HIGH-SPEED SELF-LUBRICATING STEAM-ENGINES.

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The subject of High-Speed Engines is one of such real importance and interest, that it may be useful and appropriate on the occasion of the present meeting to give some account of the part taken in their development by the writer's firm, Messrs. G. E. Belliss and Co., of this city.

Steam Cutters and Pinnaces.—In 1864 the firm commenced, with Mr. J. S. White of Cowes, to supply to our own and foreign governments steam cutters and pinnaces for use with warships. These small boats, which are now such a feature in all our harbours, were at that time unknown. The first boat was a steam life-cutter, built for the late Marquis of Hastings; and the primitive engine used in it is shown in Plate 63, having a single cylinder $5\frac{1}{4}$ inches diameter and 6 inches stroke. With all these small craft throughout, for naval and private purposes, the problem has been the same: namely to get the greatest power that can be developed out of a given weight of machinery, with a reasonable factor of safety. As far as the engines are concerned, exceeding care with the design and the materials, and quick revolutions, have alone rendered advances possible in this direction; but the limits have necessarily been soon reached, and in recent years the chief advances have been made in the boilers, with forced draught to assist the combustion. The shallow draught of these vessels requires a small diameter of propeller; and this, together with the necessity for minimum weight of machinery, has always required the speed of revolution to be kept high. In these small boats, which are carried on board the ships of war, the machinery varies in power from about

12 I.H.P. in the cutters to 200 I.H.P. in the vedette boats. The gradual progress made is illustrated by the fact that in the first vedette boat built a speed was obtained of 14 knots with 142 I.H.P. for a total weight of $5\frac{1}{2}$ tons of machinery, including water in boilers, and in the last a speed of 17.88 knots with 206 I.H.P. for the same weight of $5\frac{1}{2}$ tons.

Torpedo Boats.—A considerable number of sets of machinery have also been built for first-class torpedo-boats, and for torpedo-boat destroyers; and last year the machinery was completed for two of the latter vessels, the "Spitfire" and "Swordfish," built by Sir W. G. Armstrong, Whitworth and Co. The particulars of the machinery and of the trials are given in Tables 1 and 2, and the engines are shown in Plates 64 to 67. The general features of these engines by all makers are similar. The engine bearers are separate light steel castings, supported on the angle frames running fore and aft between the bulkheads. From these bearers the cylinders are carried by forged steel columns suitably braced. All the working parts are made as light as possible, as the momentum, due to the high piston-speed of 1,250 feet per minute on trial, is a considerable factor in the working of the machinery. A peculiar feature in these engines, which has considerably assisted in the excellent results obtained, is the arrangement of the cylinders, the low-pressure being divided into two equal cylinders with cranks opposite, and the high and intermediate being also arranged with cranks opposite. This permits the fitting of two links instead of four, reduces the fore and aft space considerably, leaves the ends clear for thrust and air-pump, and gives well-balanced pressures on the shaft bearings. This design was here adopted, because it has proved so effective and satisfactory in the two-crank compound engines, of which large numbers have been built by the writer's firm for supplying electric light and power. The absence of four sets of link motion and accompanying gear will be fully appreciated by everyone who has had charge of machinery, developing such large power in such small space, as is necessary in torpedo-boat destroyers. The engines are balanced by small weights on the crank cheeks, placed

TABLE 1.—*Full-power Trials of H.M.S. "Spitfire," 17 Aug. 1896.*

Draught of water, forward 5 ft. 2 ins., aft 7 ft. 4½ ins.

Speed of ship, mean for three hours 27·461 knots,

mean on measured mile 27·775 knots, maximum 28·571 knots.

		Three hours full-power.		Six runs on measured mile.	
Air pressure in stoke-holds inches of water		3·09		2·76	
Steam pressure in boilers, per square inch above atm. } lbs.		195		198	
Vacuum in condensers, inches of mercury		Right	Left	Right	Left
Revolutions per minute revs.		24·3	23·6	24·5	24·0
" " " mean revs.		401·9	395·7	408·7	403·6
		398·8		406·2	
Steam pressure in high lbs.		187	187	185	186
reservoirs, per sq. inter lbs.		87	90	85	87
inch above atm. low lbs.		24	25	24	24
Mean pressure in high lbs.		68·0	70·2	65·3	69·3
cylinders, per inter lbs.		30·7	33·3	30·4	32·7
square inch . . . low {forward lbs.		20·2	20·6	20·2	19·8
		19·8	18·8	19·2	19·3
Mean indicated horse- high I.H.P.		686	697	668	700
power . . . inter I.H.P.		651	700	657	699
		453	457	460	445
		446	416	439	437
Total power of each set I.H.P.		2236	2270	2224	2281
Joint power of both sets I.H.P.		4506		4505	

TABLE 2.—*Full-power Trial of H.M.S. "Swordfish," 21 Oct. 1896.*

Draught of water, forward 5 ft. 2½ ins., aft 7 ft. 5 ins.

Speed of ship, mean for three hours 27·117 knots.

Air pressure in stoke-holds 2·3 inches of water.

Steam pressure in boilers 203 lbs. per square inch above atm.

		Right	Left
Vacuum in condensers inches of mercury		24·1	24·4
Revolutions per minute revs.		399·2	398·2
" " " mean revs.		398·7	
Mean pressure in cylinders, high lbs.		66·2	66·7
per square inch inter lbs.		36·4	36·2
		19·3	19·5
		18·9	19·0
Mean indicated horse-power high I.H.P.		672	662
		771	764
		431	428
		424	418
Total power of each set I.H.P.		2298	2272
Joint power of both sets I.H.P.		4570	

at suitable angles; and although the cranks form practically a right-angled arrangement, with these weights fitted the steadiness of the hull and machinery at all powers is remarkable. The boilers are Yarrow water-tube, eight in number. By far the most important improvement in recent years in high-speed ship machinery has been the introduction of the water-tube boiler. This alone has rendered possible the great advances in speed; and there is little doubt that in the mercantile marine the same requirements for speed will lead to the more rapid adoption of this kind of boiler, perhaps more or less modified. The total weight of the boilers in each of the torpedo-boat destroyers is $41\frac{1}{4}$ tons, which for 4,590 I.H.P. is about 20 lbs. weight per horse-power. Although there are no separators fitted on the steam pipes, there was not the least symptom of difficulty throughout the trials, and no instance of leakage of tubes or other parts. In Table 3 are given for the sake of comparison the weights of several classes of marine engines.

TABLE 3.—*Total Weight of Machinery per indicated horse-power in various classes of vessels.*

Ordinary merchant steamer	450 lbs.
Passenger mail boat, twin screw	430 lbs.
Battle-ship or cruiser, natural draught	265 lbs.
" " " forced " 	195 lbs.
Torpedo gunboat, forced draught, locomotive boilers	100 lbs.
Torpedo boat, " " " " " 	75 lbs.
" Spitfire" and " Swordfish," forced draught, water-tube boilers	47 lbs.

Lubrication.—The engine-room of a torpedo-boat destroyer during a full-power trial is certainly not a comfortable situation. Constant attention on the part of a considerable number of men is required in order to ensure effective lubrication, and success largely depends on their ability, and on the care with which the lubricators are designed, and the pipes fitted and secured. Yet to anyone accustomed to slower-moving horizontal engines it is astonishing to see how easily well-designed and well-managed machinery of this kind gets through its difficult performance. In the early days of torpedo boats the writer had to take charge of the trials of large numbers of them on behalf of

the Admiralty; and, coming as he did from the massive slow-moving machinery in the ships of war of those days, he must confess to having experienced a feeling of sheer fright on finding himself for the first time boxed up in a compartment with a set of Thornycroft's machinery running at about 650 revolutions per minute. Although these engines were then, as now, the perfection of good design and manufacture, it seemed almost impossible to get through a two or three hours' trial with machinery whizzing round at a rate which rendered the details invisible. But as time went on, and the boats were satisfactorily completed, the writer's experience was that, although boilers, which of course in those days were not water-tube, might give out, or vibrating pipes might burst, or other outside parts might break down, yet the engines themselves rarely gave trouble, or if they did it was generally in some detail connected with the lubrication. But on the lubrication a great deal depended; and to ensure success the men employed about it had to be almost acrobats in their capabilities.

Since that time the field for high-speed running has gradually widened, and the more advanced engineers have for long past been prepared to accept the fact that high speed is easily possible with safety, and have used it whenever circumstances have appeared to make it desirable. That it is desirable far more frequently than it is used is a statement which is being made frequently nowadays; and it will be useful to insist upon it here. After their thirty years' experience with high-speed engines, it was natural for the writer's firm to come into the field with this kind of engine for supplying electric light and power. Some preliminary work showed clearly that open engines were not in a position, without further development, to compete with the Willans engines so largely used in central electric stations. These engines are excellent in design and manufacture; and the single-acting cylinders and enclosed plan of lubrication render them quiet running, and easy to look after in the station. Their special claims in regard to economical performance had also to be taken into consideration. It was finally decided to combine a double-acting engine of ordinary construction with a system of forced lubrication, supplying oil under pressure to every

bearing ; and to enclose all the working parts, in order to prevent splash from the abundant oil-supply, and in order to keep out dirt. In the first instance a small single-cylinder engine was put in hand, and the expectations formed were more than realised by its performance. It was found, as had been anticipated, that the oil under pressure enabled the working parts, even when slack, to work without noise, and that after some months' constant working at a load considerably higher than the ordinary full load for this size of engine the bearings had not worn perceptibly. A two-cylinder compound engine indicating 300 horse-power was then completed for driving a dynamo at Messrs. Siemens' Charlton Works. After this engine had been at work continuously for four years, doing the full load required for the supply of electric power, it was opened out ; and the working parts, which had not been adjusted during this period, were found practically unworn. These and other experiences gained during the same period proved that the plan of forced lubrication served most satisfactorily all the purposes of quiet and efficient running at high speed ; and during the last year or two many hundreds of these engines have been turned out, from the smallest size up to 500 H.P. The increasing demand for still larger engines has led to the recent erection by the author's firm of new works for building engines of this kind up to any power that may be required.

Standard make of High-Speed Engines.—The small sizes up to about 15 H.P. are all single-crank with single or tandem compound cylinders. The smaller compounds up to 300 H.P. are of the two-cylinder "Crescent" type, as shown in Plates 68 and 69. The cranks are opposite, and a single eccentric actuates the slide valves. The oil pump is an oscillating one, worked off the eccentric, and its oscillation performs the necessary valve-action on a surface at the bottom of the pump. The pumps are therefore most simple, without either valves or packing to get out of order. The engine is indeed throughout as simple in every detail as it is possible to make it. The oil is usually drawn from the bottom of the engine casing, through strainers which can be easily removed, into pipes leading to all the bearings ; but occasionally, as at Bedford, at the Charing

Cross and Strand Electricity Supply Station, at Leeds, and at other places, a complete series of reservoir tanks has been fitted, supplied by separate and independent pumps. Pure mineral oil is used at a pressure of about 15 lbs. per square inch. These two-crank engines are made triple-expansion when necessary by adding two single-acting high-pressure cylinders, tandem with the other two ; and this forms one of the simplest and most effective designs that can be devised for high-speed triple-expansion engines. Formerly the engines were fitted with outside glands, only where they were used with condensers on board ship ; but recently this design has been adopted throughout, in order to keep the patterns constant, and also to prevent the trouble which water from the glands causes with some kinds of oil. The oil question becomes of serious importance in central electric stations fitted with condensers, especially where water-tube boilers are used.

