's licensees, not because it was a bad governor, but because the Proell spring-governor, while retaining the fine astatic properties of the old form, gave about three times the energy for the same weight. The specimen exhibited, *Fig. 29*, weighing about 2 cwt., developed an energy of 21 lbs. for an increase of 2 per cent. in speed. A Porter governor, to give out the same energy, would weigh $\frac{3}{4}$ ton. The power required to compress the spring when the balls were quite

Mr. Kühne. open was 1,781 lbs. He did not, however, consider that as regulating power. In the governor exhibited was introduced for the first time the straight path, which the Author claimed for so many of the governors described. That important property, however, not only gave excellent regulation in connection with such an arrangement of spring as Dr. Proell had designed, but also enabled the governor to work in any position. He did not think that the best results would be obtained in working the governor shown in Fig. 17 horizontally, because the influence of gravity was not eliminated in any governor with rising and falling balls. He did not understand the Author's meaning that a throttle-valve reduced the power of an engine, for that was only possible if a throttling engine was furnished with a throttle-valve of too small steam-passage. All important factors, such as size of ports, laps of slide, throw of slide being equal, the throttling engine must give out the same power as an expansion engine, if the throttle-valve were fully opened by the governor, so that the passage for the steam through it was equivalent to the size of the ports. If that were not the case, the throttle-valve was too small. With reference to the indicator-diagrams, *Figs. 13, 18*, and *21*, he thought it detracted somewhat from their value that no atmospheric line nor scales had been given. It was impossible to check the diagrams under those circumstances, and he, therefore, would only express an opinion about *Fig. 18a*; to obtain which there must have been exceptional phenomena in the cylinder. The only conclusion was, that there was condensation and re-evaporation. Although he agreed that the double-beat valve was the best for the purpose, he took exception to the statement that the power to work them was insignificant, and that the steam-pressure was irrelevant. A valve to work with a 5-inch steam-passage had, for instance, an unbalanced surface of 4·3 square inches. It would, therefore, with 50 lbs. per square inch, require a pressure of 215 lbs. to detach it from its seat, while with 120 lbs. per square inch it would take 516 lbs. He could not share the opinion that the variety of the Sulzer gear, shown in Figs. 19 and 20, had any advantages over the original or over many other gears, in which he thought he might include the Proell gear, which was represented in the model on the table. There were no less than nine points of friction which had to be acted upon by the governor, before an alteration in the expansion could take place in the Robey gear, whereas in the Proell gear there were none.

It would be seen that at the point of the opening of the valves the vertical part of the bell-crank B, *Fig. 30*, pressed upon its lifter and opened the valve at a time when the tail-end of the bell-crank was not in contact with the tripping-pad of the governor-rod; therefore, the pressure required to open the valve could in the Proell gear be neglected, because it was given out in a positive manner by the engine itself and could not re-act on the governor. When the valve was once opened, it was balanced, with the exception of the slight pressure of the closing spring. The governor in the Proell gear was therefore perfectly able to effect a variation of the expansion even during the stroke, because the governor was free to move and would trip off the valve at any point when the tripping-pad and the tail-end of the bell- Mr. Kühne.

Fig. 30.



crank met. In the gear shown on the Author's cylinder it was admitted that the fulcrum of the valve-lifters was pushed down and so held rigidly in position, the movement of the fulcrum (upon which the alteration of the expansion depended) having to take place during the interval when the valve was not being lifted. He thought that was a disadvantage of the Robey gear. Supposing that such an engine worked for a time with an average cut-off of five-eighths; then the engine would be under the control of the governor only for three-eighths of the time, and the governor would be blocked for five-eighths; if then an alteration of load took place at the beginning of a stroke, the governor would be blocked and could not respond to the altered speed until a cut-off had taken place at the full five-eighths of the

Mr. Kühne. stroke, whereas, perhaps a cut-off of only one-quarter had been required; if the governor were at all sensitive it would, on its release, fly wide open, and then very likely admit less steam than would be required for the return stroke, because, at the moment when the valve opened, the action of the governor was again eliminated until the valve became once more released. It was therefore evident that any but a very static governor, if controlling such a gear, would be sure to hunt, while on the other hand a static governor was useless for close regulation.

That it could be put out of action by a cord had been stated by the Author as an advantage of the Robey gear; but he did not consider that a desirable or reliable means for the purpose. If, for instance, a cord were carried to every room of a large cotton-mill, there would be required such a length of sagging cord, running over many pulleys, that it was difficult to imagine that such a scheme had ever been carried out in practice. The Proell gear lent itself easily to the application of an electric stop-gear. If by means of an electric current the armature of an electro-magnet were attracted, a catch could be released, a weight dropped, and the tail-ends of the bell-cranks raised so high that they could not come into contact with the valve-lifters and the valves would remain closed. This scheme had the advantage of being perfectly reliable, and had been carried out in many instances with perfect success; the electric wires could be led anywhere, and the use of elastic cords and pulleys could not be compared in certainty of action with this arrangement.

The question of governing engines was of such importance that he thought the Institution should take it in hand. The Royal Agricultural Society had arranged tests of steam-, gas-, and oil-engines, to the great advantage of those industries and the agricultural interest. He ventured to submit that the engineering and manufacturing communities had an equal interest in seeing the question of regulating engines settled by competitive tests, under rules laid down by the Institution and under its control.

