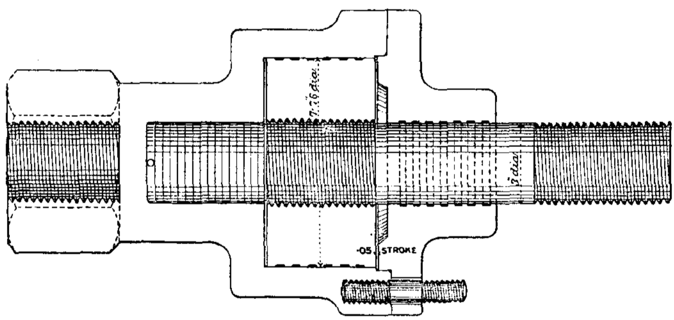
Discussion.

Mr. J. A. F. Aspinall wished to mention that most of the experiments referred to in the Paper were made in 1885, and some in 1886. The Paper had been considerably abridged, so that some of the explanations with regard to the progress of the experiments might not be quite as clear as they otherwise would have been; but he should be happy to give any additional explanation if required. The valves used were, of course, valves between the cylinders as illustrated in Plate 2, Fig. 1. He had no doubt that if experiments were tried with valves working on the top of the cylinders, or with valves under the cylinders, somewhat different results would be obtained. He regarded the whole series of experiments as of a somewhat tentative character. He had not been able to obtain much information upon the subject, and he hoped the matter would be fully discussed. He might mention that the chief difference between the diagrams taken with the Allen valve and the ordinary valve would be seen by comparing the Diagrams on Plate 3 with those on Plate 4. There was not the sudden rise with the latter which took place at the period of exhaust with the former. The serious drop, as between the boiler-pressure and the steam-chest, was due to there being too small a pipe. In the case he had mentioned the engine had a $3\frac{1}{2}$-inch steam-pipe, and it was not large enough to take the steam of 17 by 22-inch cylinders when the engine was going at so low a speed as 4 miles an hour. Mr. Aspinall.

Mr. W. Cross said the subject of the Paper was one, as the Author had stated, about which very little was known, and very few experiments had been published. The coefficient of friction 0·068 was extraordinarily low, especially as compared with ordinary marine practice, which was usually taken at 0·250. From the very careful manner in which the experiments had been conducted, there was no doubt that they were approximately true; but if so, how was it possible to account for the valve-spindles breaking, as they undoubtedly did in locomotives, and especially, as far as his experience went, in inside-cylinder engines? He had known two or three cases of valve-spindles of $1\frac{5}{8}$-inch diameter breaking. The valves were of brass, and the valve-spindles of the best Yorkshire iron. On changing the valves to cast-iron no further trouble was occasioned. He would not enter into the reason of it, but it showed that under certain circumstances the coefficient of friction must be enormously increased. It would Mr. Cross.

Mr. Cross. therefore be impossible, as would appear at first sight, to reduce to any great extent the area of the parts driving the valve. A few years ago his firm was engaged in running trial trips with a high-speed man-of-war. He believed that the vessel was one of the first fitted with high-speed piston valves. The dimensions were: cylinders, 43 by 82 by 36 inches; 116 revolutions per minute, indicating 6,500 HP.; both cylinders lp. and hp. were fitted with double piston valves, two to each cylinder. At certain speeds, with a certain number of revolutions per minute, difficulty was experienced owing to the vibration of the valve-gear. At about 90 revolutions per minute, the engine would run quietly, but at 100 it would be vibrating severely; at a gradually increasing speed the vibrations would die away altogether, and then at 112 or 115 revolutions, the vibration would be unsupportable. The matter

Fig. 1.



Indicating Cylinder for measuring Actual Strains in Valve.
Scale $\frac{1}{7}$.

was, of course, carefully investigated, and Mr. Marshall and he finally constructed the apparatus shown by Fig. 1. It was almost a reproduction of the Author's, except that there was no friction, and that they trusted only to mechanical fitting. The strains upon the two ends of the cylinders were exactly similar, as the spindle went through, and consequently the acting area was only the area of the brass piston. The stroke was exceedingly small, only 0·05 inch at each end. This dynamometer cylinder was fixed into the centre of the valve-spindle in the same manner as shown by the Author. There was an indicator at each end, the cord was fastened to some convenient portion of the valve-gear. The stroke of the valve connecting-rod being $7\frac{1}{2}$ inches, it was too much for the drum of the indicator; but by connecting it with some moving portion the stroke could be reduced to the amount required.

