Valves and Valve Gearing.

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THE refinements which are called for in modern petrol engines have necessitated very careful attention on the part of designers to the valves and their operating mechanism, as the performance of the engines with regard to development of power at high speeds, and also with regard to silence and smoothness of working, is largely influenced by the proportions and arrangement of these parts.

The subject has gained increased importance by the comparatively recent introduction of the sliding sleeve valve, which was entirely novel in petrol engine practice, and the performance of the engine in which it is embodied has led to the publication of a number of designs also using piston or slide valves.

It would seem, therefore, that a useful purpose may be served by initiating a discussion on the various types, their comparative merits, and the possibilities of some of the new designs.

The author proposes, in the first place, to discuss briefly the cycle of operations as it occurs in a modern high-speed petrol engine.

Various arrangements of poppet valves will then be described and illustrated, and some points relating to cam forms commented upon, after which a few types of engines using sliding or rotary valves will be dealt with.

The sequence of operations most common in petrol engines is that known as the Otto cycle, in which the admission or charging stroke is followed by the compression, working, and exhaust strokes in the order named.

Although it is mainly correct to say that one stroke is reserved for each of these operations, there is, in actual practice, a certain amount of overlapping.

The necessity of this overlapping is clearly seen by following carefully through the cycle of a petrol engine running at a high speed.

Commencing with the piston at the top of its stroke, prior to admission, we have in the combustion chamber a residue of exhaust gases at a pressure which is due to the resistance of the exhaust passages and the silencer.

The first outward movement of the piston causes the pressure to fall, by enlarging the space in which these gases are contained, and it is not until the piston has moved far enough to allow the pressure to fall below that of the atmosphere that the new charge can enter the cylinder, whether the admission valve is open or not.

For the remaining portion of the outward stroke, with the admission valve open, the charge flows into the cylinder, owing to the excess of atmospheric pressure over the internal pressure.

When the piston reaches the end of its stroke, the pressure inside the cylinder is still below that of the atmosphere, and if the valve be closed at this point, the cylinder would not be as fully charged as possible.

It is of course impracticable to arrest the piston at the end of its stroke, while the charging of the cylinder is completed, but in moving inwards on the next stroke the volume is reduced, and the internal pressure brought up to that of the atmosphere, when the piston has moved a certain distance inwards.

Up to the point at which atmospheric pressure is reached, the charge, owing to external atmospheric pressure and the momentum of the gas in the inlet pipe, would be capable of still making its way into the cylinder, if the valve were open, so that with the two influences at work atmospheric pressure would be reached at an earlier point, and this is the point at which the valves should be closed.

Obviously, the speed of the engine has an important influence on the charging stroke, and with higher speeds the pressure at the end of that stroke would be lower, so that the time of closing the admission valve should be later for high speeds than for low speeds.

After the admission valve is closed, the valves cease to operate during the compression and working strokes, or rather, until near the end of the latter, when the exhaust valve commences its work.

Here, again, by reason of the limited time which is available for

the expulsion of the exhaust, it is in practice found necessary to open the valve before the end of its stroke, although it would seem that a certain amount of energy must be wasted in so doing.

The exhaust valve remains open until the completion of the inward movement of the piston on the exhaust stroke, and the best time of closing is dependent on the design of the exhaust passages.

In the case of a four-cylinder engine, discharging into a common exhaust pipe close to the cylinders, there may be interference in the shape of back pressure from a neighbouring cylinder which is just commencing its exhaust stroke, and this may warrant closing the exhaust valve at, or even slightly before, the top of the stroke; but where there is provision for the exhaust gases to leave the engine freely, it is better to close a little beyond the end of the exhaust stroke.

The rate at which the charge can flow into the cylinder is dependent on the excess of outside atmospheric pressure over the internal pressure, as well as upon the resistance of the carburetter, inlet pipe and valve passages.

Beyond a certain number of revolutions (dependent on the design of the engine) the weight of the charge taken in on each admission stroke must commence to fall with an attendant falling off of the compression pressure.

This probably is the reason why some engines which have been used in competitions, and which have an abnormal compression ratio, run quite well at high speeds, while at low speeds they are very unsatisfactory.