Prof. Unwin. Prof. W. C. Unwin said the subject under discussion was one of so much complexity that he should have been glad to escape the necessity of speaking on it. The Author clearly had had considerable experience in the use of various governors, and he had brought forward some of his conclusions from practical experience in the Paper. It was only fair to point out that while the Author had put forward some very definite conclusions, he had often failed to give any reasons

Prof. Unwin.

for them. Taking a single instance, the Author, in referring to a governor with an air-dashpot, said that no dashpot ought to be worked except with incompressible fluid. That might be true or not, but no reason was given for the statement. He thought the Author was not very well acquainted, or had not cared to show that he was acquainted, with a good deal that had been written on the subject. On p. 212 he had mentioned an exceedingly valuable Paper by Mr. Ransom, on an experimental investigation in which the true action of the governor was determined by exact observations. There were three Papers[1] by Mr. Ransom, and the one quoted was perhaps not the most important. The Author had also quoted a Paper in the Proceedings of the Institution by Prof. Dwelshauvers-Dery. There were three Papers by that gentleman, and in addition to that, there had been a later investigation published within the last year under the title of "The Dynamical Study of Steam-Engines."[2] The Author had first mentioned the Watt governor, and stated that, although it might prevent an engine running away, it had really no regulating power. In one of Mr. Ransom's Papers an account was given of experiments with six or seven of the most reputed governors—the Porter, the Buss, the Pickering, and others, and it appeared from the results given that the only governor of the whole series which really gave a trustworthy regulation was the old Watt governor. He did not wish to draw the universal conclusion that the Watt governor was better than all the others. He merely said that the Author's statement that the Watt governor had no regulating power was put much too positively. In Fig. 4 the Author had shown a governor which he said he had designed about twenty years ago. In looking at it one recognised what at any rate was very commonly described as the Farcot governor. He did not positively know at what date that governor was first used by the inventor, but it was described in Callon's "Cours de Machines," published in 1875, as a well-known form of governor. He therefore suspected that it was earlier than the "twenty years ago" which the Author had mentioned. The ordinary throttle-valve with a disk pivoted in the centre had been referred to by the Author, and he said that it was simple in construction and easy to move. He had no doubt that when it was

[1] Minutes of Proceedings Inst. C.E., vols. xcviii. cix. and cxiii.

[2] "Étude expérimentale dynamique de la machine à vapeur," by Prof. V. Dwelshauvers-Dery, published by Gauthier-Villars et fils, Paris, 1894. Also Minutes of Proceedings Inst. C.E., vols. xciv. civ. and cx.

Prof. Unwin. first used it was supposed to be a balanced-valve, but it was not a balanced-valve, and was not easy to move except in very small sizes. The action of fluid rushing past an oblique plane showed that nearly all the pressure was concentrated on the anterior edge, and that there was very little pressure on the parts which were more sternward. The ordinary throttle-valve was not even approximately a balanced-valve, and except in small sizes, it was not easy to work. He supposed it was from that that some of the difficulty had arisen in using an ordinary governor with small effort in working an ordinary throttle-valve. The Paper as a whole was no doubt a plea for the use of automatic governing. No criticism was considered by the Author too severe for proceeding in any other way, although it had been known for a long time that the economical advantage of automatic governing had been in general much exaggerated by engineers. In the majority of cases there was no doubt an economical advantage, but it was usually only a small one. He supposed that from the greater beauty of the mechanical arrangement, automatic governing would probably be the most largely used, but he was persuaded that the economical advantages had been greatly over-rated.

With regard to the special problem in governing the speed of an engine, there were two sets of causes of fluctuations of the speed. There were causes which could be classed as periodic, occurring within the time of a revolution, and causes which were aperiodic. So far as the periodic causes of variation of speed were concerned, a governor could have no action whatever. The governor could not regulate the engine within the time of a revolution, and it was the fly-wheel alone that must be depended upon to neutralize to a large extent those periodic fluctuations of effort, and as far as possible to remove them from having any effect upon the governor. They resulted, of course, from the variation of the steam-pressure in the stroke, and from the variation in position and velocity of the working parts of the engine. With regard to the aperiodic causes of fluctuation of speed, the fly-wheel also had a very important function. It could not prevent the fluctuations of speed due to those, but it could make the variations so gradual that it was possible for a governor to control them. He did not believe that any consideration of governors was valid if it did not proceed with the simultaneous examination of the action of the fly-wheel and of the governor. As to the governor itself, it was troubled first by the circumstance that it could only have effect on the regulation of the engine during the period of admission of steam, which was only a fraction of the revolution, and next, that in proportion as it was made sensitive, and capable of sensitively regulating the speed, its power of overcoming the frictions and so on, which could not be altogether avoided in any form of mechanism, was reduced. There was one type of valve-gear which could be extremely well controlled by any good form of governor. Any form of trip valve-gear could be controlled by a governor, so as to produce very considerable accuracy of speed; but in regard to any other form of valve-gear, in which the governor must exert more or less considerable effort in effecting the regulation, he thought the problem was one of great complexity and intricacy. He would only say that apart from engines using trip valve-gears, he believed the real solution of the problem of governing accurately lay in the use of the relay. If the governor be regarded as a pure thinking machine, and threw all the work of governing on some relay, there was a possibility of securing any accuracy of speed that might be desired. He might be told at once that relays had been tried over and over again, and that they had one universal fault of hunting. That was perfectly true of a great many relays that had been used. The relay had been used in a great many cases without any insight into one of the conditions absolutely necessary if relays were used at all. In most forms of relay regulation which had been used, the governor started the relay, and the relay went on acting without any control till, by the alteration of the position of the governor, it was thrown into action in an opposite direction. It was impossible to avoid an extreme form of hunting with a relay governor of that kind. If a relay were used at all, it should be used much in the form in which it was used in the steering-gear of a ship, where the captain turned a small wheel which gave the signal to the relay to get into action; it also told the relay to do so much and no more. The relay came to a stop when it had turned the rudder over to a certain small extent. The captain then considered whether enough had been done; and if not, he gave a further signal, and the relay did a little more. It was only when the relay was used in that form that it could properly control the speed. Governors of that type had been used—hydraulic and ratchet relay-governors—to control large sluice-valves of turbines with remarkable accuracy. These turbines were used for driving dynamos in electric-lighting installations, where the load was necessarily varied. The dynamos ran with great regularity of speed, and the whole secret was, first, that the force required to do the regulation was thrown entirely upon the Prof. Unwin.

