

INDICATING OF GAS-ENGINES.

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In the Report of the Standards Committee on Gas-Engines of the Institution of Civil Engineers, the opinion* was expressed that the indicating of gas-engines was open to very much greater errors than was the case with steam-engines, and that they therefore preferred to draw all their conclusions from the studying of the brake horse-power. The matter was considered by the Research Committee of this Institution, and in order to determine what the error amounted to in the indicating of gas-engines, it was decided to use two indicators simultaneously; one being the ordinary string type, and the other the optical indicator. The results obtained in the present Paper are to be looked upon as purely comparisons of indicators, as it was found that, after these experiments had been concluded, the cylinder of the engine was very badly oval, and a very considerable amount of leakage was taking place from the motor cylinder to the differential piston, which vitiates the results as regards efficiencies, but as the indicator diagrams were taken simultaneously the comparison of the indicator is not affected.

The engine experimented upon had a cylinder 16 inches in diameter by 24 inches stroke, running at 165 revolutions per

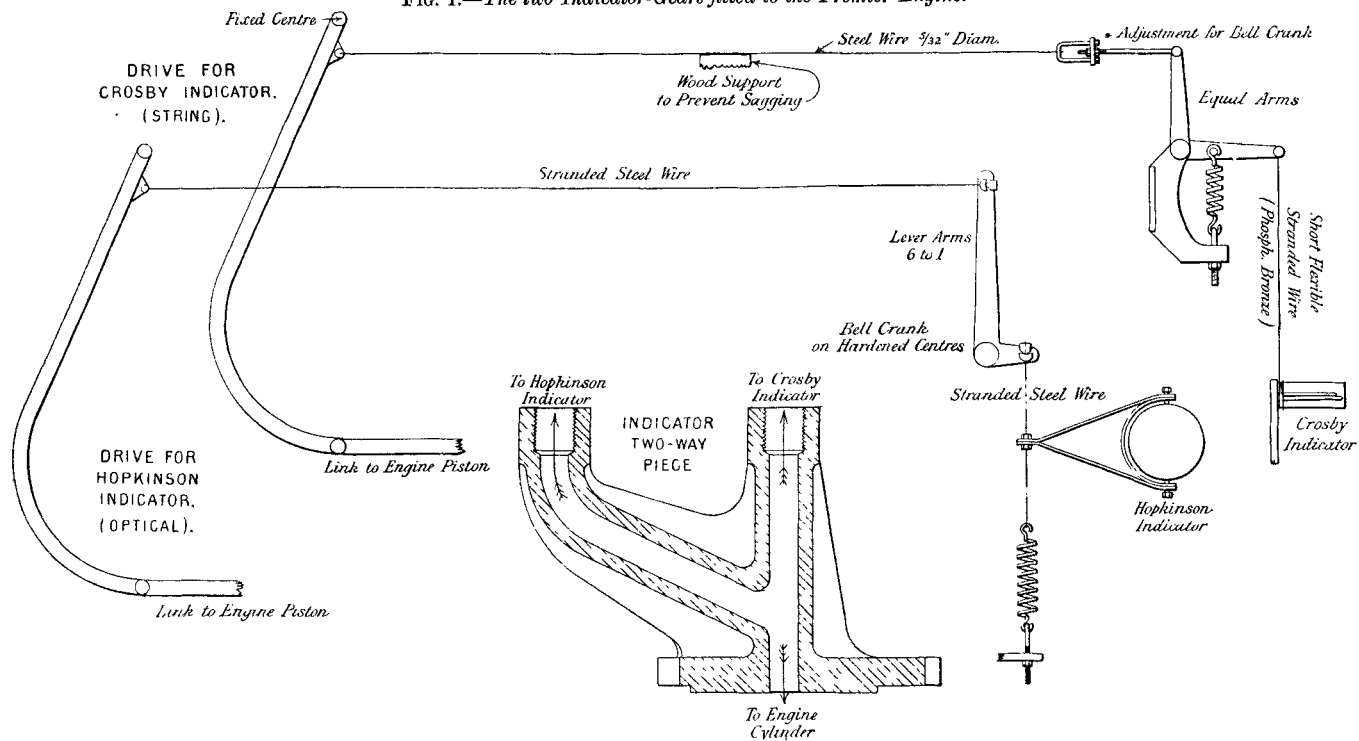
* Proceedings Institution of Civil Engineers, 1906, vol. clxiii, page 247.