Various liquids were tried, but thick glycerine was found to be the most suitable material. The machine ran for many hours without giving the slightest trouble. The friction of the piston-valve, properly speaking, was practically nothing. The weight of large valves was very serious. The cylinders were originally fitted with piston-valves weighing 1,500 lbs. each, and it would be seen (Figs. 2 and 3) that the shock at the two ends of the stroke was exceedingly severe. They then stopped the experiments, and instead of having heavy cast-iron valves they made phosphor-bronze valves as light as possible, bringing the weight down to 500 lbs. Not only was the size of the diagram much reduced Mr. Cross.

Fig. 2.

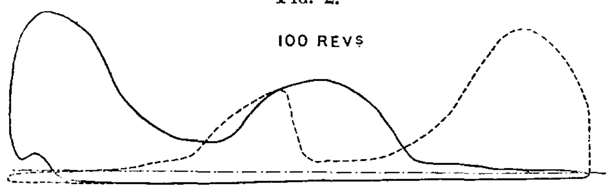
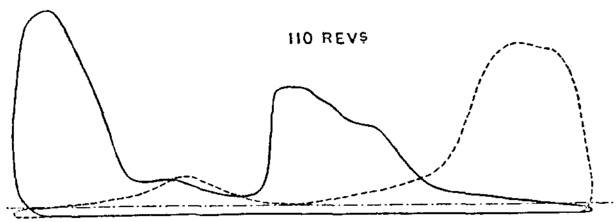


Fig. 3.



(Figs. 4, 5 and 6), but taking also into account the weight of the valves the shock upon the valve-gear was very much reduced. The result had been that, although the engines had been running some years, there had been no further trouble from this cause. The indicator-cylinder was fitted with a compensating arrangement, a kind of small by-pass valve fitted on the outside, whereby if the glycerine leaked from one end to the other, by stopping the engine it could be replaced in the centre. In some respects he thought the apparatus was an improvement upon the Author's. In the first place, he thought that the friction of the cup-leathers in the latter was extremely doubtful. It varied enormously with the age of the cup-leathers, the variation amounting sometimes to 60 or 70 per cent. As far as he could follow the Author's diagram, the dummy end of the spindle was not balanced, and consequently the areas

Mr. Cross. were different; but he presumed that a correction would be allowed for this. That the friction of the cup-leather had been excessive was shown in Table I, in the case in which the machine was tested by means of dead-weight. He therefore thought that the frictionless apparatus, trusting entirely to mechanical fitting, was decidedly superior for giving accurate results. He might be permitted to refer to a Paper read by his partner, Mr. F. C. Marshall, and his assistant, Mr. R. L. Weighton, on "High Speed Engines,"[1] in which the results of the diagrams exhibited were fully discussed. He hoped to hear something on the friction of different metals at

FIG. 4.

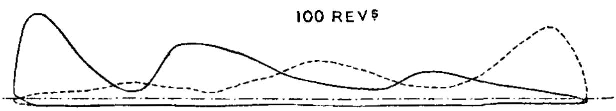


FIG. 5.

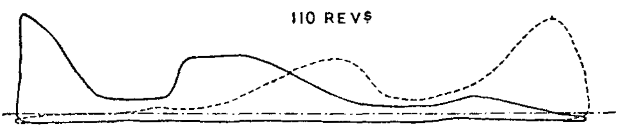
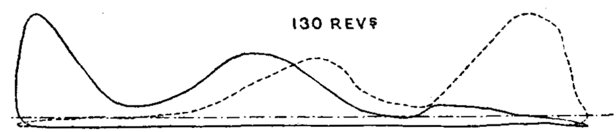


FIG. 6.



high temperatures; this was exceedingly important, especially for marine engineering in these days of very high pressures.