Prof. Unwin. relay, and, secondly, that the relay was of the steering-gear type. It had been stated that if a relay-governor of the steering-gear type were used it could not be isochronous. In general it was not desirable that a governor should be isochronous, but it was possible that a relay-governor could be virtually so if necessary. The automatic action of the relay in coming to rest after being started by the governor had been made also to readjust the position of the point of suspension of the governor arms. Thus, if the speed of the motor increased, the governor height diminished, and the relay was started. As the relay acted, it automatically came to rest again, and simultaneously corrected the error of governor height.

Mr. Swinburne. Mr. JAMES SWINBURNE said, with regard to what had been called the power or the energy of the governor, it seemed to him that the principles of mechanics should be looked to. In the case of a rotating governor, which compressed a spring with a certain force, any increase in speed must give a certain increase of that force on the spring; and the result was that, whatever form of governor was used, if there were 1 per cent. increase of speed, it would give 2 per cent. increase in the force on the spring. The force on the spring, the force lifting a controlling weight, or whatever it might be, was not, of course, the only factor. It was necessary to consider the distance through which that force could be applied when the governor moved as far as it would, in spite of the opposition of the valve-gear, and see what energy could be obtained in that way. In comparing different governors, such as those in Figs. 1 and 4, it was not fair to put everything down to the form of governor. It should be remembered that the governor in Fig. 4 was revolving much faster than that in Fig. 1. If the latter were driven fast enough, and loaded with a spring, it would give a great "effort"—a very good term to use, "energy" and "power" having other meanings. In making calculations as to centrifugal force in governors it must not be assumed that a ball acted as if its mass were concentrated at its centre. Perhaps some such inaccurate assumption had led to the discrepancies observed. He should like to accentuate the remarks of Professor Unwin on the question of relays, with which was largely involved the question of the hunting of governors. No one before Professor Unwin had pointed out the difficulties arising from governors tending to hunt. The governor might be made isochronous, or it could be designed in the other direction, like the Watt governor, Fig. 1, so that there was a very large variation of speed needed to produce any considerable variation in the position of the balls, or

Mr. Swinburne.

it could be made a compromise between the two. Even when it was intended to make an isochronous governor, it was made not quite isochronous. An isochronous governor obviously would give very little effort. Therefore, in working with it, it was necessary to have some form of relay. A non-isochronous governor, on the other hand, as pointed out in the Paper, would not regulate perfectly with regard to speed, because with different loads it had to be in different positions to control the steam perfectly, unless, of course, it was worked as a relay. But any governor, such as Fig. 1, working with a relay, at once became an isochronous governor if the distance through which it had to move was made sufficiently small. A relay-governor did not necessarily mean a governor that hunted. The other extreme might be reached, and what he had previously called a "hit and miss" governor be used.[1] It could be so made that if the speed were the least above the normal there would be no steam at all, and if the least below there would be full steam. That, of course, was used in the gas-engine, but the difficulty there was that the engine speed varied with every stroke of the piston; there was a jump, as in the case of the gas-engine, and in many cases such a system would be useless. But if an engine were small and fast enough, that no longer held, as, for instance, in the Parsons engine. When steam was admitted the engine was fully loaded; when it was not fully loaded no steam at all was taken. The method gave an efficient engine and very perfect governing, but the system obviously could not be applied to an ordinary steam-engine, and relays must then be employed. A following relay or steering-gear relay might be employed, but that would only work on a governor of the type of Fig. 1, which was not isochronous. A steering-gear relay could not be used with an isochronous governor; therefore, for a following relay a governor which did not control perfectly as to speed must be employed. The difficulty had been solved in the Knowles system, in which two governors were used, one a non-isochronous governor, and the other a secondary governor to alter the valve-gear in such a way that the non-isochronous governor worked at its normal position, and therefore at its normal speed. There was no reason for using a double governor for such a purpose, and he had seen in France a single governor which did the same thing. It might be called a Watt governor, acting directly on the valve; but immediately it moved from its normal position it also put into gear a screw

[1] British Association Report, 1894, p. 758.