It is conceivable that in such cases the actual compression pressure attained at extreme speeds is not greatly in excess of ordinary practice.

To make such an engine run satisfactorily at low, as well as at high speeds, it would be necessary to have an efficient throttling arrangement for the charge, so that its weight might be kept within reasonable limits over all ranges of speed, even at the sacrifice of torque at the lower speeds.

It is common practice to secure interchangeability of inlet and exhaust valves by making them of the same proportions; but, obviously, if the maximum results are to be obtained from an engine, it is worth making the inlet valve as large as possible, even at the expense of the exhaust valve, since the expulsion of the exhaust gases is chiefly ensured by actual displacement by the piston.

The position of the valves is a matter of some importance, as it affects not only their efficiency as valves, but also largely determines the form of combustion chamber.

A few years ago the most common arrangement, particularly in multi-cylinder engines, was to have the valves symmetrically disposed in pockets on each side of the engine. (Fig. 1.)

This design lends itself to a convenient arrangement of exhaust and inlet piping. It necessitates a form of combustion chamber that offers a rather large area of cooling surface in proportion to

FIG. 1.

its capacity, and also entails the provision of two cam shafts, with the necessary gear wheels to operate them.

At the present time, the design in which the two valves are placed side by side in a single pocket over the same cam shaft (Fig. 2), finds more favour.

Many excellent engines are built of both types.

A type which necessitates only a single pocket has the inlet valve directly over the exhaust valve. When automatic valves were used, this type was very common, but when mechanically operated, by a rocking lever and long rod, it is difficult to obtain the same degree of quietness as is possible in the types previously described.

FIG. 2.

FIG. 3.

Figs. 3 and 3A show a type of engine which is built in several sizes from the author's designs, and has been in use for a number of years. The position of the valves permits of a form of combustion chamber, which is generally regarded as having some advantages over the pocketed form.

A compound inlet and exhaust valve is used in the "Parsons" engine, illustrated in Fig. 4, Plate XXI. In this case the inner valve is used for exhaust, and the outer shell valve for admission.

A single spring controls both valves, and a piston ring is fitted on the lower portion of the inlet valve to guard against leakage between the exhaust and inlet passages.

FIG. 3A.

In the case of the "Gnome" aeronautical engine, where the crank case and cylinders revolve around a fixed crank, the charge is led into the centre of the crank-chamber, and the inlet valves are fitted into the pistons. Provision has, of course, to be made to balance them against centrifugal force.

The increase in size of valves, to admit of high engine speeds, and the simultaneous reduction in the clearance volume to raise the compression, has given rise to some difficulty in the design of engines where the two valves are placed in the same pocket.

The increase in the dimensions of the pocket to accommodate the

valves has been provided at the expense of the clearance volume in the cylinder itself, so that the piston has to travel very near to the crown of the cylinder at the top of its stroke, and the passage between the valve pocket and the cylinder is in some cases restricted to an extent that impedes the flow of the gases; the resulting form of combustion chamber, moreover, is not good.

In the case of valves placed on opposite sides of the engine, the utility of half the circumference of the valve is affected by the proximity of the walls of the combustion chamber, against which the gases bank and prevent a free flow all round the valve.

FIG. 5.

An experiment made by a member of this Institution throws some light on this point:—

In an engine of the type mentioned, the ordinary cap over the exhaust valve was replaced by one of special form, having a lip extending half-way round the circumference of the valve, and just clearing it, to admit of the valve being freely operated.

It had the effect of preventing the passage of gas past the valve for half of its circumference, but the brake tests of the engine showed very slight difference when the ordinary cap was replaced by the special one.

Similar conditions obtain, in a lesser degree, in cases where two valves are in the same pocket, but here a less amount of the circumference of the valve is masked.

With valves opening directly into the head of the cylinder, such

FIG. 6.

restrictions do not exist, and it is found, in practice, that smaller valves may be used.

Automatic inlet valves had practically fallen into disuse, except in some small air-cooled engines, but they have recently been

FIG. 7.

employed in a few cases in engines for aeronautical work. It may be useful, therefore, to consider them briefly.