minute under full load. It was constructed by the Premier Gas-Engine Co., and is fully described in the Third Report to the Gas-Engine Research Committee.*

The comparison was undertaken in connection with the C trials in the Third Report, being about 180 lb. above atmosphere. The only variation in the four tests was the amount of gas admitted, the mean pressure varying from $5\frac{1}{2}$ kg. per cm.² (78 lb. per square inch) up to about $7\frac{1}{4}$ per cm.² (103 lb. per square inch). The method of driving the two indicators and the branch piece showing the attachment are fully illustrated in Fig. 1. It will be observed that the branch piece is not symmetrical, as it was impossible to fit a symmetrical fitting on to the limited space available on the breach end. The Crosby indicator was on the end of the straight passage, while the other was at the end of the bent passage. To test the effect of this want of symmetry simultaneous diagrams were taken with two Crosby indicators, which were then interchanged, but it was not possible to detect any difference between the diagrams on either indicator. Hence it is reasonable to conclude that the actual pressure on each indicator was substantially the same. The length of the passage between the indicators and the motor cylinder was some 15 inches, and the diameter of the pipe originally $\frac{3}{8}$ inch. This was found to give serious oscillations down the expansion line, even when a comparatively heavy spring was used, namely, 400 lb. per square inch. When the indicator hole was opened up to $\frac{1}{2}$ inch in diameter these oscillations disappeared, showing the importance of having wide passages from the cylinder to the indicator when there is any considerable distance for the pressure to pass. The string indicator employed was the well-known Crosby type, selected by the Crosby Company for these tests. In previous experiments a large number of indicators have been tried of the external spring pattern, but in all cases their inertia is too great, and the waves down the expansion line become so serious as to make it impossible to

* Proceedings 1908, Part 1, page 5.

FIG. 1.—The two Indicator-Gears fitted to the Premier Engine.



measure up the diagrams. Before and after each set of trials the indicator was tested for back-lash and friction, and the spring was also calibrated. The back-lash was in all cases negligible, and the friction amounted to less than 1 lb. with a spring having a scale of 400 lb. per square inch.

The optical indicator was one kindly lent by Professor Hopkinson, and is fully described in the Proceedings of the Institution.* It was calibrated in the University, and this calibration has been employed in drawing the mean diagram. For both indicators particular attention was directed to the method for driving the indicator barrels, as this is a matter which the author ventures to consider as not receiving sufficient attention. In the string indicator the bell-crank lever, Fig. 1, was driven by a stout steel wire. This lever was controlled by a very heavy spring, in which a compression of 400 lb. produced a contraction of 2 inches. The barrel of the indicator itself was rotated by a phosphor-bronze stranded wire, and a similar wire was employed on the optical indicator. In neither case was there any measurable back-lash in the driving mechanism. The use of a hemp string in any form is certainly not so desirable as the stranded bronze wires, although the bronze wires do not last as they fracture very readily.

The mean diagrams, Figs. 2, 3, and 4 (pp. 789-791), were prepared from the individual diagrams in the same method as has been followed in the Second and Third Reports, namely, not less than twelve diagrams were divided by the method of ordinates, and the heights read by an accurate steel rule. All diagrams were taken with a hard lead-pencil on smooth paper, and the width of the line was considerably less than $1/200$ of an inch. With care it was possible to read these ordinates with an accuracy of half of one per cent. The optical indicator also had very fine lines, and could readily be measured up to the same order of accuracy. The diagrams were plotted on squared paper, and superposed one on the other, so as to exhibit whatever differences there were between the indicators.

* Proceedings 1907, Part 4, page 884.

FIG. 2.

Mean Diagrams. Trials C 1, C 2, C 3, and C 4.

For comparison these have been reproduced to the same scale as the C Trials on Plate 6, Proceedings 1908. They are reproduced on larger scale on the next two pages.