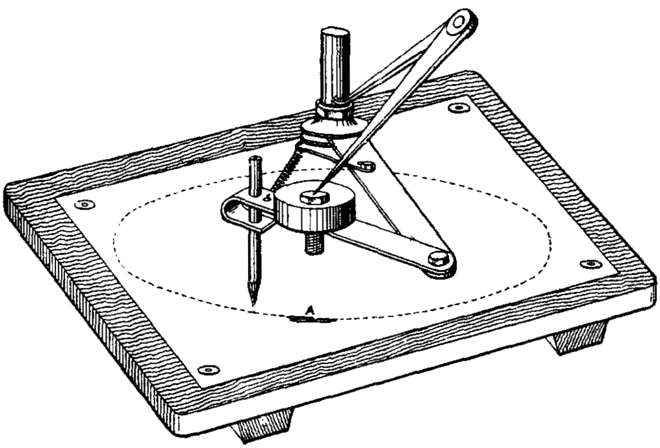
Mr. Swinburne. and catching relay of small dimensions that altered the length of the valve-rod, until the governor, in spite of the large variation of load, still controlled the engine at its normal position. In reference to dynamos, a question often arose as to whether the engine should be controlled by the torque. The idea was that if an engine were controlled by the output of a dynamo it was controlled before the variation took place. But if that were carefully examined, it would be found that the system was in unstable equilibrium. A governor could not be made to control in that way only; it must also have a speed or an electrical pressure component. With reference to the compound-wound solenoid as a means of overcoming the necessity for a pilot-wire, he remembered being exceedingly pleased in 1887, when he thought he had invented it; indeed, he felt very proud of it, until he found Dr. Hopkinson had invented it before him in 1882.

Mr. Wingfield. Mr. C. H. WINGFIELD observed that the Author had stated, with reference to Fig. 5, that "the lengths of the arms are so proportioned that the balls diverge in nearly a straight line for a considerable distance." He should like to ask the Author why that was advantageous. He supposed it was because this motion was owing to the point of suspension being at infinity. It had been stated by the Author that all attempts to give stability to a governor, by means of a dashpot, were but expedients to minimize an evil, which might and could be entirely eliminated, and he appeared to consider 10 per cent. as a fairly good result when governing without a dashpot. By adding a dashpot to a very simple form of spring governor Messrs. Thornycroft had been able to govern electric-light engines to within 3 per cent., even when all the load was thrown off. He thought, therefore, that a dashpot was a very good way of "minimizing the evil," if it were properly applied. A valve had been recommended by the Author which came down on its seat and shut the steam off entirely in that way in preference to a valve which was free to move a little further while keeping the passage still closed. If the engine suddenly began to race and the valves were shut down sharply and enough steam was left in the chest to increase the speed still further, a very strong spindle would be necessary with a powerful governor; in fact, the parts generally would have to be a good deal heavier than they needed otherwise be. A strong spindle required a large stuffing-box and caused greater resistance, and therefore an increased liability to hunt. Although the Author preferred the dead-beat valve there was still something therefore to be said for

Mr. Wingfield.

the other. It was interesting to learn that with a governor which acted by shifting the eccentric the speed increased before settling down, but that, with a governor acting on a throttle-valve, it decreased before settling down. It would be well to know if that were generally the case, and if in all forms of expansion governors the speed increased before settling down. Another point which he had some difficulty in agreeing with had been slightly alluded to by Dr. Hopkinson. The positions of the weights and the strength of the springs had been stated by the Author as not working out strictly according to the recognized laws of centrifugal force. In *Fig. 16* the theoretical radial force was shown by straight dotted lines, which, if produced, all converged to a point

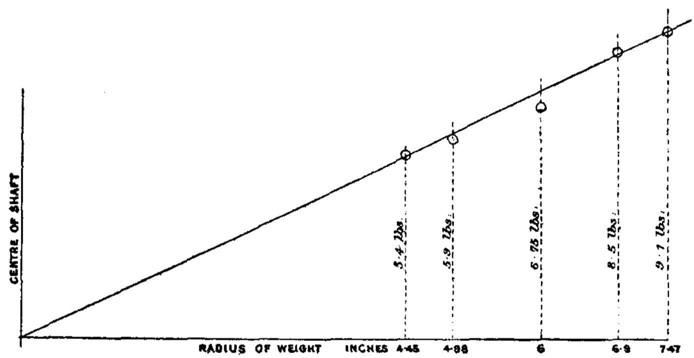
Fig. 31.



about $4\frac{1}{2}$ inches to the left of the figure. The full straight lines came to a point considerably to the right of this. Of course, where they came to a point there was no centrifugal force, and this would be the case if it were possible to place the balls at the centre of the spindle. If the black lines were correct, however, there was a second position—when the balls had diverged about half their maximum distance—at which there was no centrifugal force. He thought there must be some mistake in the observations which gave such a result as that. He had that afternoon made some experiments with a small apparatus, shown in *Fig. 31.* It consisted of two light arms jointed together, one of which carried a weight representing a governor ball, the other having a spindle by which it could be attached to the chuck of a drilling-machine

Mr. Wingfield. and caused to rotate at a constant angular velocity. When it was spinning round the weight tended to fly out, a tendency which was resisted by a spiral spring, the position of which could be so adjusted as to allow the weight to stand at different distances from the axis. He desired to measure the force acting in a direct line between the spindle and the centre of gravity[1] of the weight and arm, and the radius of the circle in which the weight was revolving at the moment this force was exerted. For the latter purpose he attached a pencil to the movable arm carrying the weight, and on the table of the drilling machine a piece of paper was placed. The apparatus was gradually lowered, while revolving, until the pencil made a scratch upon the paper. In some instances several scratches were exactly over each other, and in others they varied about a quarter of an inch as at A, *Fig. 31.* With a pair of hermaphrodites he was enabled, after the