Mr. Halpin. Mr. DRUITT HALPIN observed that indicating an engine under the most favourable circumstances was not a pleasant thing, and indicating an engine under the difficulties described, running 40 miles an hour, was still less pleasant, and was often dangerous. The Author had referred to previous contributions on the subject existing when his Paper was written, but since then a communication on the same subject by Mr. C. M. Giddings, had been published with illustrations, diagrams and results, in the Transactions of the American Society of Mechanical Engineers,[2] 1886. The experiments

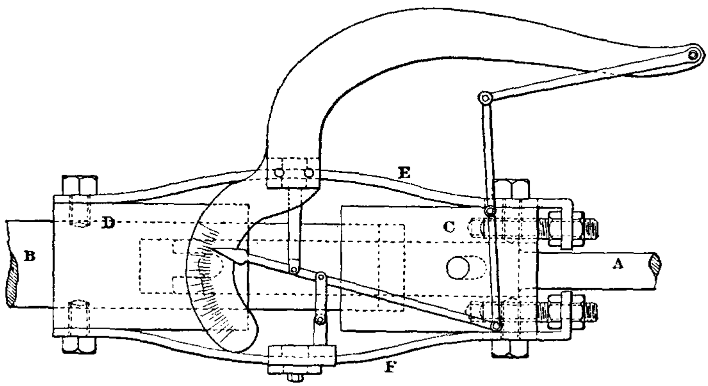
[1] Transactions of the North-East Coast Institution of Engineers and Shipbuilders, vol. ii. p. 287.

[2] Transactions, vol. vii. p. 631.

Mr. Halpin.

were made with the apparatus shown by Plate 2. Looking at the matter broadly, he certainly thought that the Author's results were almost too good to be true. Fig. 7 showed the general arrange-

Fig. 7.



ment of the instrument in side elevation. Fig. 8 was a diagramatic section on the centre line, illustrating the relative positions of the various parts of the instrument when a pushing force was applied

Fig. 8.

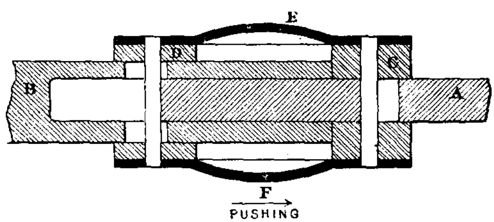
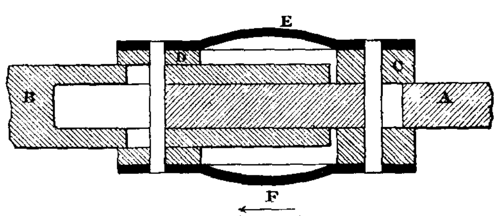


Fig. 9.



to it. Fig. 9 was a similar section showing the instrument under compression, and Figs. 10 and 11 were diagrams taken by the instrument recording the actual friction due to the valve and the

Mr. Halpin. stuffing-box. He should be afraid to design a valve-gear with the expectation of such very low frictions. Mr. Cross had referred to the errors that might arise by the use of the hydraulic cylinder with his packing, and Table II contained the results of the actual tests made by the Author, with the apparatus shown in Plate 2, Fig. 5, giving the calculated and the measured pressures. Taking the first, the calculated pressure was 12 lbs., and the recorded pressure 5 lbs., being a difference of 138 per cent. Taking the last, the calculated was 65 lbs. and the recorded pressure 49 lbs., or a difference of 33 per cent. These differences occurred when the apparatus was at rest, and might become magnified when it was in motion. He had plotted out the whole Table graphically,

Fig. 10.

Fig. 11.

and the result was a straight line, showing that the friction was pretty uniform. Still it was a large amount, and, of course, it was a varying amount, taking the condition of the packing leather into consideration. The apparatus used by Mr. Giddings was very ingenious and simple. Unfortunately the results obtained could hardly be checked. One of the engines was a small engine with a $6\frac{3}{4}$-inch by 10-inch cylinder, going at various speeds ranging from 125 to 200 revolutions, and the friction varied from 2 per cent. down to 1·4 per cent. of the whole dynamometrical power given by the engine. That was with a balanced valve. With an ordinary valve such as the Author had been using, not a balanced valve, a 9-inch by 12-inch engine was used, and there the friction varied from 4·5 per cent. to 7·3 per cent. That was very different from the frictions given in Table IV, which in one case was 1·34 per cent., and in another 2·26 per cent.