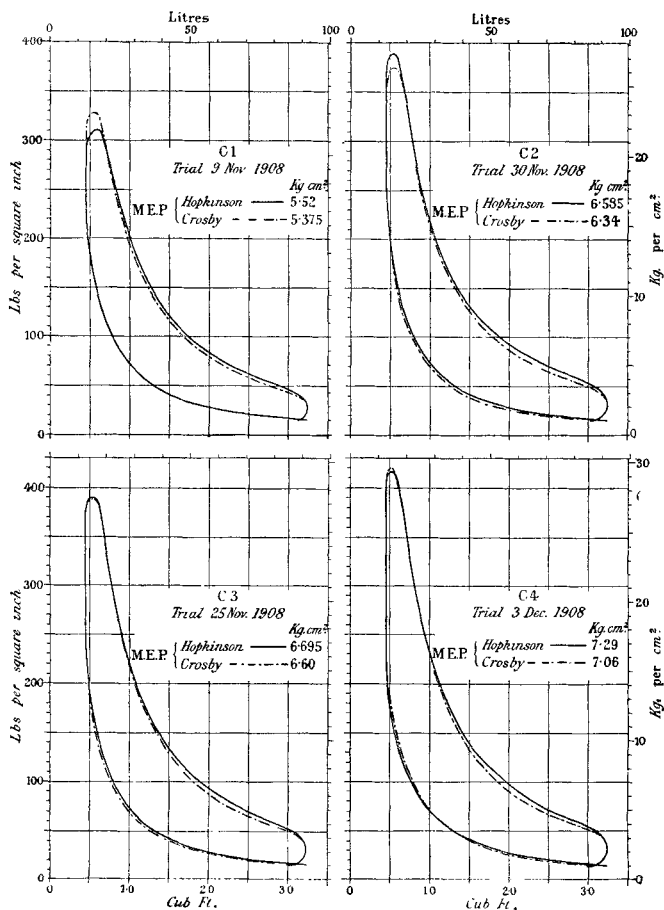


FIG. 3.—*Mean Diagrams.*
Facsimile of author's Drawings. (Reduced about half-size.)