By the use of a very light valve and a delicate spring, with arrangement to limit the lift, the automatic inlet valve can be relied

upon to open at the proper time, *i.e.*, directly the pressure inside the cylinder falls below that of the atmosphere. It will open rapidly, but close somewhat sluggishly, and has a tendency to flutter.

The difficulty of providing sufficient area of opening with the plain valve, owing to the limited lift, was dealt with by the Napier Company by the introduction of a neat form of triple valve, illustrated in Fig. 5.

The same firm has used a mechanically operated valve, having three concentric seats, as illustrated in Fig. 6. This type of valve was also used by the Mercedes Company.

FIG. 8.

Some designers have endeavoured to embody the feature of automatic opening in the mechanically operated valve by causing the tappet lever to engage first upon the spring washer, which is free to slide a short distance on the stem, thus relieving the valve from the control of the spring and permitting it to open freely under atmospheric pressure. A further movement of the tappet lever forcibly opens the valve to its proper limit.

Examples of this type are found in the Phillips valve (Fig. 7) and the Martineau valve (Fig. 8).

The operating mechanism in the case of the poppet valve usually consists of a cam engaging with a roller or rubbing piece on a lever or sliding block, which in its turn moves the valve stem. In many cases some form of adjustment is provided between the slide block and the valve stem.

The design of this mechanism is exceedingly important, both from the point of view of silence and of power.

FIG. 9.

Probably the first of these considerations is most important to manufacturers at the present time, and care is generally taken to keep the weight of the moving parts down to a minimum. The same attention, however, has not in all cases been given to the profile of the cam, and this is a question of some difficulty, as the form which is best for maximum power does not usually make for quiet running.

FIG. 10.

Before silence became so important, it was usual to design for a sharp opening, long period of full opening, and quick closing of the valve, but to secure quiet running both rise and fall must be easier.

By reference to Fig. 9 it will be seen that the diameter of the roller as well as the size of the cam must be taken into consideration. In that illustration the same diagram of valve movement is obtained from two cams of different size, in which the sum of the diameters of the base circle of the cam, and of the roller engaging with it, is the same in each case. The two cams would be equally smooth in action.

In a cam with an abrupt rise, the velocity of the moving parts may become so great that, owing to the momentum, they will leave the cam at a point where the lift becomes easier, and return into contact with it at another point, the roller centre describing a path which can be calculated by the theory of oscillation of a loaded spring.

If the cam has a broad nose on which the roller dwells with the valve at its full opening, and the change to the falling side of the cam is too abrupt, the same thing takes place.

In many cases where the old type of quick-lift cams are retained, very strong springs are used to overcome these defects, but their use may introduce other difficulties, which defeat the object aimed at.

Fig. 10 shows a cam for which the roller path has been calculated for the cam revolving at a speed corresponding to 2,000 revs. per minute of the engine. The weight of the moving parts is taken as 12 ounces, and the spring exerting a force of 30 lb. with the valve closed, varying at the rate of 60 lb. per inch of movement.

The dotted lines show the amount by which the roller leaves the cam, and to maintain contact it will be necessary to increase the strength of the spring, or, alternatively, to extend the nose of the cam.

This latter course is the means by which, with comparatively light springs, contact may be maintained, though it may entail increasing the movement of the valve beyond its useful lift.

In designing a cam to work quietly at high speed, with a comparatively light spring on the valve, it is worth calculating and plotting the oscillation diagram of the spring, taking the extreme height as something greater than the lift necessary to give full opening of the valve. This curve should be plotted to a straight-line base.

The form of the cam at the beginning of its rise can be made to give a gradually increased velocity to the moving parts, and can also be plotted to a straight line base representing time and height to the same scale as the oscillation diagram.

A portion of each of the curves may be used to make up the rising and falling side of the cam, and if the spring taken has not been too light, there will be a circular path in the contour representing the dwell at full lift.

The clearance between the valve tappet and stem has not been referred to, but in ordinary practice this may be cut down to 0.008 in., unless the valve stem is unusually long.

FIG. 11.

It is usual to calculate the area of opening of a poppet valve by multiplying its lift by its circumference. This is not strictly accurate in cases where the conical seating is used.