Mr. Halpin. That Table, he thought, needed a little further explanation. In the first experiment the valve moved $3\frac{3}{8}$ inches with 56 revolutions, taking 4·6 HP. to drive it; whereas, in another experiment with the same number of revolutions, at only two-thirds of the speed, it took rather more HP. to drive it. The Author had stated as the first cause of variation of the resistance during the stroke, "the variation of pressure on the back of the valve due to variation of the steam-chest pressure during each stroke. This in some of the full-gear diagrams amounts to 10 or 12 lbs. per square inch." The Author had given a verbal explanation of that, stating that the steam-pipe was not good enough. Mr. Halpin was of the same opinion; but he thought that the Author might have gone further. On referring to Table II, instead of finding the variations of pressure 10 or 12 lbs., he would find the total difference of pressure between the boiler and the steam-chest to reach as much as 50 lbs. Taking the Table as it stood, in the case of the goods engine, which was the first, making 56 revolutions a minute, assuming a constant piston speed throughout all parts of the stroke, the velocity was 5,800 feet per minute in the steam-pipe; and taking the extreme case with 224 revolutions, there was a velocity of 23,200 feet per minute, which was, of course, far beyond anything it could be hoped to keep up, without great loss of pressure, by means of steam-pipes of the proportions now usually adopted in locomotive practice. He had never been able to obtain a velocity of more than from 3,600 to 4,000 feet per minute without a very serious loss of steam-pressure.

Mr. Goodman. Mr. JOHN GOODMAN said, that in 1885 he wrote a letter to *The Engineer*,[1] giving a diagram, of which he now exhibited a copy, of a similar apparatus to that used by the Author for ascertaining the friction on slide-valves. He was going to carry out some experiments upon the same subject; but could not get an engine of suitable dimensions. He thought, however, that the apparatus might be improved by working upon a method of which a great deal had been heard lately, namely, the Emery system of testing machines. Here, instead of a piston, a thin diaphragm was introduced in the cylinder, and an indicator with a Bourdon tube was used instead of an ordinary piston indicator. In that way the difference in the length of the valve-rod might be reduced to a minimum, and the apparatus made to work frictionless. In the apparatus which he had designed, he had arranged the paper to work on a continuous roll. He thought it must be a

[1] Vol. lix. p. 186.

Mr. Goodman. difficult operation to put a card on the indicator-drum when the engine was going at a high speed, and that a continuous roll of paper would be a great improvement. The Author had referred to the friction of glands which, he said, was quite inappreciable. It might have been inappreciable in that instance; but persons acquainted with the working of steam-engines would know that friction on the glands might be enormous. Indeed, it was an easy matter to pull up an 8 or 10 HP. engine simply by tightening the piston-glands. He admitted that it was a very injudicious practice, but still it could be done; and hence in any experiments upon the friction of slide-valves, it might come in as a serious error, and it might, to some extent, account for difference in the results obtained by different experimenters. In the experiments, for example, mentioned in the first paragraph of the Paper, the coefficient of friction came out as 0·25, while Mr. Halpin's results, and those obtained in America, were much lower; the difference being probably due to the extra friction on the slide-valve spindle-glands. Reference had been made to the enormous friction that sometimes occurred on slide-valves from the simple reason that the buckles and slide-valve rods were not infrequently broken. He thought that was easily accounted for. It was well known that the friction of rest on all materials was far greater than the friction of motion; and not only with dry surfaces, but also with lubricated surfaces; in this case even more so, because the valve when at rest, would be metal to metal with the steam-chest; but as soon as it began to move, a film of water and steam would get under it, and would act as a lubricant, and greatly reduce the friction. Eighteen months ago he saw a balanced slide-valve, and the makers were showing how easy it was to move the valve backwards and forwards with one hand. A valve, about 8 inches square, was moved very easily in that way. He tried several experiments with the valve, allowing it to remain at rest for some minutes, tapping the steam-chest cover, and then pulling with the hand as hard as he could. He could not move it, although it was supposed to be a balanced valve; but after it was once started into motion it could be moved backwards and forwards without trouble. The experiments of Mr. Adams and Mr. Beattie were made by hanging a scale-pan with a pulley on the end of the slide-valve spindle. Weights were placed in the scale-pan until the valve began to move. That, of course, would be the friction of rest, and the greatest possible amount of friction that could come on the slide-valve. Hence, in designing a valve-gear the maximum load likely to come upon