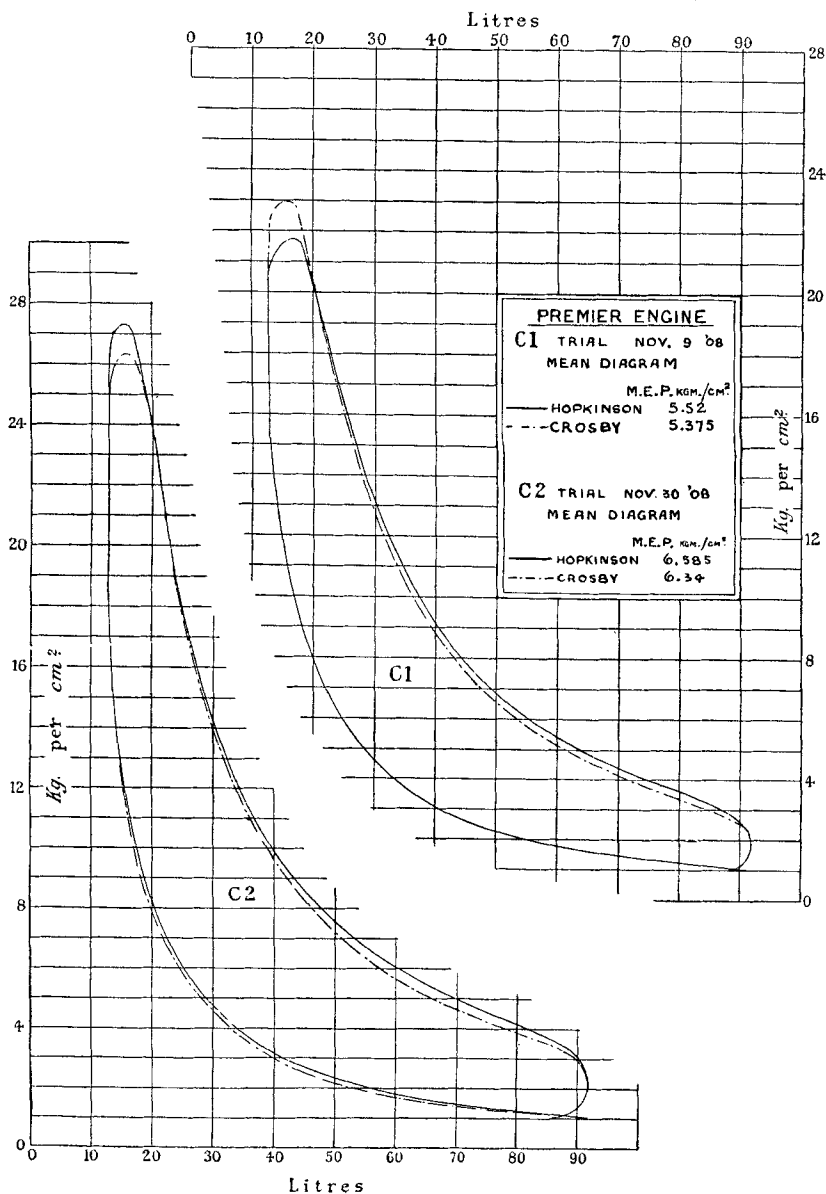
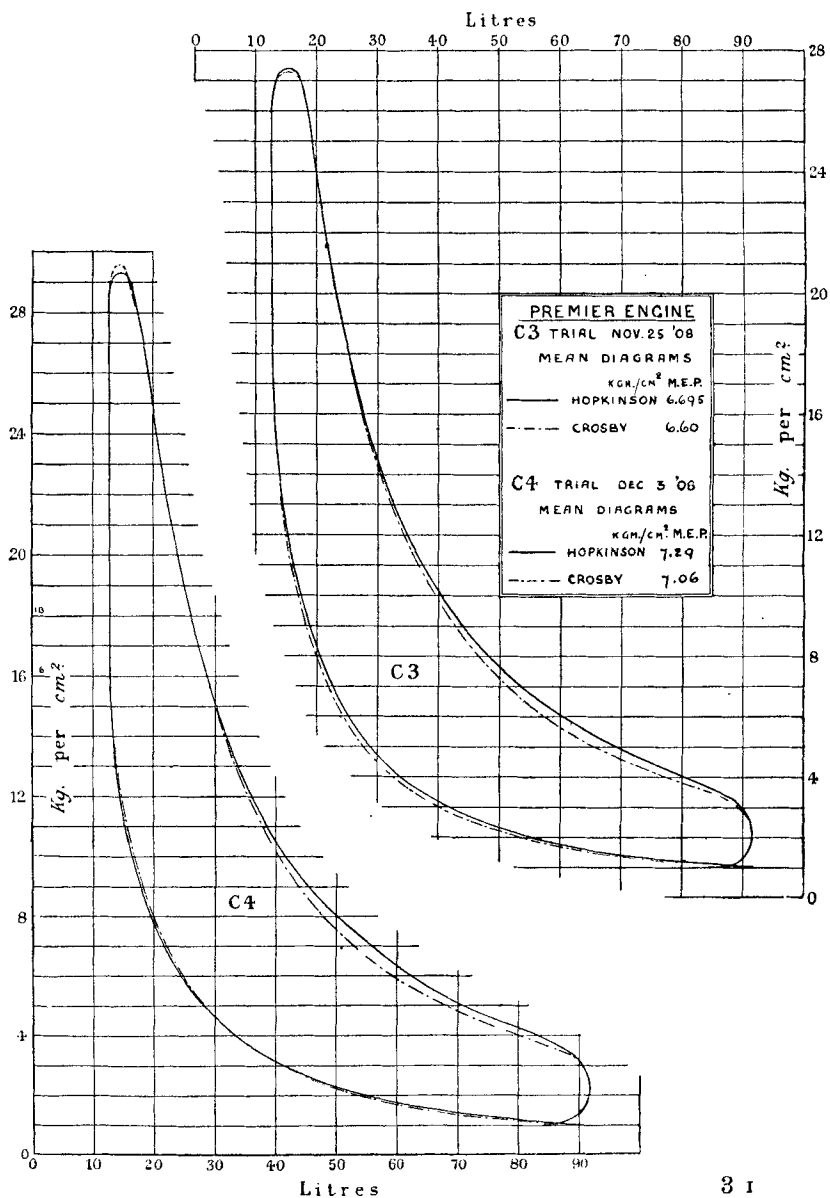


FIG. 4.—*Mean Diagrams.*
 Facsimile of author's Drawings. (Reduced about half-size.)