Fig. 32.



machine was stationary, to measure the radial distance by placing the pencil on the spot, or on the mean position of the spots, it had made on the paper when it was running. To measure the force he attached a piece of string to the bolt by which the weight was fixed, and, by a spring-balance to which the other end of the string was fastened, he stretched it in a radial line, passing through the centres of the weight and of the spindle, till the pencil was again over its marks when the load on the balance was then read off. This was a very rough experiment, but he was surprised to find how accurately the results plotted on a straight line, *Fig. 32.* He was not, however, surprised to find that

[1] The position of the weight was such that its centre of gravity and that of the arm were coincident, and were at a radial distance from the axis approximately equal to the radius of gyration.

the straight line ran in a similar direction to the dotted line in *Fig. 16*, and had no resemblance to the full lines. It intersected the base at the centre line, which represented the centre of the spindle. One of the spots fell off the line, but four others were practically upon it. He hoped the Author would explain the way in which the position of the black lines had been determined, and also how the experiments were arranged which appeared to confirm them. Mr. Wingfield.

Mr. Richardson. Mr. J. RICHARDSON, in reply, before dealing with the criticisms in detail, said that there had been probably no fewer than fifty governors invented every year for many years past, and that, as the Paper referred to the past twenty-five years, it was manifestly impossible to mention more than a very small number of those inventions. To these circumstances alone must be attributed the fact that certain governors mentioned by various speakers had not been referred to at all. He had therefore confined himself to such classes as had come under his personal observation. Referring to Captain Sankey's remarks, he was so far in agreement with him, that he recognized the advantage of simple throttle-valve governors under certain conditions, but none of them gave results equal to an equilibrium valve-gear combined with a good governor, and none that he had tested were equal to a plain slide-valve combined with a good shaft-governor. He admitted that there were many good points about the valve, Fig. 9; but, as had been rightly stated, if the cover on this valve be too small by $\frac{1}{1000}$ inch it would be too tight, and if too large by $\frac{1}{1000}$ inch it would be too slack. That being so, he saw no reason why such a valve should be used when there were others which would do quite as well and did not depend upon such extreme accuracy. The production of such accurate work was quite easy, but he did not consider it good engineering to design machinery in which such close work was essential to its success; and any piece of machinery which became imperfect or useless when it was worn to so small an extent, was not nearly so well suited to ordinary use as that in which a wider variation was permissible without interfering with its efficiency. With regard to the percentage of variation in governing, he would like to say that any record of a few minutes' or a few hours' test of the regularity of an engine indicated very little unless all the conditions were known. There were many governors and valves which would have maintained a speed within 1 per cent., or less, under certain conditions, *i.e.*, when the change of load was not a very large percentage of the whole. In the test of the Knowles

Mr. Richardson. governor, for instance, in which Mr. Druitt Halpin had used the Moscrop recorder, there had been a sudden variation of 150 HP. with a variation of $\frac{3}{4}$ per cent., but the total power was not stated. If it were a variation from 150 HP. to no load, in an engine the maximum power of which was 150 HP., the result was remarkably good; but if of an engine with a total of 600 HP., the result was good, but not extraordinary. He had frequently seen loads of 100 HP. suddenly put on and off a 400-HP. engine fitted with the gear shown in Fig. 19, without producing any perceptible variation of speed, and the shaft governor shown in Fig. 15, or the link gear in Fig. 17, would admit of such a percentage of load being put on or taken off, without a variation in the speed of more than 1 per cent. In the tests he had made the engines were in all cases driven with their maximum load at a definite speed, and with full admission, and no governor control at all, *i.e.*, with the balls in their lowest position; then, the variation was that shown where all the load was taken off, and the governor alone controlled. With regard to Mr. Raworth's remarks, comparative tests of English and American governors were given in Table I, p. 215. He had no doubt as to the accuracy of the results, but did not give the name of the American governor, because the tests were not carried out under the superintendence of the makers. Questions had been asked as to the meaning of *Fig. 16*. He had said in the Paper: "The diagram, *Fig. 16*, shows graphically the relation between the calculated, experimental, and theoretical pressures of a spring resisting a certain centrifugal force." Assuming the total height of the *Fig.* to be represented by 100, the position of the various inclined lines all bore a relation to this number. Now, if a known weight revolved at a given radius and at a definite speed, it would have a certain centrifugal force, and when removed further from the centre it would have a proportionately greater centrifugal force, which might also be obtained by calculation. The theoretical line was obtained from such results, and was represented by the dot-and-dash line in the diagram. The different heights of the two ends of this line showed the different tensions of the spring required to balance the centrifugal force at the inner and outer positions of the revolving weight, provided that such weight were quite free to move outward, except in so far as it was controlled by the spring. But when the weight was of the form shown in Fig. 15, in which one end was secured by a pin, it no longer acted as it would if free to move in its entirety, and experiment showed that if a spring corresponding to the different distances of weight were used, the governor hunted badly, and by experiment a spring was found which just allowed a variation of, say, 3 per cent. in speed. The spring so found by experiment was shown by the plain dotted lines. Mr. Richardson.