Vibration.—For large central stations situated in densely populated neighbourhoods the design of the steam engine employed has been determined largely by the single question of vibration. The amount of vibration which will cause a nuisance is small ; and several London electric stations have incurred serious losses on account of vibrations, which at the engines themselves seem inconsiderable. Having had to approach the subject of vibration in high-speed engines for land and marine purposes simultaneously, the writer was at first led astray by assuming an equality in the conditions, which really did not exist. The vibrations in the engines themselves may be classed as follows :—first, those due to vertical changes in the position of the centre of gravity of the moving parts ; second, those due to couples produced by the changing momentum in the several lines of moving parts ; and third, those due to the obliquity of the connecting-rod producing retardation and acceleration of the moving parts in each line, which occur twice in each revolution.

The “Crescent” engine, with cranks opposite, Plates 68 and 69, is practically balanced against the first class of vibrations ; but it has a big couple, and also vibrations of the third class. Engines

with three cranks at equal angles, Plates 70 to 72, are practically balanced as regards the first and third classes, but have large couples. Now it was shown by Mr. Yarrow at the Institute of Naval Architects (Transactions 1892, vol. 33, page 213) that by balancing the effects of the couples the heavy vibrations could practically be got rid of in torpedo boats and similarly built vessels with high-speed engines. This was successfully done with a few small weights in the four-cylinder engines of the "Spitfire" and "Swordfish," Plates 64 to 67, as previously mentioned.

The conclusion therefore was hastily drawn that engines for land purposes could be similarly dealt with; and an engine was built which was absolutely balanced as far as the first and second classes of vibrations were concerned, but experience showed that buildings took up the higher-speed vibrations forming the third class; and it was finally found necessary to fit a return connecting-rod to one line of cylinders, in order to obliterate these vibrations. This expedient gave both in theory and on trial a perfect non-vibrating engine in the station. Three-cylinder engines however, with equal-angle cranks, Plates 70 to 72, in which the third class of vibrations were practically obliterated, were working in central stations without difficulty from vibration; and further investigation led to the conclusion that buildings respond to the quicker vibrations, but are practically indifferent to the heavy but slower vibrating couples which give such trouble in ships. The three-cylinder engine with equal-angle cranks, Plates 70 to 72, has consequently been adopted as the standard above 200 H.P. for central stations in densely populated districts. Similar engines are also used where a uniform turning effort is especially required: though this object can of course be attained to any desired extent in other kinds of engines also, by providing a sufficiently heavy fly-wheel.

Advantages of Forced Lubrication.—For all kinds of engines the plan of forced lubrication gives the same advantages: namely, automatic lubrication, noiselessness, economy, and freedom from wear. This is due to the working surfaces being kept apart by the film of oil forced between them. Although generally the pressure per square

inch on the bearing itself is far in excess of the oil pressure used, yet the relaxation of pressure on the return stroke in a double-acting engine permits the oil at these times to be driven between the metal surfaces ; and during the fraction of a second occupied by the acting stroke the film of oil cannot be squeezed out. This might indeed be readily taken for granted, and is clearly proved by the absence of wear in the large number of engines already built. It is at least obvious that the oil is in the best position to take advantage of the momentary relaxation of pressure between the surfaces, if it is itself under a pressure sufficient to push it in between the brass and the journal, so as to flood the bearing completely. If the oil is supplied by gravity alone, under the head usually given in double-acting engines, there is not sufficient time for permitting it to penetrate to any distance. In a single-acting engine under constant thrust, no such film is possible. In both the latter cases, the journal will of course be greased ; but if friction and consequent wear of the journal are to be absolutely prevented, such a film of oil as the forced lubrication provides between the journal and brass is essential. The better the body of the oil, the less chance will there be of effective lubrication without adequate oil pressure. To show how the oil film should affect the economy, reference may be made to a paper by Professor Robert H. Thurston published in " Engineering " (1889, January 18, page 69), in which the friction in an engine with balanced slide-valve is subdivided as follows:—main bearings 47·0 per cent., piston and rod 32·9, crank-pin 6·8, cross-head and wrist-pin 5·4, valve and rod 2·5, and eccentric-strap 5·3 per cent. The friction of piston and rod here probably includes that of the guides, which are lubricated under pressure in the engines now described ; and in addition to this it will be seen that the journal friction, which can be reduced by oil under pressure, amounts to nearly 65 per cent. of the whole. When it is borne in mind that in an ordinary engine, working at one-quarter of its full power, about 50 per cent. of the power developed is wasted in friction, it is clear that the effect on the economy by the reduction of journal friction should prove considerable at low loads ; and with these double-acting self-lubricating engines, as compared with single-

acting engines, it is certain that this is so. It was first pointed out by Mr. Alexander Siemens in a paper read before the North of England Institute of Mining Engineers (8 Dec. 1894, page 212), in which he compared the results of the first Belliss 300-H.P. self-lubricating engine with a Willans engine of similar power, the two working alongside each other at his Charlton Works; his results showed that the gain due to the diminished friction increased considerably as the loads were reduced.

In dealing with high-speed engines, it is impossible to avoid referring to the admirable work which has been done by Messrs. Willans and Robinson in determining the conditions for economical working under various circumstances. Their trials however were made with single-acting engines; and although the results in general will apply to any engine, the reduction of friction in the double-acting self-lubricating engine should qualify them to some extent in detail. If the lubrication is accomplishing the purpose for which it is intended, the efficiency of the engine provided with forced lubrication ought to stand out high; and that this is so for all loads has been proved by results from some hundreds of engines. By the courtesy of Professor Kennedy the author is enabled to give in Table 4 the results of a trial made by him of one of these Belliss engines, supplied to the Sunderland Corporation Electric Supply Station, which will serve as an example. Here the engine efficiency at maximum load, it will be noted, works out at 96.3 per cent. The results are also plotted as a diagram in Fig. 12, Plate 73. The following comment upon the figures in the Sunderland tests was added by Professor Kennedy:—"The most singular point about them is the extraordinary high brake efficiency of the engine, which is altogether much higher than anything I have previously found. I do not know the special cause of this. I have been extremely suspicious of the figures, and have had everything checked repeatedly. The different figures taken at different periods are quite consistent with each other, and there is nothing in the records to suggest error, except the figures themselves. I can only place these on record, without saying more about them." There is no doubt that the efficiency is remarkably high; but the conditions, as already pointed

TABLE 4.—*Trials of Belliss 200 H.P. Quick-Revolution Self-Lubricating Engines, Condensing. See Plates 73-4.*

Cylinders 12½ and 20 inches diameter, with 9 inches stroke. Working pressure 120 lbs. per square inch above atmosphere.

Station	Sunderland Electric-Supply Engine, tested by Professor Kennedy. Fig. 12.						Cheltenham Electric-Light Engine, tested subsequently. Fig. 14.			
Load	Maxi- mum.	Normal full.	Three quarters.	Half.	One quarter.	Only ex- citing.	Normal full.	Three quarters.	Half.	One quarter.
Mean effective pressure per sq. inch } lbs. reduced to low-pressure cylinder	42·3	37·6	28·6	20·0	9·7		36·1		20·6	10·4
Mean revolutions per minute . . . revs.	364·6	365·0	364·5	363·9	363·8		365·5		361·0	361·5
Mean Indicated horse-power . . . I.H.P.	217·5	193·6	147·1	102·7	49·8		185·7		104·8	53·1
Mean Brake horse-power . . . B.H.P.	209·5	186·0	140·6	97·0	44·5		176·8		97·4	44·2
Mechanical Efficiency $\frac{\text{B.H.P.}}{\text{I.H.P.}}$ per cent.	96·3	96·1	95·2	94·4	89·3		95·2		93·0	83·2
Water per hour, total lbs.	3772	3383	2628	1920	888·5		3301		1939	987·9
" " " per B.H.P. . . . lbs.	18·0	18·2	18·7	19·8	20·0		18·6		19·9	22·3
Coupled to Continuous-Current Dynamo. Fig. 13.							Coupled to Alternator.			
Mean effective pressure per sq. inch } lbs. reduced to low-pressure cylinder		36·0	24·2	19·2	10·5	2·2		28·4	23·0	
Mean revolutions per minute . . . revs.		367·6	365·3	362·6	365·2	364·8		350·2	351·0	
Mean Indicated horse-power . . . I.H.P.		186·7	129·4	98·2	54·1	11·6		144·8	114·4	
Mean Electric horse-power . . . E.H.P.		168·6	115·1	83·8	40·9			126·8	98·5	
Combined Efficiency $\frac{\text{E.H.P.}}{\text{I.H.P.}}$ per cent.		90·3	88·9	85·3	75·6			87·5	86·1	

out, all tend in this direction, and similar results have been proved over and over again with the self-lubricating engines tested at the author's works. In order however to establish the results obtained by Professor Kennedy, a further trial was conducted with a similar engine made for the Cheltenham Electric Light Station from the same drawing as that at Sunderland; and it will be seen that the results given in Table 4, and plotted in Fig. 14, Plate 74, entirely bear out those of the other trials. The high efficiency that can thus be obtained makes itself felt in the economical working of the engine; and as it is due to an absence of friction, a far greater saving will probably arise from the diminished necessity for adjustment and repair on account of wear. In the writer's opinion there is at present too much difficulty in obtaining the necessary accuracy in indicating a high-speed engine to render the indicated horse-power alone a useful standard for comparison of efficiency. The consumption of steam for work done is what the customer looks at; and results given per indicated horse-power, which take no account of the heavy losses through friction, are useless in comparing engines of different kinds. It will be seen from Fig. 13, Plate 73, giving the curves of the combined efficiency and consumption in the subsequent tests of the Sunderland engine coupled to a continuous-current dynamo, that the previous brake tests are fully borne out. These subsequent tests were made immediately after the others, in the presence of Professor Kennedy, and Mr. Snell, the electrical engineer to the Sunderland Corporation. The results throughout are undoubtedly good; and for the sake of comparison curves have been added showing the consumption and efficiency of a Willans engine of about the same power combined with a Holmes dynamo, in a trial made by Professor Kennedy and reported in "Engineering," 2 June 1893, page 783.