Referring to Fig. 11, in which the angle of the seating is 45° , it will be seen that the distance, H between the valve and its seating is less than the lift, L , in fact $H = \frac{L}{\sqrt{2}}$.

The area of opening is equal to that of the curved surface of a truncated cone, the diameters of whose ends are $D + L$ and D respectively, and whose slant height is equal to H or $\frac{L}{\sqrt{2}}$.

This area is less than $\pi D L$, which is the area of opening of a flat-seated valve.

In cases where large valves with small lift are used with conical seats, this point should be taken into consideration in calculating the area of opening.

By far the most important development in valve design since the introduction of the petrol engine has been the use of sliding sleeves in lieu of poppet valves in the "Knight" engine. (Fig. 12, Plate XXII.)

By the adoption of eccentrics, or cranks, the cam problem has been eliminated, and the whole of the motions reduced to the simplicity of operation which is found in steam practice.

The large number of these engines which are now on the road, in the hands of private people, together with the most remarkable performance under official observation, gives ample proof of the practicability of the design.

This engine has been very fully described in the technical press, and it has also been discussed on several occasions at meetings of engineers, so that its special features should be well known to all.

Probably the contact of the portions of the sleeves which are most affected by the heat of the gases during the exhaust stroke, with the water-cooled parts of the cylinder and head, during the other strokes, ensures the rapid dispersal of this local heat, which might otherwise cause trouble, and this is, no doubt, one of the most important features in the design.

The cylinder head, which might be described as a stationary water-cooled piston, is provided with rings, the lower one of which is broader in relation to the aperture in the sleeves.

The problem of providing for the movement of a piston valve, fitted with rings over the open ports in a cylinder, is inverted here, but the conditions are practically the same, and this point must have occasioned the designer some anxiety in the first instance.

It shows that a spring ring in a piston, if made sufficiently broad in relation to the port aperture in the cylinder, will pass freely over it, if the fits are good, and that bridges in the port, to facilitate its passage, are not necessary.

The large surfaces of contact between the sleeves themselves, and also between the outer one and the cylinder wall, facilitate the passage of heat from the piston to the water jacket.

The arrangement permits of a very good form of combustion chamber, and a large valve opening is provided with comparatively small movement of the sleeves.

The advent of the "Knight" engine has directed general attention to the possibilities of piston valves, and a number of designs

FIG. 13.

FIG. 14.

have been published, some of which may attain commercial success.

The nearest approach to the "Knight" engine is one designed by Mr. Percy Riley, in which the sleeves are outside instead of inside the cylinder. This engine is illustrated in Fig. 13, from

FIG. 15.

which it will be seen that the piston is in direct contact with the water-cooled cylinder, and that each of the sleeves has one of its surfaces in contact with the water-cooled parts of the casting.

For the same port area the sleeves need not be cut away quite

so much as those of the "Knight" engine, and on the whole they would appear to be subjected to less severe working conditions.

The form of combustion chamber is good, and altogether the design seems quite a practicable one.

By the use of a transverse half-time shaft and bell cranks, with suitable connecting rods, only four cranks or eccentrics are required, as against eight in the "Knight" engine.

Fig. 14 illustrates the "Hewitt" engine, in which the piston valves outside the cylinder are operated from a half-time crankshaft. The small cylinders in which the piston valves work are thoroughly water-jacketed, and during the working stroke the small piston controlling the exhaust travels downwards, assisting the rotation of the half-time crankshaft.

Fig. 15 shows diagrammatically an engine in which piston valves are arranged on opposite sides and pass right through the pocket of the combustion chamber. The inlet and exhaust passages are above the valves, which are in equilibrium as far as pressure inside the combustion chamber is concerned. Connecting rods from half-time crankshafts in the crank chamber operate the piston valves directly, and provision against leakage is made by ordinary piston rings in the lower portion of the valve, but the upper ring, through which the perforated part of the piston valve passes, would appear to be an uncertain feature in the design.

Numerous other arrangements of piston valves have been suggested, bearing more or less resemblance to those referred to.

In addition to the piston valve, the rotary valve has received a good deal of attention of late.

Its prior use on heavy gas and oil engines had not been entirely attended with success, although under some conditions it proved fairly efficient.