The results of three experiments were given in *Fig. 16*, one for a governor controlling an engine at 300, one at 250 and one at 200 revolutions per minute, and in all these cases a difference was found of half the smaller pressure of the spring, the higher pressure remaining constant. Of course with the balls thus balanced at all points they would stand indifferently at all points, but by adding double the percentage of variation in speed allowed to the greatest pressure of the spring, the line representing it took the position shown in the diagram crossing the theoretical line at the same point in all cases. This line represented the pressure of the spring as found by experiment. The black line was one nearly corresponding to it, and was called the calculated line, because in practice with such a disposition of weights and springs as shown in Fig. 15, the foregoing calculation gave at once the two pressures of spring required to secure governing within a percentage of 3 per cent. He did not, as one or two members appeared to think, claim to have been the first to introduce the shaft governor, but he believed that that shown in Fig. 12, which was first exhibited in 1869, was the first one used in England. Messrs. Hartnell and Guthrie had patented one some months before, though he believed that his was the first introduced to the public, and that for several years from that date, viz., 1869, it and the Hartnell governor were the only shaft governors used in England. It would be seen on reference to Table I, that at all pressures between 50 lbs. and 100 lbs. per square inch, first, the possible power developed was less with the American than with the Robey governor; and secondly, while the variation in speed with the shaft-governor was between 2·8 and 3·8 per cent. only, the variation was between 9·5 and 15·2 per cent. with the American governor under the same conditions as to engine and load. The amount of momentary fluctuation was in most cases greater with the American type, though at its lowest duty it was nil, while at 100 lbs. per square inch pressure it was 25 per cent., whereas with the shaft-governor it was less than 9 per cent. fluctuation. There was, however, one slight advantage possessed by the American governor. Although it varied through a wider range, it came to rest as might be expected somewhat more quickly. The 1 per cent. variation stated by some American makers for their governors was unattainable if the variation in load was so extreme as in the tests he had applied, Mr. Richardson. though such accuracy might be obtained easily by any good governor under more favourable conditions. He agreed that the compounding of dynamos was now so well accomplished that electrical regulation for varying speeds was not now so much needed for incandescent lighting in parallel, but for series lighting it was not only useful but was much used; and he was also surprised that it had not been more used for the purpose of meeting the sudden and great variations in load of electrical tramways. There was one incidental advantage in connection with electrical regulation, viz., that while the speed varied the cut-off remained practically constant and thus the engine was enabled always to work with the best distribution of steam. It was well known that there was one best point of distribution in compound or triple-expansion engines, and this distribution of steam could be maintained when the power of the engine was varied by varying its speed. With regard to the Willans electrical governor this was referred to on p. 212 of the Paper, and as he had been afforded an opportunity of taking part in the discussion on that Paper,[1] there was no need to repeat his views now. It should be remembered, however, that the Willans governor was fitted with an hydraulic relay of very ingenious construction, but with unnecessary complications.

The criticism offered by Mr. Rigg was interesting; the illustration of the Watt governor shown was not a working drawing, but merely a diagram illustrating the type. He quite agreed that it was a "non-sensitive governor working through an extremely small space," and that the governor shown in Fig. 17 was by far the best. With regard to Fig. 14, the present form was only about two years old, and was shown as a modification of Fig. 12, the principle of which was the same. His experience with shaft-governors only went back some twenty-five years, and he believed those of Mr. Hartnell, and that shown in Fig. 12, were among the first and were the only ones used for some years. With regard to the wedge motion adjustment, this was an independent invention so far as he was concerned, and he still thought it was then for the first time used in connection with a governor, though he had learned afterwards, what perhaps he ought to have known before, that it had been invented many years earlier and used as an adjustable hand-reversing gear. With regard to the position of the centres in Fig. 15, in order to place them where Mr. Rigg had suggested would require, as he rightly said, that

[1] Minutes of Proceedings Inst. C.E., vol. lxxxi. p. 202.

Mr. Richardson.

the diameter of disk should be considerably enlarged, and the position shown gave the advantage of more compact form, and the governing power was extremely good. He fully endorsed Mr. Rigg's remarks, that the best thing, "in order to get a governor to do its work well, was to give it nothing to do." This had been carried out with the governor and expansion gear shown in the model, and in Figs. 19 and 20. The power required to do all the adjustment from zero to $\frac{7}{8}$ cut-off was practically nil, so that the governor might be made extremely sensitive, as there was absolutely no strain upon it. With such a governor and valve-gear there was no difficulty in governing well to within less than 1 per cent., even without the supplementary governor alluded to by Mr. Druitt Halpin.

With regard to the best movement for throttle-valves he had in a few cases used one adjusted by turning upon an axis instead of sliding. It required very little power to move it, but it needed extreme accuracy to obtain a sufficiently good fit to prevent leakage, and still remain sufficiently free to prevent sticking. Further it had the disadvantage of requiring a weight or spring to pull it open so as to take up any backlash, a disadvantage which did not rule with the valve shown in Fig. 10. The disadvantage of a vertical sliding movement was less than appeared at first sight; the total vertical movement in this valve was about $\frac{1}{2}$ inch, and it took this every time the engine was stopped or started, while the amount of movement for adjustment seldom exceeded $\frac{1}{16}$ inch. It had been asked by Mr. Phillips how a governor could be made to increase the power of an engine, and at the same time economize steam. While the statement might seem paradoxical, the answer was quite easy. Governors had to deal with varying loads; an engine without a governor must be set to either the smallest load, the greatest, or what is more probable, the average. In the latter case, when a greater load was applied, the speed and therefore the power of the engine would fall; and when the load was reduced, the steam would be admitted at a less economical cut-off, and wasted in running the engine too fast; while, with a good governor, controlling either the throttle-valve or the expansion-gear, neither of these evils would take place, and an engine so fitted would be both more powerful and more economical. It had been asked whether he had seen the Thury automatic regulator used in Switzerland. He had not, but his attention had been called to an illustration of it. It was apparently a very good governor, and he had no doubt would work well. It would be seen that it had

Mr. Richardson. many features in common with the electric regulator shown in Fig. 28.