Governing.—Amongst the many admirable papers emanating from Messrs. Willans and Robinson on the subject of high-speed engines is a recent paper read to this Institution by Captain Sankey (Proceedings 1895, page 154), in which governing by expansion-valve is compared with ordinary governing by throttle-valve. This

important contribution to the subject is chiefly remarkable for the tendency of the results presented to displace the expansion-valve governor from the high position it has hitherto held as an economical appendage for reducing power. The disadvantages due to the higher initial pressure with consequent leakage, the frictional loss due to compression, and the increased losses due to liquefaction, are clearly pointed out; and the resulting efficiencies of the two modes of governing, especially when determined by work done and not by indicated horse-power, are shown to be not greatly in favour of the expansion-valve governor. Expansion gear of this sort is also far more liable to wear; and a small amount of wear, or of wrong adjustment after repair, might lead to a steam distribution yielding at low loads considerably worse economy than that obtained in the official trial at the works. As in the case of economical results, the comparative efficiency of the two methods of governing will also depend in detail somewhat on the kind of engine; and for this reason the trials that have been made by the author for determining the value of the two kinds of governor with the self-lubricating engine may be of interest. The results given by Capt. Sankey are also based entirely on the indicated horse-power; but as the output of the engine is largely modified by frictional and other losses due to the action of the governor itself, the indicated horse-power results are of little practical value. The circumstance that the "Crescent" engine, Plates 68-9, is arranged with both the valves driven by a single eccentric naturally led in the direction of expansion governing, owing to the ability of this governor to act simultaneously on both high and low-pressure valves. Trials made in 1891 with a number of sets of dynamo machinery of about 80 horse-power, constructed by the writer's firm for the Cunard steamships "Campania" and "Lucania," gave excellent results as far as governing went; but at low powers the results in respect of economy and efficiency were by no means as good as anticipated; and although in consequence of its effective action the use of the governor was continued, the poor economical results led to special trials being made further on for determining this point more exactly. So far as the governing itself is concerned, since the above machinery was built, the throttle

governor with ordinary fly-wheel has been made by the reduction of friction to give exceedingly steady results, with a permanent variation of only 2 to 3 per cent., and a momentary run-up to about 10 or 12 per cent. when all the load was suddenly thrown off. With the ordinary fly-wheel it is not possible to get much finer governing without introducing a tendency to hunt. The effect of a large fly-wheel permits the fitting of a much more sensitive governor; and with a fly-wheel of suitable dimensions governing by throttle can be made as fine and steady as may be required. Alternators of ordinary design have of course in themselves quite enough fly-wheel effect for enabling the usual engine fly-wheel to be dispensed with; and with these there is no difficulty in keeping the run-up below 5 per cent., with permanent variation of 2 per cent. The reputation of the expansion-valve governor has been much increased by the value set upon it in the United States, where it is almost universally used; but this fact is largely qualified by a consideration of the high fly-wheel effects employed in conjunction with the governor in order to obtain the maximum results. The following Table 5 gives a few typical examples for

TABLE 5.

*Energy stored in Fly-wheel and revolving parts of Dynamo
per electric horse-power at full load, for various services.*

	Foot-Tons.	Revs. per min. of engine.
Ordinary High-Speed Engines for electric lighting with continuous-current dynamos	0.2 to 0.3	350
Ditto, with heavy alternator.	1.5 to 3.5	360
Electric Traction, Continental example. . . .	2.0	150
„ „ Montreal Street Railway	4.0	70
„ „ Brooklyn Electric Tramway	4.7	75

enabling a comparison of these fly-wheel effects to be made for various services. For the Waterloo and City Railway, where it is desired to light the trains steadily, direct from the motor currents, a fly-wheel of about $5\frac{1}{2}$ tons has been fitted on each of the 300-H.P. sets in order to obtain the required results, namely permanent

variation not exceeding $1\frac{1}{4}$ per cent. and momentary not exceeding $2\frac{1}{2}$ per cent. when all the load is suddenly removed. As far as governing is concerned therefore it may be allowed that the advantage, if any, is on the side of the throttle-valve governor, because it is equally powerful in governing, far less liable to derangement and wear, and much easier to adjust.

In respect of economy, the matter will naturally be looked at from two points of view:—firstly for electric lighting and electric power supply, where the maximum economy is required at about full load; and secondly for electric traction, where the normal load will probably be a much smaller fraction of the full load than in electric lighting. For electric lighting and power supply, there is no question in the author's mind as to the superior efficiency of the throttle-valve governor. For electric traction, his experiments seem to show that with the double-acting self-lubricating engine there is little if any benefit to be derived from the expansion-valve governor; and this benefit will probably be neutralised by the mechanical difficulties, which the extra wear on the expansion governor will subsequently entail. To determine this point a number of experiments have been made, of which the results are shown in Table 6 and in the curves in Fig. 15, Plate 74. These trials were made with a self-lubricating engine of 250 horse-power, fitted with an expansion governor actuating an eccentric common to both valves. The curves XX show the results with the expansion governor, and the curves TT the results from the same engine when governed by the throttle valve. It will be noticed that, whilst the expansion-valve governor has a slight advantage when indicated horse-power is considered, the advantage is all on the side of the throttle valve when the output or electric horse-power is considered; and this of course is the only matter of importance in practice.

From all the diagrams it will be seen that the characteristic curve of water consumption for the Belliss engine is more horizontal than those for single-acting engines. This is due, as already pointed out, to the action of the forced lubrication in reducing the amount of friction, and consequently the amount of steam used per brake horse-power. In order to elucidate this point more fully, there is added

TABLE 6.—*Comparative trials of Belliss 250 H.P. Quick-Revolution Self-Lubricating Engine, Condensing, when governing by Expanding and by Throttling. See Fig. 15, Plate 74.*

Cylinders 12 and 20 inches diameter, with 10 inches stroke. Boiler pressure 150 lbs. per square inch above atmosphere.

Governing by Expansion Governor or by Throttling.	EXPANDING. Expansion Governor <i>in</i> action.				THROTTLING. Expansion Governor <i>out</i> of action.			
	Full.	Five eighths.	One third.	One quarter.	Full.	Five eighths.	One third.	One quarter.
Load								
Mean effective pressure per sq. inch } reduced to low-pressure cylinder }	41·0	27·0	16·4	12·4	40·1	25·9	15·7	10·9
Mean revolutions per minute . . . revs.	370	373	380	380	370	370	380	382
Mean Indicated horse-power . . . I.H.P.	240·9	161·0	99·0	75·3	235·4	152·2	95·0	66·2
Mean Electric horse-power . . . E.H.P.	213·0	132·8	77·8	53·0	213·0	132·2	77·8	53·0
Combined Efficiency $\frac{\text{E.H.P.}}{\text{I.H.P.}}$. . . per cent.	88·3	82·4	78·5	70·3	90·4	86·8	81·9	80·0
Water per hour, total lbs.	4579	3041	2209	1818	4473	2871	1992	1505
„ „ „ per E.H.P. lbs.	21·5	22·9	28·5	34·3	21·0	21·7	25·6	28·4

in Fig. 12, Plate 73, for comparison with Sunderland, as shown by the dotted lines, the consumption per brake horse-power for a Westinghouse engine of about the same power, fitted with an expansion-valve governor, for which the data are taken from the *Proceedings of the Institution of Civil Engineers*, vol. cxiv, page 68. It will again be seen that, while with the expansion governor in the Westinghouse engine the result at half load is better than at full load, it is not better than the result obtained at half load with the throttle governor in the Belliss engine, which has moreover a decided advantage at full and low loads.

For the sake of further comparison another curve has also been added to Fig. 12, Plate 73, showing the efficiency of the Willans 150 H.P. engine, reported in the same volume of the *Civil Engineers*, pages 89-90.

Discussion.

Mr. Morcom called attention to the additional diagram shown in Plate 75, which, though altogether a hypothetical diagram, would serve to illustrate what had been referred to at the end of the paper (page 330): namely that, in an engine in which the constant friction was low owing to forced lubrication, the curve of water consumption per brake horse-power was more horizontal than when the friction was higher. Here the thin curve A A represented the consumption in a single-acting engine with throttle governing; the thick dotted curve X X pertained to the same engine with expansion governing; and the thick full curve L L to the double-acting self-lubricating engine with throttle governing. The larger area B D E consequently showed the advantage of expansion governing over throttling in single-acting engines; while the much smaller area C D E showed the much smaller advantage of expansion governing in the single-acting engine over throttle governing in the double-acting self-lubricating engine.

Mr. JOHN I. THORNYCROFT, Member of Council, said the paper dealt with a subject which had occupied his attention a great deal ; and he thanked the author for the complimentary allusions to the work of his own firm. When he had himself commenced working with engines of rapid rotation, he had been led to use engines which made a large number of reciprocations per minute, because the particular work he had to do rendered it necessary to have as light an engine as possible. From what had now been stated in the paper it appeared that, with the plan of forced lubrication here described, not only could a light engine be made an economical engine, but it could also be made a durable engine. He therefore thought that, owing to the economy and reduction of space thus realised, there was a great future for rapid rotating engines. The effect of high-pressure lubrication, in enabling double-acting engines to do work which it had been considered could be done with advantage only by single-acting engines, was a great gain if it could be accomplished, as he believed it could be, because it increased the quantity of work that could be got out of a given weight of material ; a double-acting cylinder did double the duty of a single-acting of nearly the same weight. A journal must necessarily have a little freedom in its bearing, and although the relaxation of pressure in the return stroke was for so short a period, the oil being under considerable pressure was able to force its way in, first on one side and then on the other, and to cover the whole rubbing surface effectually with a film which could hardly be displaced in the short time occupied by the acting stroke. It was desirable to use all the pressure that was practicable, provided that too much power was not wasted in pumping the oil. With the rapid flow of oil through the circulation, it appeared to him that any dirt it contained might be likely to go round and round, and do repeated damage ; and he suggested that it would be an advantage if more storage space were allowed, so that the oil might have some time to settle. In a land engine it would not be a considerable space that would be required ; nothing like so large as was desirable in the boiler, but a sufficient space where any sediment could fall. Oil filters also were now used. In a gas-engine which he had running, the oil

(Mr. John I. Thornycroft.)

went round and round, passing through the filter in each circuit. Although it appeared dirty as it came from the engine, it went back again clean into the circulation ; and no trouble was found in using it over and over again, he did not know for how long. If something of that sort could be combined with the forced lubrication in the rapid rotating engine, he thought it would be an advantage.

He asked what was considered by the author to be a reasonable factor of safety, such as was referred to in the first page of the paper.

Professor W. CAWTHORNE UNWIN considered it highly interesting that journal friction, which seemed for so long to have been generally looked upon in a rather theoretical kind of way, should at last have been dealt with in such a practical manner as to lead to so great an improvement in the working of engines. In Table 5 (page 329), in which the energy stored in the fly-wheel and revolving parts of the dynamo was given per electric horse-power, it would add he thought to the interest and instructiveness of the information if the energy could also be stated on the basis of the work done in one revolution. [See page 360.]