Mr. Goodman.

it should be taken, and he thought it would be advisable to adhere to the old-fashioned coefficient 0·25. The question of lubricants was one of very great importance. Some of the so-called valve oils were of no value. He knew of a case in which an enormous quantity of a well-known lubricant was sent out to one of the colonies, and after it had been at work three or four months complaints were received to the effect that all the ports and all the parts of the piston were choked with a hard mass of carbon. The oil had been largely advertised as a valve oil, but it was far from being suitable for the work. A few years ago he had carried out some experiments for Mr. Stroudley, with reference to suitable lubricants for slide-valve and piston work; and he believed that the method adopted was the only one for ascertaining whether an oil was suitable or not. The oil proposed to be used was heated on a plate to about the temperature at which it was to be used in the cylinder. If after a reasonable time it turned thick and gummy, and ultimately solid, it was rejected; but if it stood the heat for several hours, and ultimately almost entirely evaporated leaving practically no residue, it was deemed to be suitable oil for use in the cylinders. Recent experiments, especially those of Mr. Tower, and some which he had himself carried out, distinctly showed that with the ordinary system of lubrication, such as that used with siphons, there was a great waste of oil. He thought there was a wide field open for inventors to devise some means of lubricating slide-valves by pad lubrication, instead of the present method of allowing the lubricant to go drop by drop into the cylinder. There was a method that he thought might be worth trying, something similar to that adopted by Messrs. Aveling and Porter at Rochester for lubricating their traction-engine axles. It was a piece of wood $\frac{3}{4}$-inch in diameter, floating in a bath of oil touching the bottom of the axle. As the axle revolved, the wood revolved and brought oil on to the axle. That method had proved economical and efficient, and he would suggest whether some such method could not be used for slide-valves. A small roller might be inserted in some part of the bars of the steam-chest (of course it would not be of wood but of metal), and small quantities of oil could be admitted to the centre of the rollers. That, he thought, would be more economical and efficient in reducing friction than the method of putting in oil drop by drop. The pressure required to move the valves was considerably less when the valves were working full stroke than when they were notched up to one-quarter stroke. It would be found that the work done in moving the

Mr. Goodman. valve through the stroke was approximately constant. If some apparatus of that kind were adopted for the use of piston-rods, so as to indicate the work done by the piston, some valuable and interesting results might be obtained, that would throw light upon the friction of pistons and glands as well as of slide-valves.

Mr. Tower. Mr. BEAUCHAMP TOWER asked the Author how he had obtained the results given in Table I. He presumed that he had added the weights one by one from 76 lbs. to 412 lbs. on the lever; that in the first place he found that he had 132 lbs. indicated when the actual pull was 316 lbs., and so on until he had 1,765 lbs. when the indication was 1,285·7 lbs. He wished to ask whether the weights were then taken off and the indication noted. In the case where he had 1,715 lbs., and only 1,285·7 indicated, the friction amounted to 429·9 lbs. It would therefore appear that he could go on taking off the weights until the pull was 429·9 lbs. less than 1,285·7 lbs.; that was 855·8 lbs., without overcoming the friction of the apparatus, and between 1,715·6 lbs. and 855·8 lbs. his indicator would not have moved. The Author's formula, given on p. 170, would clearly be useless in that case. With a frictional apparatus where there were changes of force going on inside, of which there was no external indication, such a formula would not apply. Finding that the frictions were so great, he thought it was a pity that the Author had not contrived some less frictional method, which would have made his results much more valuable. He might have adopted some such plan as Mr. Cross had mentioned, which, from Mr. Tower's own experience, answered perfectly well. With oil or glycerine there was practically no leakage and no friction. The straight horizontal lines, which were characteristic of the diagrams, clearly indicated the excessive friction of the apparatus. Within certain variations of load the Author's indicator showed no variation of force at all; hence there was a straight line where there ought to be a wavy one.