Speaking generally, the compression curves are coincident. In C 1 this coincidence is complete within the error of measuring the diagrams, which amounts to about one-tenth of a kilogram per square centimetre. In the C 2 and C 3 there are slight diversions. The maximum pressures practically agree in tests C 3 and C 4; while in C 1 the Crosby gives the higher initial pressure, in C 2 the Hopkinson gives the higher initial pressure. Down the expansion line the two indicators agree for the third of the stroke. After that the Hopkinson gives a persistently higher expansion line, the difference between the two being larger than the probable experimental error of the measurements. The effect of this higher expansion line makes the Hopkinson indicator give about three per cent. higher mean pressure than the Crosby. This difference has been carefully considered, and the effects of inertia and friction investigated, but the author is of opinion that neither of these causes is likely to account for such a persistent difference between the two expansion lines.

In the Hopkinson indicator the spring was in the form of a flat bar rigidly fixed at the ends, and loaded in the centre; the central deflection in this beam is a direct measure of the pressure on the piston. During the calibration with dead-weights from which the scale of the springs is obtained, the ends of the bar may be assumed to be absolutely fixed, but when the indicator is in use it is possible that there is a slight slip in the bar through the screws which constrain it, which would cause a compression on the lower side of the bar, and thus prevent the pressure falling as rapidly in this indicator as in the string one; and for this reason alone the author is inclined to prefer the results obtained from the string indicator, and also for the reason that were the string indicator persistently low it would make the efficiencies in the Third Report still higher than they are, which, while not impossible, is certainly not a result to be expected.

The result of these comparisons, while not an absolute proof of the accuracy of either of the indicators, is still strong evidence that both are giving results very close to the truth. The two are

entirely dissimilar types, one multiplying the motion of the indicator piston by six, and the other by about one hundred and twenty, and a very similar multiplication being the case with the rotation of the drum and the mirror. In the optical indicator the inertia is certainly negligible; that the two give results to within three per cent. on the mean pressure, and very nearly the same figures for the initial pressure, is good presumptive evidence that when either indicator is used with the precautions which have been described, the results so obtained are at least as accurate as any other measurement which can be made in engine testing.

The author expresses the opinion that unless these precautions are taken when obtaining indicator diagrams, the results should only be looked upon as affording a clue to the valve-setting, and giving no reliable figures as to the power developed in the engine cylinder.

The Paper is illustrated by 4 Figs. in the letterpress, and is accompanied by an Appendix containing 4 Tables.

APPENDIX.

Trial C 1.

Volume. Litres.	Pressures. Kg. per cm. ²			
	Compression.		Expansion.	
	Hopkinson.	Crosby.	Hopkinson.	Crosby.
12.75	14.90	14.90	20.30	20.30
14	13.00	13.00	21.30	22.75
15	11.85	11.85	21.55	22.90
16	10.80	10.80	21.70	22.95
19	8.40	8.40	21.05	21.40
20	7.90	7.90	20.30	20.30
25	5.90	5.90	16.40	16.10
30	4.65	4.65	13.17	12.80
35	3.75	3.75	10.85	11.55
40	3.05	3.05	9.15	8.85
45	2.60	2.60	7.85	7.45
50	2.25	2.25	6.85	6.55
55	2.00	2.00	6.05	5.80
60	1.75	1.75	5.42	5.15
65	1.60	1.60	4.87	4.62
70	1.45	1.45	4.40	4.15
75	1.35	1.35	4.00	3.75
80	1.23	1.23	3.65	3.37
85	1.12	1.12	3.24	3.00
87.5	1.10	1.10	3.00	2.80
90	1.05	1.05	2.62	2.40
91	1.02	1.02	2.40	2.40
91.75	1.00	1.00	2.10	2.10

Trial C 2.