Mr. BRYAN DONKIN, Member of Council, criticized the unqualified use of the designation "high-speed" in the title of the paper inasmuch as the piston speed of 550 to 640 feet per minute in Tables 4 and 6 was not a high piston-speed, but rather a low one. The term "rapid rotating" would perhaps be more correct for these engines. In mill engines the piston speed was from 600 to 700 feet per minute ; here it was only from 550 to 640 feet per minute. The tendency at the present time he supposed was to shorten the stroke and increase the rotative speed, with a view to greater economy. The high mechanical efficiency was remarkable. It would be interesting to have an experiment made on the same engine, if possible at the same speed and the same load, at first with the forced lubrication, and afterwards without it, that is, with only the old-fashioned lubrication. This could be done either without steam in the cylinders, or with steam

in them; the latter of course would be preferable in order to make the experiment truly comparative.

Respecting the two-cylinder compound engine at Messrs. Siemens' Charlton Works, which had worked continuously for four years (page 321), he asked what was the number of hours per day or the number per week; was it running practically all day?

MR. WILLIAM BROWN, manager of the works, replied that the engine had been running for about four months from six o'clock on Monday morning until one o'clock on Saturday, without stopping. Generally it ran from 10½ to 11 hours per day.

MR. J. HARTLEY WICKSTEED, Vice-President, asked for an explanation of how it came about that governing by the expansion valve was better when the water consumption was measured per indicated horse-power per hour, whereas governing by the throttle valve was better when the electric horse-power was made the basis for the comparison (page 330).

MR. A. TANNETT WALKER, Member of Council, was glad to have been one of those who had visited the works of Messrs. Belliss on the previous day; and he had been greatly delighted with the work he had seen being there carried out. What had struck him most with regard to it was the smallness or thinness of the material, the beautiful castings, the fine work, and the little space occupied by the engine when it was complete. It had also been impressed upon his mind that, when there was such good material and such good workmanship, and when an engine had been so well put together, it was of the utmost importance to respect the good material and the good workmanship by keeping the engine clean; and it was impossible to keep it clean and free from friction unless the oil were forced to flow all over the surfaces that were rubbing together under pressure. This matter he felt much indebted to the author for having emphasized in the paper, from which he thought a good lesson might be learnt. In regard to the piston speeds, he remembered his firm many years ago making for the President an

(Mr. A. Tannett Walker.)

engine of six feet stroke, indicating from 3,000 to 4,000 horse-power, which had a piston speed of 1,200 feet per minute, and the bearings did not get hot.

Mr. R. E. CROMPTON thought that, when such a valuable paper as the present had been prepared for the Institution, it was only fair that in the discussion those who had used these engines successfully to a considerable extent, as he himself had done, should say something about them. From his own experience he could say nothing but good of them. While he was himself in favour of what he considered were rightly called high-speed engines, he gathered from remarks which he frequently heard made that there was still lingering in the minds of some mechanical engineers the idea that there was something novel, something yet untried, in high-speed engines as compared with the slower and heavier make of engines formerly used. As perhaps almost the first user of large high-speed engines, he might deal from practical experience with such a question as that of how many hours they would run continuously. From the question itself it would appear that there was still a lingering idea that long hours of running proved a difficult test for an engine. Tested in that way he could state that no engines in the world had run such long hours as high-speed engines. High-speed colliery engines he knew were running year and year about, and stopping only for a few hours for cleaning during the Christmas week. There were also many cases that he knew of high-speed engines employed in electrolytic work which ran continuously, stopping only during the Christmas week. Professor Kennedy would no doubt corroborate the statement that modern well-constructed high-speed engines, of which the Belliss engine was a leading example, could be worked with only one cleaning down and general over-looking in the year. Such a result had been arrived at after twelve years' continued development, so that this kind of engine could no longer be considered in its initial stage. Where steam engines of large power were required for meeting the great modern development of large central electric-power stations, the high-speed engines had deservedly won their position, and he believed

they would gradually supersede low-speed engines, because not only was there so much less material in them, but also they required no larger quantity of good workmanship than the others. In every respect, in economy of fuel, of water, and especially of lubricants, and in a further economy of the labour and attendance required to start and take care of them, high-speed engines possessed such important practical advantages over others, that the engineers of large electric-power stations were continually finding there was no comparison between the old slow-running engines and the high-speed engines in doing the largest amount of work at the lowest cost. The papers that had appeared from time to time from Mr. Willans and others, and now from Mr. Morcom, on high-speed engines, he always kept beside him as most useful works of reference; they were undoubtedly of the highest value.

Sir EDWARD H. CARBUTT, Bart, Past-President, had yesterday had the pleasure with a large number of other members of going round Messrs. Belliss' works, and had been much struck with their new construction of high-speed engines pumping in oil under high pressure, and enabling them to arrive at the result pointed out by Mr. Crompton, so that if these self-lubricating engines would run for an hour they would run for a year. It would be remembered that something of the same kind had formerly been experienced with rolling-mill engines, of which it had rightly been said that, if they could roll only a short length, say a few inches, they could roll a mile, or as great a length as the material would allow. The corresponding fact with regard to these high-speed self-lubricating engines had been thoroughly brought out by the present capital paper, for which he considered that the members were greatly indebted to the author, and for the many valuable facts he had placed before them. In regard to the vibrations emanating from large central electric stations situated in densely populated neighbourhoods, he had mentioned at the Belfast Meeting last summer (page 333) that at the St. James' electric station in London considerable trouble had been experienced from vibration, though not in the immediate neighbourhood of the station. It had been found that, when two engines were running

(Sir Edward H. Carbutt, Bart.)

together synchronously, the vibration would be started in some of the clubs as much as two hundred yards away, being transmitted all through the foundations; the windows at some distance off would shake, showing that the vibration set up at the engines was carried underground to that distance. A great deal of work he believed had had to be done in putting in new foundations; and even these had hardly proved successful for satisfying the clubs that there was not a nuisance. If the difficulty of vibration could be overcome by such engines as were described in the paper, these would be of great benefit to electric-lighting stations.

Professor ALEXANDER B. W. KENNEDY, Past-President, had come to Birmingham not only for the purpose of attending the present meeting, but also in order to have an opportunity of going to Messrs. Belliss' works, with a view to inspecting one of their engines with which the author had undertaken to produce, with a throttle governor, results of a somewhat unusual kind. The statements with which his own name had been connected in pages 325-7 of the paper were perfectly correct. The brake efficiency of the particular engine used in Sunderland was so high as to render him at first strongly suspicious of some mistake, and he did his best to cross-examine all his own records as well as the author's; he had not been able however to find any mistake in them. The figures appeared to be consistent, and he could only conclude that the engine really had an unusually high brake efficiency. Although on that occasion the brake efficiency was higher than he had ever found in any previous tests of the same kind of engine, it had since been repeatedly found that exceptionally high brake efficiencies had been realized. This he did not doubt was due to the fact that the engine was double-acting, the plan of forced lubrication having rendered the use of such an engine practicable. As to the suggestion (page 334) that one of these engines should be run at full load without the forced lubrication, he should certainly feel some hesitation about it himself, and in any case should not like it to be done with any of his own engines. Engineers he thought were indebted to Messrs. Belliss for their insisting on working down to brake horse-

power, in addition to the common practice of working through to electrical horse-power. Naturally for the purposes for which so many of these engines were used the main result wanted, as mentioned in the paper (pages 330-1), was the combined efficiency or ratio of electrical to indicated horse-power. At the same time it was important to get at the mechanical efficiency or ratio of brake to indicated horse-power; otherwise it could not be seen whether a high combined efficiency was due to a particularly good dynamo or to a particularly good engine. In emphasizing the necessity for obtaining the measurement of brake horse-power, the author was probably stimulated by the remarkably good brake efficiency attained with the self-lubricating engines. A statement of efficiency in terms of pure mechanical engine efficiency or brake horse-power was specially important when it was seen from the diagrams exhibited that the extra indicated horse-power obtained per lb. of water by means of forced lubrication might be all used up in working some special apparatus which possibly was not wanted. Whether this were so could only be ascertained by analysis, with the help of brake trials such as had been carried out by the author.

There had been some places in London where high-speed engines of various kinds had caused considerable vibration: the St. James' electric station in Pall Mall, referred to by Sir Edward Carbutt (page 337), was one. In that instance however he believed there was no doubt that the vibration had been due to an imperfectly designed foundation; and he was afraid that neither the use of the Belliss engines nor of any others would have prevented vibration. Another serious case which he had had occasion to consider carefully had been due, he had no doubt, to the fact that a somewhat badly designed foundation block had been placed on what had afterwards been found to be the site of an old river bed; and the vibration was in some way communicated by underground water to places at a distance of some hundreds of yards, to an extent which really amounted to an intolerable nuisance.

He could thoroughly confirm what had been said by Mr. Crompton (page 336) about the way in which high-speed engines, both of the Willans and of the Belliss kind, would run day after

(Professor Alex. B. W. Kennedy.)

day and year after year continuously, with a minimum amount of looking after or repair. He had a number of Belliss engines at work, and he knew nothing about the inside condition of them, nor did he trouble himself about it. They would run for twelve months continuously, and then required to be cleaned. It was just the same with the Willans engines: under ordinary circumstances nothing whatever was known about their internal arrangement, nor about the main bearing brasses. When the slack time came in the summer they were opened up and cleaned, when piston rings could be renewed and other such matters attended to. Both of these high-speed engines did a great amount of hard work, as was well understood by everyone concerned with electric lighting, and still more with electrolytic work; and they did it at an expense in maintenance and attendance which was ridiculously small. The present paper formed in his opinion a valuable addition to the literature of high-speed engines, a literature which had been of singular value already.

Mr. ALFRED SAXON said that, while undoubtedly there was a field for high-speed engines, he had noticed in going through Messrs. Belliss' works on the previous afternoon—and he desired to express his obligations for the opportunity of seeing them—that a beginning was just being made there in building engines of a larger size; and it was with these he thought that difficulties would now be likely to be met with, in competing with ordinary Lancashire mill-engines for economy. All the comparisons that had been presented in the diagrams exhibited were comparisons of high-speed engines with other high-speed engines. The result however would be different if a comparison were made with some of the best Lancashire mill-engines for economy and efficiency: apart at least from brake efficiency, because it had been clearly proved that the plan of forced lubrication was of great advantage in producing the remarkably high brake efficiency obtained from the Belliss engine; but for water or steam consumption the latter he thought would not compare favourably with the best Lancashire mill-engines. In all high-speed engines there were features which militated against their economy, particularly the somewhat higher percentage of clearance

in the cylinders. In the large mill-engines the chief improvements of late years had been brought about by a reduction of cylinder clearances. The waste due to excessive cylinder clearance on account of the high speed of rotation seemed to him therefore to be the great difficulty which would have to be overcome in high-speed engines. The slower revolutions of large mill-engines, even with a high piston-speed, were attended with less waste by cylinder clearance because the number of steam admissions was fewer in the same time. The more frequent admissions formed one of the great disadvantages in high-speed engines, which for the larger powers he considered would consequently compare unfavourably with the best commercial engines for mill purposes. The latter had also been introduced in some instances for electric lighting, particularly in Manchester. The choice between the two kinds of engines for large powers he believed would depend upon whether the high brake efficiency of the self-lubricated engine would assist it as a high-speed engine in competing with the higher economy of the slower-revolution engine in respect of steam consumption.