Mr. Stroudley. Mr. W. STROUDLEY thought the Author had done well to bring the matter before the Institution, as it was one of great importance, and deserved to be carefully studied. About the year 1855 he had charge of some locomotive express engines very troublesome to keep in order, the slide-valves having a very small bearing-surface, and the pressure being high. He then devised a plan of drilling two rows of holes down each face of the valve, and filled them with pure block tin, which reduced the friction so as nearly to double the life of the slide-valve. He afterwards saw some extreme cases of friction, some engines having slide-valves $20\frac{1}{2}$ inches by $11\frac{1}{2}$ inches, working at 160 lbs. pressure, and having $4\frac{1}{2}$ inches travel. They also were express engines, and the slide-valves wore down a good deal within a month or six weeks. The metalling of the valves just turned the scale. Before being metalled he had seen the slide-valve turned over on the edge, so that it would measure $\frac{1}{4}$ inch more across, and the exhaust-port would be reduced by $\frac{3}{8}$ inch. That was the result of extreme friction. Guided by previous experience, he had endeavoured to reduce the size of the valve as far as possible, so that the load should not exceed a reasonable one, and that removed much of the friction, as was proved by the wear that took place. The B and C class of engines on the Brighton Railway, with slide-valves placed below, ran for $\frac{1}{32}$ inch wear on the face (equivalent to 1 lb. of metal in a phosphor-bronze valve) 14,460 miles, the wear including the re-facing of the valve. With a brass valve the distance run was in some cases only 7,000 miles. There was, however, extreme difference in the wear of valves, dependent, no doubt, on the nature of the metal of the cylinders, as well as the difference in the care exercised by the driver, the extreme varying from 7,000 to as high as 77,000 miles per lb. of metal worn and turned off the face. The phosphor-bronze valve was nearly twice as durable as the ordinary brass valve. With the D class of valves placed vertically, the wear was $\frac{1}{23}$ inch for 7,000 miles with a brass valve, and 13,000 miles with a bronze valve. Nearly as good results were obtained with a vertical phosphor-bronze valve as with a horizontal brass valve. The friction had, in his opinion, always been assigned a higher value than it ought to have. Many years ago he tried experiments with the balanced valves (Adams's), changing the proportions and reducing the friction. With a 17-inch cylinder engine he could hold the reversing gear with one hand standing at right-angles when running at full speed. In that case the friction must have been very small, yet the consumption of coal was not appreciably altered. The quantity of oil required to keep the balanced valves from squeaking, and in working order, was much greater than for the ordinary valve. The result of his experiments was that the balanced valves were taken out and thrown away. That went to prove, in his opinion, that the friction must have been much smaller than it was generally supposed to be. With reference to the Author's estimate of the friction and the power used by eccentrics and eccentric straps, he had now a great number of eccentric straps of cast-iron that had been running since 1872-3-4 with all classes of engines. If the friction were as great as had been stated by previous writers on the subject, those straps would have been worn to a much greater extent than Mr. Stroudley.

Mr. Stroudley. they were, they not having been refitted in any way since their construction. He thought that experiments made under any other conditions than actual working ones were not of much value. The Author's arrangement was well designed to illustrate what actually took place in work.