Volume. Litres.	Pressures. Kg. per cm. ²			
	Compression.		Expansion.	
	Hopkinson.	Crosby.	Hopkinson.	Crosby.
12.75	18.50	18.50	26.10	25.10
14	14.50	14.50	27.10	26.20
15	12.80	12.40	27.30	26.30
16	11.60	11.10	27.30	26.30
19	8.90	8.50	25.00	24.90
20	8.30	7.95	24.00	24.00
25	6.10	5.90	18.00	17.65
30	4.75	4.60	14.35	14.05
35	3.80	3.70	11.80	11.50
40	3.15	3.00	9.90	9.60
45	2.67	2.40	8.60	8.30
50	2.30	2.15	7.60	7.20
55	2.00	1.85	6.70	6.35
60	1.80	1.65	6.05	5.65
65	1.60	1.50	5.50	5.10
70	1.40	1.35	5.00	4.60
75	1.30	1.25	4.50	4.20
80	1.20	1.20	4.15	3.85
85	1.10	1.10	3.70	3.50
87.5	1.10	1.10	3.50	3.30
90	1.30	1.30	3.10	3.00
91	1.40	1.40	2.80	2.80
91.75	2.00	2.00	2.20	2.20

Trial C 3.

Volume. Litres.	Pressures. Kg. per cm. ²			
	Compression.		Expansion.	
	Hopkinson.	Crosby.	Hopkinson.	Crosby.
12·75	18·70	18·70	25·60	25·60
14	14·20	13·10	27·25	27·05
15	12·45	11·60	27·45	27·30
16	11·25	10·70	27·40	27·30
19	8·95	8·50	25·50	25·50
20	8·35	7·90	24·10	24·10
25	6·05	5·80	18·40	18·20
30	4·70	4·45	14·55	14·30
35	3·80	3·60	12·00	9·75
40	3·20	3·00	10·20	9·85
45	2·70	2·55	8·75	8·40
50	2·30	2·20	7·65	7·25
55	2·00	1·90	6·80	6·35
60	1·75	1·70	6·05	5·60
65	1·55	1·50	5·45	5·05
70	1·40	1·30	4·90	4·60
75	1·30	1·20	4·45	4·20
80	1·20	1·10	4·05	3·80
85	1·10	1·10	3·60	3·45
87·5	1·10	1·10	3·40	3·30
90	1·40	1·40	3·00	3·00
91	1·55	1·55	2·65	2·65
91·75	1·80	1·80	2·00	2·00

Trial C 4.

Volume. Litres.	Pressures.		Kg. per cm. ²	
	Compression.		Expansion.	
	Hopkinson.	Crosby.	Hopkinson.	Crosby.
12.75	15.60	15.60	28.50	28.80
14	12.80	13.30	29.25	29.65
15	11.35	11.90	29.30	29.55
16	10.40	10.90	29.10	29.00
19	8.30	8.70	26.00	26.00
20	7.80	8.10	24.70	24.70
25	5.85	5.90	19.00	19.00
30	4.65	4.65	15.10	15.10
35	3.75	3.75	12.50	12.30
40	3.15	3.10	10.50	10.20
45	2.70	2.60	9.10	8.70
50	2.30	2.20	8.00	7.55
55	2.00	1.90	7.10	6.65
60	1.75	1.70	6.30	5.90
65	1.55	1.50	5.60	5.30
70	1.30	1.40	5.10	4.80
75	1.20	1.30	4.60	4.40
80	1.10	1.20	4.20	4.00
85	1.10	1.10	3.80	3.65
87.5	1.10	1.10	3.55	3.45
90	1.35	1.35	3.10	3.10
91	1.60	1.60	2.85	2.85
91.75	2.20	2.20	2.30	2.30

Communications.

Professor BERTRAM HOPKINSON wrote that he had been privileged to be present during some of the tests described in the Paper, and he could testify to the great care with which they were conducted. The Crosby indicator, as might be expected from the fact that it had been selected for these tests by the manufacturers, was one of the best instruments of its class which he had ever handled, and his own instrument had been in use in the Laboratory at Cambridge for some time, and was one which he was able to submit for trial with full confidence in its accuracy. The driving mechanism for the indicators, on the importance of which Professor Burstall had so rightly insisted, had been designed with great care and was probably as perfect as it could be made.