Professor JOHN GOODMAN said it was particularly interesting to those who had worked at the subject of lubrication to find the remarkably high mechanical efficiency which had been obtained by means of forced lubrication. At the time when the Reports were presented of the Research Committee on Friction (Proceedings 1883-85-88-91) he remembered hearing it asked, what was the use of recommending bath lubrication, which could not be obtained in practice? Here however was now an admirable illustration of the practical value of the experiments then made by Mr. Tower for the Institution. In the present paper was exemplified a practical method of applying bath lubrication to a high-speed engine; and he therefore thought the Institution was greatly to be congratulated upon the research work that had been done by the Friction Committee, which had proved so extremely valuable in practice.

One reason he believed why the engine now described gave such high mechanical efficiency was that white metal was used in all the bearings instead of brass. Having done a good deal of experimental

(Professor John Goodman.)

work during the last six years with different kinds of white metal for bearings running under high pressures, he had found that the coefficient of friction with even the worst of them was considerably lower than with the very best brass or phosphor-bronze or hard gunmetal. The true reason he believed to be that when the engine or machine was working there must be some spring in the shafts and in the bearings, however slight. If the bearings were made of a hard material, like phosphor-bronze or brass or gunmetal, it was like sitting on the sharp edge of a hard chair; but with bearings of soft white-metal it was like sitting on the edge of a well-padded chair. This illustration represented what he thought really took place in the working of machinery. When the spring occurred in a shaft, the whole of the load came on one edge or at one end of the bearing. White metal allowed the pressure to be distributed more evenly than it would be distributed on a harder metal. A mechanical efficiency of 94 per cent. he had previously heard of as having been obtained with an engine fitted with white-metal bearings, tested by Mr. Wilson Hartnell of Leeds.

An interesting point in the diagrams was the parallelism of the lines representing indicated horse-power and brake horse-power: thus showing that the power required to drive the engine itself was practically constant at all loads. In years gone by this had sometimes been regarded as a mere theory; but here was an admirable instance of the interval between the two lines of indicated and brake horse-power being practically constant. Such a result he believed was largely due to the fact that the lubrication was so excellent. If there were poor lubrication, these two lines would not be parallel.

It would be of great value and interest if the author would give the working pressures per square inch on all the bearings, both the crank-pins and the rest of the rotating bearings; and also the surface speeds of those bearings. He asked also what quantity of oil was used; how would it compare during a year's running with the quantity of oil used in the ordinary way? The engine being boxed in and flooded with oil, he should imagine that the quantity of oil used under these circumstances would be much less than with the

ordinary mode of oiling bearings. In a double-acting engine it had been pointed out in the paper (page 324) that the reversal of pressure on the bearings permitted the film of oil to be maintained between the bearing surfaces, because there was not time for it to be squeezed out in the acting stroke. In some experiments which he had been recently making on this very point, he had made use of a friction-testing machine in which the whole load could be suddenly applied, and the friction automatically recorded. The machine was allowed to run with the lever propped up, so that the bearing was practically under no pressure; and the friction line was recorded on the drum, which was revolving rapidly. Then suddenly the lever was dropped, and a load of about 1,000 lbs. per square inch was brought upon the bearing. It was thus found that it took from two to three seconds before the full friction came upon the bearing; the interval depended somewhat on the viscosity of the oil. Roughly speaking, the thicker the oil, the longer was the time it took; and the thinner the oil, the shorter the time before the bearing felt the full friction. It was distinctly seen that it took from two to three seconds for the friction to get to the maximum; and this of course represented the time taken in squeezing the oil out from between the rubbing surfaces.

In the balancing of the engine referred to in page 323 he enquired what was meant by the return connecting-rod which it had been found necessary to fit to one line of cylinders in order to obliterate the vibrations.

Mr. MORCOM explained that it was like the return connecting-rod employed in the old marine engines of the Maudslay build, in which the crank shaft had been so close to the cylinder that a pair of piston-rods had to be carried to a cross-head on the far side of the shaft, whence a return connecting-rod was brought back to the crank.

Mr. WILLIAM SISSON agreed with Mr. Donkin (page 334) in wishing if possible to know what was the difference in friction between the engine running with forced or pumped lubrication, and the same engine running with the ordinary bath lubrication. The friction experiments conducted for the Institution by Mr. Tower

(Mr. William Sisson.)

had opened the eyes of engineers to the practical requirements of lubrication, and had been of the utmost value. They had shown that bath lubrication—not indeed forced lubrication by pumping, but free washing lubrication—gave an average coefficient of friction about one-sixth or one-seventh of that obtained with good siphon lubrication. The point was whether an oil pressure of 15 lbs. per square inch, which was admittedly far below the pressure per square inch on the bearing surfaces, made much difference in regard to efficiency of lubrication: whether ordinary bath or free washing lubrication would not be almost equally efficient, if not quite so. This was what he imagined many engineers besides himself would like to see tested. It would be remembered that an interesting experiment had been tried by Mr. Tower with a rotating journal having a brass on the top, the lubricant being supplied by a bath on the under side (Proceedings 1885, page 58). A number of small holes were pierced through the brass to the bearing surface, and a pressure gauge was connected with them successively, which was found to indicate practically the pressure per square inch on the actual surfaces in contact. Those experiments showed that, even without forced lubrication by a pump, oil might be got in freely, and would flow in to such an extent as might be required, whatever might be the pressure on the bearing within the limits of the experiments. In his own experience with some high-speed engines he had met with something that seemed to point in the same direction. In the crank-shaft bearings of a double-acting engine the oil was forced back up the vertical pipe of the sight-feed lubricator to a height of 4 or 5 inches above the top of the bearing surface (compare Proceedings 1883, page 638). As shown by Mr. Tower's experiments the oil must be supplied at a place where there was no pressure: it was useless to attempt to put oil in on the pressure side; it must be supplied on the slack side.

The unequal pressure on a bearing in working, to which attention had been called by Professor Goodman (page 342), seemed an important point; because, whatever might be the strength of the shaft or the journal used, there must be more or less spring or

yielding when it took the load. Instead of putting in a soft metal, which could be compressed but would not return into place, a better plan he suggested was to make the pedestal or bearing swivel or spring, much in the same way as the armature-spindle bearing of a dynamo was held, and to let the brass overhang considerably at each end. This he believed would be found to be an excellent plan to carry out, to allow of the necessary spring of the shaft or journal. Having himself had some experience in carrying it out with double-acting high-speed engines, he had found that it worked well. The bearing of the brass on the shaft might be perhaps three times or at least twice the length of the support of the brass in the frame or pedestal; and it seemed to accommodate itself well to the shaft by means of the slight swivelling movement.

With regard to governing, he was afraid that many engineers besides himself were obliged to differ to some extent from the author. The difficulty in depending on throttle governing alone was that, in an engine with a variable load, which might be called upon to exert a high power for a short time, say for example only one hour in the week, the cut-off must be so late as to suit the minimum boiler-pressure that could be depended upon. It seemed clear, as had been pointed out in Capt. Sankey's paper (Proceedings 1895, page 168), that at the beginning of a reduction of load automatic-expansion governing ought to be employed down to a certain point, which had to be determined by experiment; below this load the regulation ought to be continued and completed by throttle governing. It would appear that such an arrangement ought to give the best results. There could be no doubt that, as had been pointed out both by the author of the present paper and previously by Capt. Sankey, to continue governing by automatic expansion down to the lowest load was rather a cruel thing to the engine; as Mr. Crompton had recently said, it banged the engine about. Government by the cut-off was wanted at the beginning when coming down from the full load, especially if the engine was adjusted to work up to an overload; from the overload downwards the governing ought to be by automatic expansion down to half load or some other determined point. With regard to the

(Mr. William Sisson.)

trustworthiness of shaft governors controlling the expansion, he could not see that there was any more difficulty in making a shaft governor trustworthy for regulating the expansion than for controlling the throttle valve. A great number of shaft governors that he had known had worked for many years without adjustment. They might be designed so as to give ample power, with large surfaces and with arrangements for oiling; and he believed they could be depended upon fully as much as throttle governors. With a shaft governor directly controlling the distribution valves it was almost impossible for an accident to take place by reason of the engine running away, because there were so few working parts in the governor that there was hardly anything to get out of order; and if a spring broke, the weights flew out and shut off the steam. Engines with ordinary shaft governors he knew had been running twenty hours a day for three or four years; nothing except occasional cleaning had been done to them, and they were running now as well as ever. For electric traction, where the average load was probably a much smaller fraction of the full load than in electric lighting, expansion governing was particularly required; but the best arrangement was the combination already mentioned of expansion and throttle governing.

Personally he desired to thank the author's firm for the privilege he had enjoyed in visiting their works. It was a generous act on their part to permit so many who might be competitors to see their works, and he desired heartily to acknowledge the privilege.

Dr. JOHN RYAN asked whether in the first class of vibrations dealt with in page 322 it was sufficient to consider such changes in position of the centre of gravity of the moving parts as took place in the vertical direction only. The three classes enumerated he supposed were not considered to be exhaustive. Vibrations due to faulty workmanship and design were probably considered to lie outside the scope of the paper, as they doubtless lay outside the practice of the best engine builders. With the statement that a small amount of vibration might develop into a nuisance, as instanced by Sir Edward Carbutt (page 337), he fully sympathised, because

in University College, Bristol, though he had only a slow running engine, making about 140 revolutions a minute, he was worried by people who complained of the effects. It was astonishing how sensitive some people seemed to be to mechanical movements of one kind and another; and it was perhaps not surprising that vibrations were detected sixty yards away, which were wholly unnoticed in the immediate vicinity of the engines by those more used to the working of machinery. The question of preventing synchronism in engines was likely to be of importance, inasmuch as the unpleasant vibration experienced must be largely due to agreement of the impulses with the period of vibration of some of the parts or connections; and it might be necessary, if speed of revolution went on increasing, to "tune" the engine and its connections by modifications in design, so as to prevent the vibrations from being carried, as at present they undoubtedly were in certain instances, to a considerable distance from the engines. A good deal naturally depended on the foundations; and if these happened to be placed, as in the instance mentioned (page 339), on an old river-bed or a water-bearing subsoil, extreme effects would of course be produced. His own experience hardly agreed with the author's conclusion (page 323) that buildings picked out only the quicker vibrations; for unfortunately the college buildings in Bristol seemed with singular perversity to respond to all kinds of vibrations.