The boldest scheme that has been put forward (Fig. 16) includes the provision of a revolving liner between the piston and the cylinder walls. This liner extends downwards into the crank-chamber, its lower end being cut in the form of a worm wheel, which engages with a worm on a shaft parallel to the crankshaft.

The water-cooled cylinder cover projects some distance into the revolving liner, and its lower side takes the form of a hollow cone, which is pierced by gas passages opposite the ports through the main water jacket. When the aperture of the revolving liner comes opposite these ports, the gases have a free flow, and the

timing of the engine is simply determined by the relative angular position of the two ports.

With a single aperture in the revolving sleeve it would be necessary to rotate the latter at half engine speed, but, subject to the limitations of port area, two, or possibly three, apertures can be arranged, reducing the revolutions of the liner to one-quarter or one-sixth of the engine speed.

FIG. 17.

A modification of this design shows the rotating liner carried through and operated from above, leaving the piston to run in direct contact with the walls of the water-cooled cylinder, but the difficulty of providing against leakage of the gases tells against this variation of the design.

Fig. 17 illustrates a rotary valve engine designed by Mr. E. W. Lewis, and in this case the valve is led along the top of the cylinders, and is cooled by water passing through its entire length.

The case in which the valve rotates is split horizontally, the lower half being cast with the cylinders.

A most interesting feature of the engine is the provision for maintaining a gas-tight joint between the rotating valve and its seating on the top of the cylinder. The cylinders themselves are not directly attached to the crank chamber, but are inserted from

above into an aluminium water jacket, which is bored to receive them.

The joints are made by rubber washers, and the bearings of the rotary valve are carried, not from the cylinders, but from the aluminium water jacket. The pressure inside the cylinders therefore keeps the latter up to the rotating valve, and the rubber washers are sufficient to allow for the slight movement necessary to maintain the contact between the seating and the valve.

An experimental engine of this type has been built and subjected to a considerable amount of testing.

Rotary valves do not entail the use of either cams or eccentrics for their operation, but the timing is simply determined by the spacing of the ports over which they move, and with their simplicity of operation and timing, provided that the difficulties which attended their use in earlier engines can be surmounted, they would appear to possess important advantages over other forms of slide valves.

The poppet valve engine is now on its trial against the slide valve type. It has had a longer time in which to prove its reliability, and, in the opinion of the author, if all the manufacturers devote the same attention to silence and smoothness of working that has been given to its newer rival, it will retain the confidence of the users of motor vehicles.

In conclusion, the author desires to express his thanks to the proprietors of the "Autocar" and "Motor Traction" for the use of blocks from which to produce the illustrations.

THE DISCUSSION.

Mr. C. Y. KNIGHT, in opening the discussion, said:—I did not come here this evening with the expectation of opening the discussion, but I do feel that, as Mr. Craig opened a discussion for me once, so it is more than fitting that I should do the same for him.

Mr. Craig says, if people would pay more attention to making the poppet valve silent than to attacking the "Silent Knight" valve they would be doing more good. I do not agree with him. I am afraid, when it comes to a matter of silence, the poppet valve is not in it with the slide valve. I am going to deal with the slide valve proposition, and I am going to say a few things about slide valves and rotary valves, and in doing so I hope it will not be thought that I am endeavouring to do to others what some of our friends did to me a few years ago, when they attempted to discourage me. I must say that in the matter of the development of valves and valve gears, I have the utmost sympathy with others in regard to some of the "freaky contrivances," as mine was called, and as it was in its original state. At the same time, there are a good many things relating to the production of a slide valve motor which the majority of people have overlooked, and Mr. Craig hit upon one at once, and that is the matter of lubrication. In order to understand the "Knight" engine you must understand a great deal more than is shown in the drawing, and one of the necessities in the production of any sort of motor is that the lubrication must not be complex. Any attempt to divide your lubrication systems between the valve system itself and the motor, is only courting trouble. A motor, in order to be a success, must be so built that the same system of lubrication will do for valve gear, piston, cylinder, and crank-shaft; that is to say, if your lubricating system fails, it should fail altogether. The bearings should be served first in order that in case of failure of lubrication, everything comes down together. Take, for instance, the case of the overhead rotary valve; this is a construction that requires an independent lubricating system all the time. The minute that the lubricating