Mr Cowper. Mr. E. A. COWPER said the Author had not done full justice to himself in Table III, where the various frictions of motion were given, namely, Adams, 9,752 lbs.; Beattie, 4,620 lbs.; Aspinall, 1,321 lbs. with a brass Allen valve full stroke, 1,096 lbs. with a brass plain valve full stroke, and 982 lbs. with a cast-iron valve full stroke. He considered the Author had not laid sufficient stress on the last being cast-iron, because it appeared that with the cast-iron valve far less driving power was required than with the other valves. He believed many people thought that it was best to have a brass valve, so that the faces of the ports should not suffer. With regard to the Allen valve, the Author had mentioned cutting out the inside equal to the length of the ports. That was a principle which Mr. Cowper had long adopted; indeed he had cut out the inside considerably more than the distance between the ports, when working a single common high-pressure engine expansively, so as not to have too much compression; more thorough expansion with a single valve was then possible. He should have liked to have heard more about balanced valves. For instance, there was Robert Wilson's valve, which had a plate on the back of it, carried, not by the slide-valve itself, but by two sides or supports, one on each side of the slide-valve, and these touched the slide face. This plate and its supports was stationary, and the slide-valve worked under it, the plate taking the pressure of the steam on its own back. Then, if water occurred in the cylinder, and the valve lifted off its face, the valve and plate lifted together, and no harm occurred to the cylinder bottoms. The mode of fitting up the plate to its place was to put a pressure on the back, to spring it as much as the steam would, and then get it up true, the back of the slide-valve being also got up true (without pressure); then the two were put together, and the faces to bear on the ports were got up true together, and thus no stuffing-box or relieving-piston was required for the back of the slide-valve. This valve worked very freely, and, he was informed, assisted in making the steam-hammer quite easy to handle. He had further been informed, by a thoroughly practical locomotive engineer, that if the plate was allowed to travel a little, it wore away like the slide-valve, and thus avoided the necessity of having a little taken off the face, to keep it to fit to the back of the slide-valve. This would seem to be an important point. With regard to a large valve with a short stroke, requiring more power to move it than if it had a long stroke, it would appear that any lubricant would be worked out more with a short and reciprocating motion, than with a longer motion, and as a proof of this, he might instance the fact that the axles of a common carriage placed on a railway truck would, in a long journey, set fast in their boxes, if the wheels were not thoroughly well fastened to prevent motion. Also the old rock shaft, formerly employed in Bury's engine, and others with the "Gab-Motion," frequently cut, and even seized with the slight motion they got when running. With regard to slide-rods breaking in marine engines, or engines with very wide ports and slides, he had no doubt but that in some cases the edges of the slides had caught against the ports, from their springing down or dropping into the ports, from the pressure of the steam on their backs. This might be expected if the valves were made too weak, as they often were, and if the edges of the ports were not rounded off a little, as they ought to be. Mr. Cowper.

Mr. E. WOODS, Past President, thought that the Author's researches and experiments ought to receive the attention of engineers, especially as showing that the friction of slide-valves was much less than had been commonly supposed. The first application of the balance valve to locomotives was by Mr. John Gray, about the year 1838, who applied it on the Liverpool and Manchester Railway to one of the engines used to assist in propelling trains up the Sutton and Whiston inclined planes. To one of the two, the "Sampson," or the "Goliath," he placed a short cylinder at the back of the valve-chest with a piston in it, and a connection between the piston-rod and the back of the valve, so as to balance the pressure of the two. But, as Mr. Stroudley had pointed out, the complexity of the method told against it, and it was finally abandoned, it being found that on the whole the friction was not actually reduced. Mr. Woods.

Mr. ASPINALL, in reply, said he did not find that the breaking of valve-spindles, as mentioned by Mr. Cross, often happened. Speaking from the experience of a very large number of engines, he found that it was not a frequent occurrence with valve-spindles that had been properly proportioned, unless the glands were screwed up too tight, or the valve was allowed to wear too thin, and caught in the steam-ports. With regard to the use of thick glycerine, he had no doubt that it would answer extremely well. He did not think he had mentioned that oil was tried with the apparatus shown in Plate 2, Fig. 5. No doubt, as Mr. Halpin Mr. Aspinall.