Professor WILLIAM RIPPER agreed with the remark made in page 327, that there was at present too much difficulty in obtaining the necessary accuracy in indicating a high-speed engine to render the indicated horse-power alone a useful standard for comparison of efficiency. For indicating high-speed engines he had himself lately used a simple device, which, although it was only approximate at slow speeds, became more and more accurate as the speed of revolution of the engine increased. As shown in Figs. 17 to 20, Plate 76, it consisted of two barrels, in each of which was a piston valve working over ports in the barrels. Each barrel was surrounded by a chamber, which was connected to a pressure-gauge for recording the pressure of the steam entering the chamber. The valves were arranged to work so

(Professor William Ripper.)

that the chamber surrounding one barrel was connected continuously with the steam or impulse side only of the piston, while the chamber surrounding the other barrel was connected continuously with the exhaust side only. The mean pressure in the first chamber was the mean pressure on the steam side of the piston; and in the second chamber the mean pressure on the exhaust side. The difference between these two pressures was the mean effective pressure on the piston. The oscillations of the fingers of the gauge were reduced to a minimum by throttling down the gauge cocks, as was now done with the gauges on the receivers of compound engines, and with vacuum gauges. Either two separate gauges might be used, or a single differential pressure-gauge, from which the average difference of pressure on the two sides of the piston could be read directly. The higher the speed of the engine, the less was the angle of oscillation of the gauge pointer, and the less the need for throttling the gauge cocks in order to read the mean effective pressure. The action of the piston valves was as follows, I being the impulse-steam valve, and E the exhaust-steam valve. The pipes leading from each end of the engine cylinder entered the indicator as shown in Figs. 18 and 19; one end of the engine cylinder was connected with the passage AB, and the other with the passage CD; and these passages were so arranged that each connected one end of one indicator barrel with the opposite end of the other barrel. The valves were shown in mid-position, which was their correct position when the engine piston was at either end of its stroke. Both valves moved together, and were worked by the same lever. Supposing steam was being admitted to the top end of a vertical cylinder when the piston was at the top of its stroke, then impulse steam would be entering the indicator both at C and at D, and exhaust steam at A and at B. The valves I and E would now move downwards, uncovering their top ports. The impulse-steam valve I thereby opened communication at C between the steam side of the piston and the impulse pressure-gauge; but at D, the port being shut, no steam from this side of the piston could influence the exhaust pressure-gauge. Meanwhile the steam from the exhaust side of the piston entered the indicator

at A and B. At A the port was open, making direct communication between the exhaust side of the piston and the exhaust pressure-gauge; but at B the port was closed, and there was no communication with the impulse pressure-gauge. On the return stroke the impulse steam and the exhaust steam again communicated directly with their respective pressure-gauges. The valve ports remained open or closed during the whole period of each single stroke of the engine piston. The piston valves were without lap; they might be worked either by a lever connected with an eccentric set 90° ahead of the engine crank, or by an equivalent motion, which could easily be obtained without an eccentric in an engine having the main cranks at right angles. The indicator might be made to work continuously, inasmuch as the wear and tear due to the movement of the working parts was extremely small; if required, it might be made to record a continuous mean-pressure line upon a continuously rotating drum.

Having checked this instrument against the ordinary indicator, he had found that with comparatively slow running engines it agreed within three or four per cent.; while the higher the speed went up, the greater became the accuracy. The average pressure indicated by the pressure-gauge was of course a time pressure average, whereas the average pressure registered by an ordinary indicator diagram was a space pressure average. If any ordinary indicator diagram were converted, as could easily be done, from a space diagram into a time diagram, it would be found that the error in the pressure-gauge method was extremely small. In his own experience he had found the instrument very useful.

Mr. M. HOLROYD SMITH gathered from the remarks of previous speakers that a great deal of trouble had been taken in so preparing the foundation on which an engine should stand that the vibrations caused by the engine should not be communicated to the most sensitive residents in the neighbourhood. It seemed to him however that the proper course would be to try to prevent vibration in the engine itself. This had no doubt been done to a large extent successfully; and yet in connection with motor-car work that he

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had recently had in hand the question of vibration had again come prominently to the front. It therefore became necessary to go thoroughly into the subject of vibration in the engine itself. If he rightly understood the three classes of vibration mentioned in the paper, he agreed with them, though he thought they might be put somewhat more simply. In a vertical engine vibration might be taken as the result of the reciprocation of the piston up and down, and of the conversion of this reciprocating movement into a circular movement. The latter might be regarded as a combination of two movements at right angles, vertical and horizontal; and the difficulty of overcoming vibration resulted from the fact that, when the crank or disc of the engine was loaded with a balance weight and was revolving at approximately a uniform velocity, at the moment when the piston arrived at either end of its stroke the balance weight upon the crank was still moving at the same velocity, but in a direction at right angles to the movement of the piston. Therefore the balance weight which had been put upon the crank in order to balance the vertical downward movement of the piston was now producing an unbalanced horizontal movement of its own, when it swung across the vertical centre line at the top of its revolution, and again when it swung across at the bottom. The plan of arranging two or three or four cranks, or as many more as might be desired, did to a certain degree lessen this result; but it was still there all the same. Remembering that equal and opposite forces counterbalanced each other, he had reflected that the proper plan of balancing these movements would be to make two equal cranks, and cause them to revolve in opposite directions; and instead of putting the whole of the balance weight upon one crank, to divide it equally between the two. By this arrangement, with the cranks running opposite ways to each other, when the piston was coming down the balance weights were coming up on either side; and when the piston was stationary at the bottom or top of its stroke, the weights were crossing each other at the top or bottom of their revolution. This seemed sound reasoning, and the only difficulty still attending it in practice would be that, as the two weights crossing each other at the top and bottom of their revolution would not be crossing exactly in

the same vertical plane, they would have a tendency to produce a slight oscillating movement of the crank-shaft longitudinally. The small model exhibited had been constructed in order to test the truth of this theory as thoroughly as it could be tested: more thoroughly indeed than it could be tested in the engine itself. As represented in the photographs, Plate 77, there was no cylinder surrounding the piston, and no bed-plate; there was simply a light frame-work for guiding the piston in its vertical movement, and for keeping the bearings together. The small fly-wheels here adopted were more ornamental than useful, because a fly-wheel of such lightness would not be fit for a piston of the proportionate weight here employed. The first thing illustrated by the working of the model was the well known effect of attempting to put a single-acting engine to work before putting any balance weights on it at all. It was seen that the vertical vibrations were then so violent even at a low speed as to cause the entire model to jump bodily up and down upon the table supporting it. The next step was to put the balance weights on in the ordinary way, for balancing as nearly as possible the weight of the piston; but as the balance weights revolved together in the same direction, according to the usual plan of balancing with a single weight, it was seen that, while the vertical jumping had been done away with, there was now a horizontal transverse oscillation to and fro, sufficiently powerful to produce both a visible and an audible side-shake, which not only communicated itself to the table supporting the model, but also produced a perceptible tremor in the platform on which the table stood. This experiment showed why success had not hitherto been attained in thoroughly balancing the weight of the piston: namely because of the evil effect of the violent side-shake which ensued from the unbalanced horizontal movement of the balance weight itself. As soon however as the ordinary single crank was divided into two, and the two balance weights which here replaced the ordinary single weight were compelled to revolve in opposite directions, it was seen that there was scarcely any shake in working the model, even at a high speed. The little that still remained was due simply to the necessity of working the model by gearing, which drove one of the

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cranks; this crank had to act as a driver to the piston through the connecting-rod, which was alternately under compression and tension; the other crank was driven from the piston through the other connecting-rod, which was also under compression and tension, but in the reverse order; hence there was a slight knock as the two cranks passed the top and bottom centres in opposite directions. This would not occur in practice. As it was essential that the two cranks with their balance weights should invariably rotate in opposite directions, it was necessary to provide some arrangement which should preclude the possibility of their ever revolving in the same direction, from whatever position the engine might have to be started, or whichever way it might have to run. This object could be accomplished in many ways, one of which was illustrated in the diagrams, Plate 78; though not quite according to working proportions, they served to show the action clearly. Here each connecting-rod C was shaped like a bell-crank lever at its upper end, from which a link L was carried down to a sleeve S sliding upon a central vertical guide-pin I. With this contrivance it was evident that the two cranks could not possibly rotate in the same direction, and that their contrary rotation was thereby rendered compulsory.

Mr. LESLIE S. ROBINSON had recently had an opportunity of seeing a low-speed engine running on a method of lubrication somewhat similar to that described in the paper. In the last two boats that had been put on the Dover and Calais route by Messrs. Denny of Dumbarton a plan of forced lubrication was used, with the practical result that the trouble of wiping the engines down had been greatly reduced, and, as pointed out by the author, the attention necessary for such engines was also much reduced. The engines ran on the trips between Dover and Calais at a high speed of boat, and there had been no trouble with the lubrication; it was an entire success. Instead of oil a kind of grease was used, which was forced through at a pressure by a piston in a cylinder; and the rate of the lubrication depended upon the speed of the engine, just as it did in the self-lubricating engines described in the paper.

Mr. G. L. ADDENBROOKE said electrical engineers were all particularly interested in the speed at which an engine could be run. As electricity had now been adapted to so many other purposes besides lighting, it was important that the machinery employed in its generation should be as cheap as it could be made. The cost of dynamos varied largely with the speed at which they could be run; and if they could be run safely at a higher speed the capital cost of performing the work required would thereby be reduced. The advantage of high-speed engines was that they enabled the dynamos to be coupled direct to them; and this was the cause of the great success they had attained in electric lighting. The torpedo-boat engines in Table 1 he noticed ran at about 400 revolutions per minute and indicated about 2,250 horse-power; while the electric-lighting engines in Table 4 were about one-tenth of that size, indicating 217 horse-power and running at about 365 revolutions per minute, which was about the present usual practice for electric lighting. Hitherto engines of about 2,000 horse-power intended for electric work, particularly for driving tramway generators, had all been made slow-speed, especially in America. If in a torpedo-boat, where it had no foundations, an engine of that power and lightly built could be kept running at 400 revolutions per minute, he hoped there was a reasonable chance of making such an engine work continuously in a central electric station, where any amount of material could be put into it, and it could be worked under the best conditions. For indicating high-speed engines, he wondered that more use had not been made of the indicator worked out some years ago by Professor Perry,* on the principle of a diaphragm bulged by the steam pressure behind it and carrying a small mirror in front, which reflected a beam of light through an angle proportional to the deflection of the diaphragm, and could thus be made to give a permanent record photographically. As the instrument was one that could be mounted conveniently, and as its records could be taken easily, it appeared to him that there would be a great advantage in using it where engines were tested. It also had the further advantage that with high-speed engines the diagram assumed the appearance of a luminous line: so

* Proceedings 1894, page 228 and Plate 53.