system fails at this valve, and the motor still retains its power as a result of being well lubricated, the valve is going to pieces, and you cannot help it. The one feature of the "Knight" motor is the fact that oil is automatically brought up from the base to lubricate those parts of the heads which require lubrication. For a number of years we have lubricated our motors in America entirely from the base. The Daimler Company, when we came over here, thought it possible that we should need more lubrication in the heads than we were giving them; they arranged therefore for a system of lubrication for the heads. I believe that all the trouble we have ever had has been the result of this introduction of oil in the head; for the reason that if you introduce oil into the valve system independently of the base and you get smoke, you think you are over-lubricating the engine, and are led to believe that the whole lubrication is wrong, whereas the lower part may be dry and the smoke be coming entirely from the oil which goes to the valve mechanism itself. In the "Knight" motor, as I have said, the lubrication is provided so that the splash system lubricates the sleeves and also the piston from the bottom. The sleeves are so arranged that when the piston comes to the top of its exhaust stroke the inner sleeve is at the bottom of its travel, and the travel is just the proper distance to bring that portion of the sleeve which goes back over the junk ring, as we call it, down to the line which the piston has reached in the upper part of its stroke. The ring of oil which the piston leaves on the up stroke by the reciprocation of the sleeve is carried up to the junk ring above, the sleeve acting simply as a conveyor. The sleeve comes down, and the piston goes up; the piston brings up a ring of oil, and the sleeve comes down to get it. The piston goes down, and the sleeve carries the oil up again to the head, and so on. Wherever the sleeves operate outside the cylinders, as suggested in some designs, you require an independent system of lubrication. You have got oil going to the head, and you must have an independent lead, and when the independent system fails, and the other does not, you get into trouble every time. The same is true of the rotary valve in the head. A design of that kind was patented by the Mercedes Company some months ago showing a revolving disc in the head, a cone-shaped arrangement. These rotary valves are subject not only to that difficulty of lubrication, but also to those which arise from the tremendous pressure due to the explosion which

presses these surfaces together; this pressure makes it impossible to keep oil between their faces which soon leads to scoring and total disruption of the whole device. We also have some trouble in cases of the rotary valve which has been alluded to this evening, and that is where a tight joint is made through the cylinder being made free, to work free, and only allowing a few thousandths latitude for reciprocation, so that the pressure holds the top of this cylinder up against the rotary valve. You can imagine what it would be to have 7,000 lb. pressure against a valve which, if it is to have great efficiency, must have a considerable surface exposed.

Now, in the matter of cams, a motor here is spoken of as doing away with four eccentrics, that is, having four instead of eight as used in the "Knight" motor. We have found, in our attempts to re-design and improve the motor of the sleeve type, that to put another joint in the shape of a bellcrank or lever between the small connecting rods and sleeves, means failure of the system, because it introduces bearings and elements which in a very short time begin to rattle, and as we have almost got to a point where the ticking of a very small clock would be noticed when the engine is running idle, or even under a load, we cannot afford to run any risks of this kind. Any sort of mechanism introduced which would develop play even as loud as the tapping of the point of a pencil on a table covered with leather would totally destroy the value of the system.

There are some things regarding general valve constructions, openings and closings, which I should like to hear discussed. In particular, what part or what influence on the internal combustion engine is it that limits the torque? Why is it that at a certain piston speed the torque reaches its maximum, and beyond this decreases? Is it in the valve? Is it reciprocating weight, or what is it?

MR. MAX LAWRENCE: I am sorry that Mr. Craig has not given us some of his experience. In the paper to-night he has described different systems of valve gear, but has said nothing about their relative merits or defects. I think we should like to hear from him some criticisms as to the working of these various systems. He also has confined himself entirely to the valve gears of the "Otto" cycle, and has not described the valve gear of any other cycle. It is true that the "Otto" cycle at the present time holds the field in point of numbers in automobile engines,

but we had it from our late President Mr. Dugald Clerk, in his presidential address, that the improvement of the explosion engine in the future would be chiefly in the development of the cycle, upon the lines of a scavenged engine or an engine with a variable combustion space. It is therefore regrettable that Mr. Craig has not dealt with some of the valve gears designed to meet the requirements of other cycles.