In reply to Dr. Hopkinson, it was hardly correct to refer to *Fig. 16* as showing a discrepancy between the recognised laws of centrifugal force and practical application. He had the greatest reverence for the ascertained laws of motion, but it would be admitted that there was a difference between the movement, and therefore, control, of a body free to move in all its parts, and the same body controlled and fixed by a pin at one point. The allowance that should be made for this, and other forces which came into play, would no doubt be easily calculated, but such a calculation would be tedious and liable to error. All that was given in the Table prepared by Mr. Wansbrough was a simple and very convenient graphical method of arriving at the same result. He desired to thank Dr. Hopkinson for pointing out how, in governing by electricity, it was possible to compensate for the loss of pressure over the resistance of the conductors in a simple way, and did not doubt that the way suggested would be very effective.

He agreed that the Proell governor was first designed in 1871. As he had stated, however, it was introduced into England through his firm in 1884, and he was given to understand then that it was a recent invention. He found on reference that the English patent was taken out in 1881. With regard to the question of stability, he meant by a stable governor, one which, when revolving at a definite speed, resisted any extraneous force to cause it to change its position, and which when forced from its position immediately returned to it. This quality was possessed in an eminent degree in the spring governors shown in Figs. 12, 15, and 19, and his experience with more than one hundred Proell governors had convinced him that this was a quality which that governor lacked. The fact that Dr. Proell's licensees no longer used the governor shown, but now used a powerful spring in connection with it, entirely confirmed his statement as to the superiority of the spring over weight- or gravity-governors. The dashpot (or air-brake, as Mr. Kühne had called it) was applied to the Proell governor to prevent the dancing of the balls, and had been introduced because such a governor needed it. Being merely an air-cushion, it did not answer its purpose perfectly, though it diminished the movement. Mr. Kühne's statement that the influence of gravity was not eliminated in any governor with rising and falling balls was correct, and it was for this reason that a governor like those

Mr. Richardson.

shown in Figs. 5 and 12 was preferred where the balls flew out in practically a straight line. The governor shown in Fig. 17 was also designed on the same principle, and when used in a horizontal position the sleeve was fixed and the centre spindle moved. He thought that experience in making or working engines showed that throttle-valves reduced their maximum power. There were practical limits to the relative size of a throttle-valve to an engine, and any such valve interfered with the free passage of steam, and to that extent reduced the power of the engine. If an experiment were tried with a throttle-valve of any size, it would be seen at once that there was a material difference between the maximum loads an engine could carry with and without such a valve.

With regard to the indicator-diagrams, they were given merely to illustrate the action and range of the valve-gear, and contained all the lines necessary for that purpose. The statement that there were fewer parts in the Proell gear was not correct, and the illustration given was not altogether a fair one. In counting the parts of the Robey trip-gear, Mr. Kühne enumerated every joint between the valve and the governor, whereas in the working paper model shown of the Proell gear the governor and its connections as used in actual practice were entirely omitted. His further statement that in the Proell gear there was no possibility of friction coming between the governor and the gear was also doubtful. When the bell-crank or tripper which depressed the valve lever was doing its work, one of its arms was depressing the valve lever and the other arm rested on the moving collar connected with the governor, and a very perceptible pressure was put on the governor at that time, tending to produce the dancing or oscillation objected to. On the other hand, in the Robey gear this lever or tripper was connected entirely with the eccentric rod, and did not touch the governor, which was thus quite free from the mechanical part of the valve gear, and had no work beyond a fine adjustment of the centre of the lifting lever H, Fig. 20, Plate 1.

The subject of the Paper had naturally and rightly been looked at by Professor Unwin from a theoretical and scientific standpoint, and such standpoint was a most important one. He had, however, in the introduction to the Paper stated clearly that as so much attention had been already given to the subject of governors from a theoretical point of view, he would confine himself entirely to the results of practice. It would probably be admitted that though some conclusions might have been

Mr. Richardson. arrived at, and stated without all the reasons being given for them, yet, that a set of conclusions arrived at upon a particular subject, through observations of the practical working of several thousands of examples during a period of over a quarter of a century, might at least rank as of equal value with those formed from the observations of a limited number of laboratory experiments and calculations. He stated this without in the least wishing to depreciate the value of such experiments. With regard to the dashpot referred to by Professor Unwin, that used in connection with a governor controlling expansion-gear was generally employed to prevent small and rapid fluctuations in the position of the governor while permitting a wide range of movement. This object could not be attained with an elastic medium filling the dashpot cylinder, because air offered but a slight resistance to very small and frequent movements, though it was a good regulating medium for large and slow movements. The contrary was the case when a piston, with a small hole in it, worked in a cylinder filled with an incompressible fluid. The small oscillations were prevented because the fluid could not pass rapidly from one side to the other of the piston, but the latter was perfectly free to take up its place in any part of the cylinder, the rate at which it could be moved being determined by the pressure upon it and the size of the regulating hole in the piston.