The agreement between the two instruments was certainly remarkable, the maximum difference shown at any point in the Tables was 0.45 kg. per cm.², which was equivalent to only 1.6 hundredths of an inch on the Crosby diagram. Professor Burstall said that the ordinates on the Crosby diagram could be read correct to one-half per cent. This statement was not quite clear, since the limit of error in measuring an ordinate would not depend upon the length of that ordinate; it might, however, be taken to mean that the height of the ordinate could be determined to within about $\frac{1}{200}$ th of an inch. He (Professor Hopkinson) having seen some of the Crosby diagrams, thought it doubtful whether so high a degree of accuracy could be attained, having regard to the fact that the position of the atmospheric line had to be taken into account as well as that of the diagram lines. He considered that the absolute height of an ordinate in the Crosby diagram was subject to a possible error of at least $\frac{1}{100}$ th of an inch, which would amount to nearly, but not quite, all the maximum difference between the two diagrams. To put the matter another way: by a slight relative shift of the atmospheric line it was possible in every case to bring the two diagrams completely into coincidence within $\frac{1}{200}$ th of an inch on the Crosby scale, except at points near maximum pressure.

As regards the mean pressure, it had only to be noted that the maximum difference—that in Trial C 2—amounted to but 0·008 inch on the Crosby diagram, to appreciate the closeness of the agreement.

The agreement between the two instruments was so close that it seemed hardly necessary to discuss the cause of the slight systematic discrepancy which remained. Both were probably giving results within 3 per cent. of the truth. He would, however, say that he did not agree with Professor Burstall's suggestion that the friction of the spring in the supports of the optical indicator was the sole cause, or even an important cause, of this difference. It was the fact that such friction or hysteresis existed to some extent and it could be detected in some instruments in calibration, but he did not think that it ever amounted to more than two pounds on the square inch with a spring and piston such as that used by Professor Burstall. In this respect the optical instrument did not differ from the ordinary type in which there was always some elastic hysteresis. Moreover, the vibration in actual use would tend to reduce this effect considerably below what it would be in the static calibration. A more probable explanation of the difference was a point in the construction of the Crosby instrument to which he had drawn attention on a previous occasion, namely, the horizontal back-lash in the pencil mechanism. The effect of this was to make the diagram slightly too small, raising the compression line and lowering the expansion line about the middle of the stroke. A very small amount of this defect would suffice to account for the minute difference between the diagrams.

It was stated in the Paper that these comparisons had been undertaken because of the opinion expressed by the Institution of Civil Engineers' Committee as to the difficulty of obtaining accurate measurements of the indicated power of a gas-engine. He had himself had occasion to discuss this same question before the Institution of Mechanical Engineers, and had arrived at the conclusion that for indicating modern engines with high maximum pressures the pencil indicator was liable to errors of 5 per cent. For that conclusion there was very ample evidence both in his own experience and that of others, including some of Professor Burstall's

(Professor Bertram Hopkinson.)

own experiments, in which simultaneous measurements of brake power and indicated power had been made. He thought, however, that Professor Burstall had demonstrated by the trials described in this Paper that with a carefully selected instrument such as he had used, manipulated with the care which he and his assistants had employed, the measurements might be relied upon to within 3 per cent., or perhaps a little closer. The conditions necessary to securing such accuracy were, however, not easy to comply with, and he believed that for the majority of instruments as supplied in the market his statement held good. The prominence which had recently been given to the subject would, however, doubtless result in an improvement in the accuracy both of indicators and of the measurements made with them.

Sir ALEXANDER B. W. KENNEDY, Past-President, wrote that the accuracy of the Crosby indicator for use with gas-engines had been, if he remembered rightly, somewhat vehemently challenged on more than one occasion. He was glad to see that the very careful comparative experiments which Professor Burstall had now carried out—and which no doubt showed each type of instrument to the very best advantage—showed also that any differences between them appeared to lie quite within the practical limits of error of the experiments altogether. It would seem, therefore, that there was no longer any reason to doubt the accuracy of any indicator results on the ground that the diagrams had been drawn mechanically and not optically. The differences shown by Professor Burstall between the two were so small that it did not appear to the writer wise to attempt to account for them definitely, still less to suggest that because they differed, one or other of them was necessarily wrong. In both there was liability to error, both on account of the apparatus used, and still more on account of methods of using it, but he saw no reason to suppose that with good apparatus, and careful methods, there was much to choose between the two in the only matter which concerned them, namely, the substantial accuracy of the results obtained.

Mr. GEORGE A. MOWER wrote that the Crosby indicator referred to (page 786) as having been "selected" by the Crosby Company was taken from the general stock, and was in every way similar to the indicators supplied in the ordinary way of business.