Then also, Mr. Craig has left out one of the most ingenious valve gears in existence, namely, that of Mr. Lanchester, which has the very great advantage that the valve gets a cold puff of wind for every hot one, and therefore keeps a great deal cooler than some valves which are not exactly surrounded by water. Mr. Craig also dismissed rather quickly the Phillips and the Martineau valve gears, where the inlet valve is not operated positively itself, but where tension is taken off the spring and the valve is sucked open when the pressure in the cylinder so dictates, that is to say, when it has fallen below the atmosphere sufficiently to overcome the friction of the valve. This makes for heavy and cumbersome valve gear, but in my experience it materially increases the horse-power developed by an engine at low speeds. I have made experiments with an engine fitted with the Phillips valve gear so arranged that the inlet valve could be opened by relieving the spring pressure, while by inserting a split pin and locking the parts together the valve could be operated positively in the usual way. The Phillips gear gave a much better torque up to 1,000 revs. per minute, after which speed the power developed by both was identical. The reason why these valve gears are not more used in present day design is due partly to their extra weight, but chiefly to the fact that they are not so quiet. This brings us to the all-important feature of silence.

I do not agree with Mr. Craig at all that the hollow-backed cam which he condemns as noisy necessarily increases the power of the engine by the rapid opening which it gives; in my experience it does not do so in all cases. In the valve gear experiment just described the inlet valve opened later than when positively actuated, and the power was increased. The inlet valve is usually opened about 15 deg. after the piston has got over the dead centre, and whether it opens slowly or quickly makes but little difference. In making experiments to find the best position for valve openings, I have gone to great extremes, and have

opened the valve as late as half way down the stroke, and with certain carburetters I only found a reduction of five per cent. of power from the best or normal opening. Slow opening and closing of the inlet valve does not necessarily mean any reduction of power whatever; much more depends upon the valve areas. The fact that these valves are opening and closing when the piston is moving very slowly, must not be lost sight of.

The opening and closing of the exhaust valves depends so much upon the resistance of the exhaust piping, that it is not possible to give the best setting for each individual case without knowledge of what this actually is. Broadly speaking, my experience dictates that there are wide limits, and if the exhaust is opening anywhere between 48 deg. and 20 deg. before the dead centre, there is practically no difference in the power developed in engines where the power is limited by the valve area. That is to say, supposing the engine is designed for its best running conditions at 1,100 or 1,200 revs. per min., and the power begins to fall off seriously at about 1,500 revs. per min., the exhaust valve may be opening anywhere between these two figures. The correct closing position, however, is so largely dependent upon the nature of the exhaust piping, that it is hard to give a figure, but about 9 deg. over the dead centre of the exhaust stroke is a good normal position. The best position of the opening of the inlet valve depends largely on the carburetter used, but one essential feature is that the two valves must not be open together, unless the engine is scavenged.

In these days, with such a great demand for silence, it is of great importance to let a valve down gently on to its seat; no advantage is gained by letting it down smartly with a blow. Besides the avoidance of noise the valves and seatings wear better, and a spring of less strength is needed to overcome the inertia. Then in regard to the clearance of 0.008 in. that Mr. Craig suggests as necessary between the valve and the plunger, I am able to work with much less than this. It is mostly a question of truly formed cams. I do not think we desire in any way to get a clearance of more than 0.002 in. If the plunger is allowed to get up speed before touching the valve, as it will do with 0.008 in. clearance, it will hit the valve stem a considerable blow, which will certainly be heard.