With regard to Fig. 4, though designed by himself, as stated twenty years ago, it was perhaps in culpable ignorance of either the Farcot governor or the book in which it was referred to. That a similar design had been made previously was by no means unlikely. Many of these governors were at work and gave good results in controlling throttle-valves, Fig. 2, but were of no use for expansion-gears where considerable power was required to move the working parts.

It had been rightly said "that the Paper as a whole was a plea for the use of automatic-expansion governing," but he did not go so far as to say that "there were no terms too bad to be used in regard to the want of economy in proceeding in any other way." It was, on the contrary, stated in the Paper that for many purposes such a valve as Fig. 10, *i.e.*, a throttle-valve, was all that was required. The advantage, however, of automatic expansion-gear was so well recognised that the method of throttle-valve governing was defended principally by those engineers who did not apply automatic gear. He agreed "that trip-valve gear could be controlled by a governor so as to maintain considerable accuracy in speed," but entirely differed from thinking "that in other classes of valve-gear the real solution of the problem lay in the relay." When such a relay as Professor Unwin had indicated had been used for any considerable length of time, and found to avoid hunting, his opinion might be modified, but not until then. On this subject it would be recalled that the Allan link-expansion gear, the Hartnell gear, and others of that class, as well as that shown in Fig. 17, did now govern "so as to produce very considerable accuracy of speed" without any relay being needed, and such relays were, in his opinion, quite unnecessary conditions to a good governor gear. The principal objection to slide-valve gears was not that they did not govern well, but that in large engines the movement of the valve absorbed too much power and necessitated a large and expensive governor. Relays, especially those controlled by electricity, doubtless, were useful in moving turbine sluices, but were not needed for governing engines. These observations applied also to a great deal which had been said by Mr. J. Swinburne, with whose other remarks he was in accord. Replying to Mr. Wingfield respecting the movement of the balls in Fig. 5, the reason why it was an advantage for the balls to diverge in a straight line, or, as it might be better described, "revolve in one plane," was that in so doing gravity was eliminated, as there was no weight lifted, and such a governor would work as well horizontally as vertically. The governor, Fig. 5, was an experimental form only of that of similar design shown in Fig. 12; two or three hundred examples had been made, and were in all cases used horizontally. Mr. Richardson.

He would like to correct an impression which seemed to have been conveyed, viz., with regard to the lifting- and forcing-power of the spring-governor, Fig. 17. Naturally the power of the governor did not correspond to the pressure of the spring only. When the balls were closed the spring was exerting a force of 216 lbs., when wide open the spring was compressed until it exerted a force of 416 lbs. While this was so, yet when a certain speed was attained the centrifugal force generated by the revolving balls just balanced the spring pressure at the lowest point, and as the speed increased of course balanced it at every point; but at slightly different speeds, the centrifugal forces were balanced only at one particular point of its travel, when this corresponded to a certain speed and no other, and a very considerable pressure was needed to force the sleeve out of this position for any distance, and it tended instantly to return to it. That governor

Mr. Richardson. therefore had the greatest lifting- and forcing-power which, when revolving at a speed corresponding to its lowest position, would require the greatest force to make it take up the highest position at the same speed, and, conversely, when revolving at a speed corresponding to its highest position, would require the greatest force to make it take up the lowest position. In some governors this lifting- and forcing-power was very small, but in such as shown in Figs. 17 and 19 it was very great, these being forms of governor which combined delicacy and quickness of action with great power.

Correspondence.

Dr. Anderson. Dr. W. Anderson desired to contribute a statement as to some successful governors he had met with in connection with the prize competitions of the Royal Agricultural Society of England. At the trials of thrashing-machines at Cardiff[1] in 1872, an eight-horse portable engine, by Aveling and Porter, was coupled direct to a rotary dynamometer through which the competing machines were driven. It was regulated by a high speed Porter governor actuating a butterfly throttle-valve which differed only from ordinary valves in the spindle passing through the valve about $\frac{1}{16}$ inch to one side of the centre, and the valve was so placed that the steam issuing from the boiler and acting on the unequal wing of the valve, always tended to open it. By this arrangement the proclivity of throttle-valves to stick, when quite closed, was so completely overcome that the engine did not vary 2 revolutions in 120 when the load was suddenly removed. At Newcastle[2] in 1887 a variety of governor gears fitted to the portable engines under trial were exhibited. The best was unquestionably the arrangement adopted by Messrs. Davey, Paxman and Co., both to their simple and compound engines. The valve gear consisted of a main and cut-off slide-valve, the latter deriving its motion from a link controlled by a Paxman high-speed governor. Each end of the link was connected to an eccentric, one giving a late cut-off and the other closing the admission ports altogether. The cut-off plate had twin parts with the object of reducing its travel. The governor controlled the speed absolutely, and did not permit the least hunting. A Farcot cut-off arrangement, applied to two of the engines, though efficient in regulating the speed on the average, did not prevent hunting. There were other varieties of governor

[1] Journal of the Royal Agricultural Society of England, vol. viii. 1872, p. 409.
[2] *Ibid*, vol. xxiii. 1887, p. 667.