(Mr. G. L. Addenbrooke.)

that, without the trouble of taking diagrams in the usual way, it could be seen at the time what the engine was doing throughout the whole of the test. Having himself had to do with several Belliss engines, he had put them to severe tests. Three or four that he had tested eighteen months ago had been loaded up to the full extent, and the whole load then suddenly thrown off; and the rapidity with which they came back to their normal speed struck him as being exceedingly satisfactory. At the moment of the load being thrown off, the speed rose about 20 per cent. above the normal, and then came down again so quickly that in about four seconds the engine was running within 2 or 3 per cent. of its normal speed.

Mr. E. FUHRMANN CLARKE noticed that the force pump supplying the oil under pressure for lubrication was a single-acting pump; and he asked whether any observations had been made as to the variation in the pressure of the oil during a revolution of the engine. As the pump worked synchronously with the engine, he should suppose that the pressure would vary, unless there was some means of keeping the oil at a constant pressure. He should also like to know what pressure the oil was under when the engine was at work.

Mr. MORCOM said there was always a certain amount of air in the oil, which tended to keep the pressure constant (page 354). On watching the small oil-pressure gauge fixed in front of any of the self-lubricating engines, it would be found that while running the finger of the gauge was kept steadily at the usual working pressure of about 15 lbs. per square inch. The single action of the pump therefore did not practically affect the steadiness of the pressure.

A big engine, of the size that would satisfy Mr. Addenbrooke's hope (page 353), he had no doubt could be built and made to run at any required number of revolutions within reason. Practically there was no reason why engines should not be run at much quicker revolutions than they were run at, especially the three-crank equal-angle. The main reason at present was that consulting engineers would not permit it. The evidence in favour of quick-revolving engines was growing slowly, and indications of progress

could be seen in the manner in which the engine makers were pushing their way towards higher speeds of revolution. What was to be the limit he did not know. Already 400 revolutions per minute had been reached in the torpedo-boat destroyer machinery with 18 inches stroke, bringing the piston speed up to 1,200 feet per minute. Although the engine was not required to run for twelve months without stopping, he thought there would be no difficulty in running at 400 revolutions per minute for any period required in practice without stopping, if the parts were adequate for the work and the lubrication perfect.

The experience reported by Mr. Robinson (page 352) formed a practical confirmation of the beneficial action of forced lubrication on a large scale. There could be no doubt that, if the forced lubrication was tested on the bigger engines, the reduction of friction which had been shown in the diagrams exhibited from the smaller engines was bound to be felt to an equally important extent in the bigger.

The speech of Mr. Holroyd Smith (page 349) constituted of itself a paper in brief; and the exhibition of his model was most interesting. The vibration which had caused the annoyance referred to by Sir Edward Carbutt (page 337) had been due he believed to one of the Belliss engines in the St. James' electric station. It was a 300 H.P. engine, in which the couples or pairs mentioned in the paper had been got rid of entirely, and there was nothing whatever tending to make the engine itself rock or vibrate. Nevertheless it had been found necessary to take the engine out of the station: it was no use arguing from theory while in practice an annoyance was established. The obliquity of the connecting-rod he had not anticipated could be the cause of such trouble; but there was the fact, that the whole of the trouble in this case was due to it. A severe experience of a similar kind had at first befallen Mr. Crompton with an engine that had been put underneath the house in which he lived and slept. The engine was built in the same manner as that in the St. James' station. Afterwards a return connecting-rod was fitted in lieu of the direct one to the central or high-pressure cylinder, and this acted somewhat

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in the same manner as Mr. Holroyd Smith's arrangement. As the pistons worked vertically upwards and downwards, the differences in the upward and downward retardation and acceleration which occurred in each stroke, due to the obliquity of the connecting-rod, caused a vertical vibration; but as soon as the return connecting-rod was put to work in the opposite direction, the two outer lines of working parts were counteracted by the central or high-pressure line, and the engine was most perfectly balanced, with the result he believed that the vibration had been reduced practically to zero. No doubt there were innumerable ways in which theoretically vibration could be brought to nought; but engines had to be made practically at a reasonable cost, and in competition with other makers. In engines with three cranks at equal angles the vibrations which had previously given trouble had been largely got rid of. With the two-crank engines Messrs. Willans had experienced considerable trouble in central stations; but with the three-crank engines the trouble had disappeared. The three-crank engine had moreover acquired a recognised commercial character; it was an engine that would sell, while a theoretically perfect engine would not sell, although in the paper he had himself been arguing in favour of the latter. The three-crank engine was practically good enough.

Before leaving the works this morning he had enquired how the preliminary testing had been proceeding of the engines for the City and Waterloo Railway which had just been completed for Professor Kennedy's final testing. In Mr. Addenbrooke's trials (page 354) he had spoken about the engine running up to 20 per cent. above the normal revolutions at the moment of the full load being thrown off; that was a point which had been passed long ago. For electric traction many engineers he believed would have gone in for engines with expansion-valve governors; but he had preferred not to do so after the experience he had had, and he had advised throttle governors. The result of this morning's testing he had heard was that the momentary variation from the mean steady speed was only 2·6 per cent. when the load was thrown off, and in a few seconds it settled down to 1·4 per cent. as the permanent increase above the

TABLE 7.—*Belliss 300 H.P. Quick-Revolution Self-Lubricating Engine fitted with Throttle-Valve Governor, for Waterloo and City Electric Railway.*

Results of Governor Tests after final adjustments.

Variation in Speed above and below general mean speed, load being switched off or on as suddenly as possible.*

Change of Load.	NON-CONDENSING.					CONDENSING.				
	Revolutions per minute.*			Percentage of Variation in Speed.		Revolutions per minute.*			Percentage of Variation in Speed.	
	From	To	Settle	Momentary.	Permanent.	From	To	Settle	Momentary.	Permanent.
	Revs.	Revs.	Revs.	Per cent.	Per cent.	Revs.	Revs.	Revs.	Per cent.	Per cent.
None to Half . . .	387	381	382	0·91	0·65	387	380	382	0·78	0·26
Half to None . . .	382	389	387	1·17	0·65	382	388	387	1·30	1·04
Full to None . . .	382	390	387	1·43	0·65	379½	392½	387	2·48	1·04
None to Full . . .	387	379	382	1·43	0·65	387	377	379	1·56	1·04
1-15th to Half . . .	386½	382	382½	0·65	0·52	385	381	381	0·52	0·52
Half to 1-15th . . .	382½	386½	386½	0·52	0·52	381	386½	385	0·91	0·52
1-15th to Full . . .	386½	377½	382½	1·82	0·52	385	375	379	2·09	1·04
Full to 1-15th . . .	382½	389	386½	1·17	0·52	379	389	386	1·56	0·78
Half to Full . . .	382½	379	382	1·43	0·65	381	377	379½	1·56	0·91
Full to Half . . .	382	384	383	0·13	0·39	379½	382	382	0·26	0·26
Emergency to None . .						379½	392½	387	2·48	1·04

* Steady Speed { Non-condensing, Full load 382 No load 387 Mean 384½ } revolutions per minute.
 Condensing, " " 379½ " " 387 " 383 }

(Mr. Morcom.)

mean speed. This was well within the contract, and fulfilled all the requirements of the engines for lighting the tunnels and carriages off the same current that supplied the motive power for the trains. [See Table 7, page 357.]

In enumerating in the paper the three classes of vibration, he had thought it undesirable to go further into the mathematical details (page 346), because in papers read to the Institution of Naval Architects the bugbear of vibration had been dealt with for many years; and it would there be found that almost every way in which vibration had been creating disturbance either afloat or ashore had been considered and he hoped remedied.

High-speed engineers, among whom Mr. Sisson was an authority, he was glad to find were not now disputing among themselves to the same extent that they were some years ago. They had a big battle to fight in common against the slow-speed engineers; and it was an encouragement when those who were best qualified by experience entered into the contest, and joined in pressing forwards in the direction in which they wanted to advance. An expansion-valve governor, if it could be arranged outside the engine and be made big enough and have room enough to work comfortably, he quite agreed with Mr. Sisson (page 345) was a first-rate governor, and acted exceedingly well. But in these high-speed self-lubricating engines it had been found that the governor had to be put inside, so as to get the benefit of the lubrication; and a governor inside was a great nuisance. Hence it had been a welcome discovery when it had further been found out that, owing to the more horizontal nature of the water-consumption curve obtained with forced lubrication, there would not be any considerable benefit in governing by the slide-valve rather than by the throttle-valve. No doubt economy was to be obtained, not only theoretically but practically, with the expansion-valve governor, where an engine had to be worked for most of its time at and under half load. All that he wished to point out was that the experiments recorded in the paper had been made carefully in order to show what amount of benefit in economy was being derived with the forced lubrication from expansion-valve governing as compared with throttling. The results showed clearly

that with engines intended for working an electric-lighting station, that is to say, where the maximum economy was required to be at about three-quarters of the full load, it was not worth while to go in for the expansion-valve governor with a view to getting any saving at the year's end.

With reference to the oil pressure (page 344), the pressures that came upon the bearing were of course far higher than any oil pressure which he thought need be employed; but the pressure of oil was sufficient to establish a thick film flooding the whole bearing surface, when the action of the return stroke parted the surfaces slightly. All engineers who had used these self-lubricating engines would agree that, when the lubricant and fitting were correct, this film prevented contact, because the oil could not be squeezed out in the very small fraction of a second taken up by a single stroke. The film of oil should be able to do its work so effectually during the acting stroke that the particular metal used for the bearing ought not to be of much importance. If the wear were taking place on the oil itself and not on the metal, it did not matter whether white-metal or gun-metal was used. But as the difference in cost between white-metal and gun-metal bearings for steel journals was inconsiderable, caution had led him always to put the white-metal bearings in where the journals were of mild steel, for fear of any possible mishap with harder bearings. With the oil pressure however, a harder metal he thought could be adopted for the bearings, if necessary; but he did not contemplate making the trial himself.

The quantity of oil used with the forced lubrication was much less than that required with the ordinary mode of lubrication (page 342). Into one of the engines driving the works of Messrs. Belliss about 10 gallons of oil were put, and at the end of six weeks there was found to be about 12 gallons. The reason appeared to be that there was some water coming from the glands, which presumably got so intimately mixed with the oil as to increase the volume to that extent.