Mr. Aspinall. had said, the age of cup-leathers might affect the experiments, and the greatest possible care was taken in that respect. Only once during the experiments were the leathers changed, and then a fresh set of experiments was tried with the apparatus, and it was found that the friction was the same as before. As to the question of greater power being used in a short stroke, that had been answered by Mr. Goodman. That it was more difficult to lubricate valves when notched up than when going full stroke, was a matter of practical experience. In reference to Mr. Halpin's remark as to the reduction of pressure, he meant that the very great reduction, amounting to more than 30 lbs. in some cases, as between 160 lbs. boiler-pressure and the steam-chest pressure, was due to the small steam-pipe. In speaking of 10 lbs. or 12 lbs. he was referring to those depressions in the steam-chest pressure due to the gulp of steam taken by the cylinders. Mr. Goodman had stated that he would prefer a diaphragm to leathers. No doubt such an apparatus would be better in some ways as the movement of the piston was so slight, and the result of his experiments had been to satisfy him that his apparatus could be considerably improved. If he were to start again he had no doubt that he could get better tackle all round. But such matters required a long time, and there was not always the opportunity of trying such experiments. The question of gland-friction of course applied to the present case. The greatest possible care was taken to ensure that there should be no gland-friction, and that the packing should be properly done, and when the valve-spindle was disconnected from the rest of the gear, it could be put in by hand with ease. With regard to the increase of friction, which might be caused by screwing or packing the gland improperly; it was only necessary to look at valve-spindles when they came into the shop deeply cut by wear, after being in the hands of a careless driver, to see how a driver might increase the friction of the glands. In the case under consideration the aim was to eliminate the gland-friction, and to get the valve-friction. Mr. Goodman was right in saying that there was the greatest difficulty in obtaining good oil for lubricating. Many of the so-called cylinder oils produced a choking-up of the ports with a black substance, which had to be chipped out when the engine came into the shop. He had experienced something of that kind quite recently. The objection to the balanced valves, apart from any question of their deficiency as valves, was the fact that there were so many loose parts to deal with. If Mr. Goodman's suggestion as to little rollers were carried out, it would be introducing loose pieces into a part of the engine where it was most desirable to keep them out. Mr. Tower had spoken of the results in Table I obtained by trying the apparatus shown by Plate 2, Fig. 5, and he appeared to think that if the weights were put on and taken off one by one, the apparatus would not record any movement. That was what he himself had anticipated, and the apparatus was most carefully tested on that account. The weights were placed on the end of the lever one by one, and taken off one by one, and for every additional weight taken off or put on, the indicator responded at once. Having tested them in that way, they were tried by screwing up the apparatus at the end as a whole, to see whether, starting with the whole weight (1,200 lbs. in one case, or 1,700 lbs. in the other), the same results followed; and he was satisfied that, so far as the results were concerned, they were as accurate as they could be under the circumstances. Mr. Tower also spoke of the straight horizontal lines on diagram 17 (Plate 3) as indicating friction in the apparatus. These straight lines were, however, not due to that cause but to the use of the Allen valve. If the diagrams on Plate 4, taken with an ordinary valve, were compared with those on Plate 3, taken with the Allen valve, the former would be found to show curved wavy lines. When the Allen valve was removed from the engine, and the ordinary valve substituted, these straight lines disappeared; when it was put back again they reappeared. The explanation might be that given on p. 175. He could quite bear out the remarks of Mr. Stroudley as to the very slight wear with cast-iron eccentric straps, which after running for a long time came into the shops without the tool-marks being worn out. Mr. Cowper had spoken of cast-iron valves, and had pointed out the fact that the friction was lower within than with brass valves. That was shown clearly by Table II, where it would be seen that the force required to move the valve amounted to 992 lbs. in one case, and to 998 lbs. in the other. As long as the kind of valve was right, cast-iron seemed to do very well, and for engines starting and stopping repeatedly extremely good results were obtained. Mr. J. C. Park, had told him that, during the last two or three years, all the brass valves had been taken out of the engines of the North London Railway Company, and cast-iron valves substituted. The result was a good deal less wear and tear, and consequently less lubrication; and there had not been the slightest difficulty in reversing the engines with the steam full on at a pressure of 160 lbs. He did not think there could be better evidence as to the value of cast-iron valves, under certain circumstances, where they could be well lubricated by the steam. It was true that the North London Mr. Aspinall.

Mr. Aspinall. engines did not run any great distance at one time. With an express engine running long distances, he doubted whether cast-iron valves would give the same results.

Correspondence.

Mr. Park. Mr. J. C. Park remarked that slide-valve friction had been under consideration for many years on the North London Railway, and that experimental trials, with valves more or less balanced, had been made from 1856 up to the present time, but without success. On the North London Railway, where more than 7,000 stoppages were made daily, the engine-drivers much preferred cast-iron valves, as they were able, without effort, to work the reversing lever quite easily with steam at 160 lbs. per square inch full on; whereas with brass valves they were compelled to partially close the regulator. The wear was as 1 to 3 in favour of iron valves. For the last six years cast-iron valves had been used on the North London line, and he hoped in a short time all the engines would be fitted with them. The valves were made of 1 part of No. 1 Carron and No. 3 Cleator hematite iron, and 2 parts of clean scrap. The average mileage of these valves, if properly lubricated, was 82,491, with a wear of barely $\frac{1}{16}$ inch, whereas brass valves were completely worn out under the same mileage. He would, later on, present fuller details to the Institution on this subject.