The question of clearance, which had been brought up by Mr. Saxon (page 341), was an old bugbear. In these quick-rotating engines with single-eccentric valve-gear he should not

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be surprised if it was as much as a quarter of the stroke; certainly it was something more than an eighth. In the Cheltenham engine (page 327) the actual clearance was 22 per cent. in the high-pressure cylinder and 15 per cent. in the low-pressure. But even when varying it between large limits he had found that it had hardly any effect, if the necessary care was taken with the slide-valves to ensure that the compression was right for enabling the proper indicator curves to be obtained. Anyhow the good results recorded in the paper were those which had been arrived at with the clearances as they actually existed. If there was anything to be gained by reducing the clearance, of course this could be done. In the engines illustrated in the drawings there were great advantages in having the slide-valves placed where they would readily be seen and got at by engineers who liked to have as few working parts as possible. From his own experience he was willing to accept the clearance, however great; for he had found no difficulty from it as far as economy was concerned, when required to guarantee as great an economy of water per horse-power as was possible with any other engines. He had not found that a modification of the clearance necessarily affected the economical working of the engines to anything like the extent that many engineers evidently believed.

The reason why governing by the throttle valve was better when the electric horse-power was made the basis for measuring the water consumption (page 335) was that the expansion-valve governor in itself caused losses by friction and otherwise, whereby the efficiency of the engine was reduced. Hence the results per effective horse-power, and therefore per electric horse-power, came out worse with the expansion-valve governor than with throttle-valve governing.

The inexpediency pointed out by Mr. Donkin (page 334) of calling these engines "high-speed" engines had already been realised by the makers, by whom they were now called "quick-revolution" engines. The latter designation had been substituted for some time past, and it was undoubtedly the right one to use.

With the modification suggested by Professor Unwin (page 334) in regard to Table 5 he entirely concurred; and the revolutions of the engines selected as examples had accordingly been added

to the table. Having himself received his engineering education from Professor Unwin thirty years ago, he thought that probably the seed which had then been sown in his mind might have been germinating gradually towards self-lubrication; and he wished that the fatherly interest which Professor Unwin might therefore be expected to take in the subject had tempted him to amplify his remarks thereon.

The important suggestion offered by Mr. Thornycroft (page 333) had already led to a considerable modification of the arrangements, for enlarging the settlement space provided in the base of the engine, so as to permit the oil to get free from dirt. In the latest engines the oil was carried away through pipes into a well space, where it could have a sufficient period of quietness for the dirt to settle. At the central station in Birmingham it was carried away to a small tank outside the engine, where it had a still longer period of quietness. At Leeds, and at the Charing Cross and Strand Electric Supply, and at many other stations, the same plan was now carried out; the oil was led right away from the engine into a settling tank.

The question about a reasonable factor of safety (page 334) was such a poser that he was half inclined to regard it as having been asked sarcastically. At any rate an attempt to reply thereto would involve a much longer paper than the present, and even then he feared would probably fail to meet the requirements of engine builders generally.

The PRESIDENT was sure Mr. Morcom must have been highly gratified by the animated tone of the discussion, and by the cordial acknowledgments expressed by those who had spoken on the subject of the paper. He himself thoroughly endorsed all that had been said as to the value of the paper; and he invited the members to show their appreciation by a hearty vote of thanks to the author.

Mr. W. W. F. PULLEN wrote that he presumed the small single-crank engines referred to in page 321 were all fitted with piston-valves. If so, he asked whether they were plain piston-valves without rings,

(Mr. W. W. F. Pullen.)

and how much smaller in diameter was the valve than its seating; and whether these valves had been tested for leakage, both standing and running, and with what result. In some trials which he had recently made of a small non-compound double-acting engine, fitted with a plain piston-valve without packing of any kind, he had found the leakage past the valve was excessive; the normal speed was 350 revolutions per minute. This he believed was not an isolated example. If leakage to any great extent did take place past a piston-valve, the reason for employing a piston-valve was done away with, and it would be more economical to revert to the old **D** slide-valve with a plane face.

Details of the gland packing used in the engines which gave so remarkable a mechanical efficiency would be acceptable; because it was well known that ordinary packing might be so screwed up as to put a considerable load on the engine, whereas this was impossible with many of the metallic packings now used.

In the trials recorded in Table 4, page 326, he noticed that at all loads the engine was more efficient as a machine than the dynamo which it drove. According to the figures here given, the efficiency of the dynamo could not be much above 94 per cent. at normal full load, and 90 per cent. at half load; whereas the corresponding efficiencies of the engine were seen to be 96 and 94 per cent. respectively.

The advantages of forced lubrication, which would generally be admitted by those who had had experience of it in the Belliss engines, were emphasized by the trials here recorded. But in the face of the journal experiments of Mr. Dewrance (*Proceedings Inst. C.E.*, 1896, vol. cxxv, page 351) he thought the assertion in page 324 was hardly justified, that in a single-acting engine under constant thrust no such film of oil was possible as was maintained between the bearing surfaces of a double-acting engine by forced lubrication. In a constant-thrust splashed bearing, the film of oil of course could not be so thick as with forced lubrication. The question was to a great extent one of thickness of the oil film. In a set of Belliss engines under his own charge he had found that a thin oil with little body would allow knocking to take place, while a little

thicker oil would completely eliminate all traces of knock. With impure mineral oil, in which the leakage of water from the glands produced saponification, the engines ran smoothly, but the oil pressure rose to 20 and 25 lbs. per square inch. It would be interesting to learn what effect was produced upon the running of the self-lubricating engine by considerably increasing the oil pressure, and what limiting pressure the oil connections would stand. In the engines of which he had charge the little oil safety-valve at one time made so much noise that it was impossible by the ear to form any opinion as to how the engines were running; and an india-rubber buffer had to be inserted for preventing the noise.

With these engines he had experienced no trouble from vibration. They were of the two-crank kind with the cranks opposite, running at 450 revolutions per minute. The foundation was deep, and completely isolated from the surrounding floor and other foundations. The exhaust pipe, which was heavy, vibrated a little, and communicated the vibration to the feed heater, but with no ill effect. Were it necessary to avoid the vibration of steam or exhaust pipes, the connections might be made with flexible metallic tubing.

In the trials mentioned in page 325 he should like to know the kind of brake used, and how it was applied to the engine tested.

Mr. MORCOM replied that the small single-crank engines were all fitted with solid piston-valves, and in grinding these valves into the bores in the cylinder casting great care was taken to ensure the absolute accuracy of the guide with the bore. With proper care in this matter it was found that the wear on the valve was so trivial that experiments made on one of the small engines at their works after eighteen months' constant running showed no difference in the economy. With a high-speed engine the escape of steam when the valve was running was naturally much less than it would be with the valve standing under the same steam pressure.

The engines were generally completed with metallic packing for the high-pressure piston-rod, and soft packing for the low-pressure rod; but on the trials the glands were packed with asbestos dagger packing for the high-pressure, and locomotive packing for the low.

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Care was of course taken to avoid screwing up this packing any harder than was necessary for securing steam and vacuum tightness.

Mr. Pullen's experience with the thick oil and thin oil appeared to prove the assertion made in the paper as to the difference between the film of oil with forced and ordinary lubrication. With a sufficiently thick oil, as that experience showed, more time was required to drive out the lubricant from between the surfaces than the speed of the engine permitted, and this would also occur with a thinner oil if the surfaces were closer fitting; but without such a thickness of film the surfaces would probably be permitted to come into contact, entailing an increase of friction and wear. The experience gained by his firm seemed to prove this clearly.

The trials mentioned in page 325 had been made with a Froude water-brake coupled direct to the engine shaft.

QUICK-REVOLUTION ENGINES.

Plate 63.

Steam Life-Boat Screw-Engine,

1865.

Scale 1/8th

Fig 1.

End Elevation.

Fig 2.

*Side
Elevation.*

Mechanical Engineers 1897.

Scale 1/8th

0 5 10 15 20 inches

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Plate 63.

QUICK-REVOLUTION ENGINES.

"Spitfire" and "Swordfish."

1896.

Plate 64.

Fig. 3.
Longitudinal
Section.

Self-Lubricating
Triple-expansion
four cranks.

See
Plate
65.

See
Plate
66.

Plate 64.

Mechanical Engineers 1897.

Scale $\frac{1}{30}$ in.

QUICK-REVOLUTION ENGINES.

Plate 65.

"Spitfire" and "Swordfish" 1896.

Self-Lubricating Triple-expansion four cranks.

Fig. 4. Longitudinal Section.

See continuation on Plate 66.

Mechanical Engineers 1897.

Scale $\frac{1}{20}$ th

Inches 12 6 Downloaded from pib.sagepub.com at Purdue University Libraries on June 5, 2016

5 Feet.

"Spitfire" and "Swordfish" 1896.

Self-Lubricating Triple-expansion four cranks.

Fig 5. *Longitudinal Section.*

QUICK - REVOLUTION ENGINES. *Plate 67.*
"Spitfire" and "Swordfish" 1896.

Self-lubricating Compound.

Two opposite Cranks.

Fig. 7. *Longitudinal Section.*

Mechanical Engineers 1897.

Scale 1/20th

Self-lubricating Compound.

Two opposite cranks.

Fig. 8. *Transverse Section.*

Mechanical Engineers 1897.

Scale $\frac{1}{16}^{\text{th}}$

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Ins. 12 6 0 1 2 3 Feet 4

QUICK - REVOLUTION ENGINES.

PL. 70.

Self-Lubricating Triple-expansion, Three equal cranks.

Fig. 9. *Longitudinal Section.*

Plate 70.

*Self-Lubricating Triple-expansion,
Three equal cranks.*

Fig 10.
*Longitudinal
Section .*

Mechanical Engineers 1897.

Scale 1/20th

Self-Lubricating Triple - expansion,

Three equal cranks.

Fig. 11.
*End
Elevation.*

Mechanical Engineers 1897.

Scale $\frac{1}{24}$ in.

Ins. 12 6 0 1 2 3 4 5 6 Feet

QUICK-REVOLUTION ENGINES.

Plate 73.

Belliss 200 H.P. Quick-Revolution Self-Lubricating Engines, Condensing.

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Mechanical Engineers 1897.

Plate 73.

QUICK - REVOLUTION ENGINES.

Plate 74.

Belliss Quick - Revolution Self - Lubricating Engines, Condensing.

Cheltenham Electric - Light Engine.

200 H.P.

Table 4.

Percent.

Fig. 14.

HP 240

Governing by Expanding and by Throttling.

250 H.P.

Table 6.

Fig. 15.

Mechanical Engineers 1897.

Pl. 74.

QUICK-REVOLUTION ENGINES.

Plate 75.

Fig. 16. *Water Consumption per brake horse-power.*

Brake Horse-Power.

Mechanical Engineers 1897.

Plate 75.

Fig. 17.

Mechanical Engineers 1897.

QUICK-REVOLUTION ENGINES.

Mean - Effective - Pressure Gauge.

Fig. 18.

Scale 1/4th

Fig. 19.

Fig. 20.

*Scale
half size*

Model of Anti-Vibrator.

QUICK-REVOLUTION ENGINES.

Plate 78.

*Anti -
Vibrator.*

Mechanical Engineers 1897.

Plate 78.