With regard to the rotating sleeves and reciprocating sleeves and valve gears of that nature, Mr. Knight disclaims any know-

ledge of such matters, and in opening the discussion has confined himself entirely to valve gears of the sleeve type. It is significant that he has directed nearly the whole of his remarks to the lubrication of these sleeves. I gather therefore that the lubrication of the sleeves is the difficulty and disadvantage of this gear. It certainly sounds very nice to get a valve which is opened without a blow by an eccentric or crank on the lay shaft. Provision has to be made to take up the slack in the big and little ends of its connecting rod, but beyond that the valve works smoothly and evenly; it evidently, however, introduces serious lubrication difficulties. I should very much like to know what sort of clearances are necessary between the various sleeves and the piston; perhaps Mr. Knight or someone else will be good enough to tell us. It strikes me that these clearances must be of vital importance, and their proper proportion must make all the difference between the success and failure of such valve gears; one or two thousandths of an inch too much or too little will cause a heavy knock or a seizure. This form of valve gear gives a very quick opening and large port areas, and a well-shaped combustion space, but as all design is necessarily a compromise, one usually has to pay for these things by introducing some other disadvantage. It would appear from Mr. Knight's remarks that the disadvantage of this particular valve gear is the introduction of the lubricating difficulty.

It is well known that by giving large valve areas and openings to an explosion engine a little more power, say 1 or 2 per cent., is obtained thereby from a certain cylinder volume, but the same power can also be obtained by employing a slightly larger cylinder volume. The great thing to bear in mind is what one desires to bring about, and in these small explosion engines used for motor-car work, I think the desire to obtain the maximum power from a given cylinder volume may be carried a great deal too far. Nobody attempts to do this in stationary work; in fact, all engineers dealing with electric light machinery specify for a certain load, and allow for an ample margin by requiring the machinery to stand 25 per cent. overload for a period of 3 hours, or by making some similar proviso to ensure that the designers have allowed ample margin for the satisfactory working of their machinery. It is chiefly a question of expediency, and nearly always resolves itself into one of money.

In automobile work weight and silence, of course, have an

important bearing, but I myself have no sympathy with the desire to get the last ounce of power out of a given cylinder volume, and I think you can pay too dearly for large port areas.

Ordinary tappet or poppet valves can be made silent, and of sufficient area to fill up any automobile engine with enough mixture to develop a good horse power from the cylinder volume of engines such as are used for automobile work, and the mean effective pressure I have obtained with petrol as fuel under these conditions would certainly not be 1 per cent. less than that obtained by the best arrangement of the Knight valve gear, and I am very doubtful whether the lubrication and other difficulties introduced by this valve gear are worth this small advantage. This gear certainly makes an engine of a given power heavier than one of the same power fitted with poppet valves but having a larger cylinder volume. These engines get into the hands of unskilled owners; they have to be driven for long periods without any skilled attention whatever, therefore work under the most onerous conditions. We all know that poppet valves are never lubricated, and never require any lubrication, and work perfectly satisfactorily. I therefore fail to see how such a valve gear as the Knight, which is both heavier and more liable to trouble from lubrication, can be worth while.

I want to emphasize very strongly the point that I do not think any serious development can take place upon the lines of any new valve gear that we know of at the present time, unless the cycle is altered. I think the improvements we shall see will not be in valves and valve mechanism. The mechanism of the poppet valve is successful; the Lanchester is a very successful one, and there are others, but the improvement one looks to at the present time is not so much in the valve mechanism, as we know it at the present time, but in a change of the Otto cycle for some other cycle in which super-compression or variable compression can be obtained.

MR. D. J. SMITH: I notice that Mr. Craig did not touch on the simplest type of valve mechanism we have, in which the piston alone constitutes the whole valve gear. I allude to the usual arrangement adopted for admitting and exhausting the charge on two-cycle engines.

There is one type of two-cycle engine in which the piston is made to act as a throttle, and also to vary the volume of the combustion chamber. This engine is of American origin; I do

not know the name of the makers or whether it is still manufactured, but have seen one only, at work in a boat. In this engine the main bearing bushes were made to revolve, or partly revolve, in the crank chamber by suitable gearing, and the crankshaft was placed eccentrically in the bushes.

This had the effect of altering the travel of the piston in relation to the inlet ports in the side of the cylinder, and so throttling the charge. The exhaust ports were made extra wide, so were not affected. The piston also varied the size of the compression chamber at the same time.

It is not a method of any practical use, I merely mention it as a novel form of "valve gear."

With regard to eccentrics for working the ordinary tappet valves, I have never seen this method applied to any internal combustion engine used for motor car purposes, though it is old practice on gas engines, and on all steam engines. The valves of the latter, whether slide or tappet, are almost invariably worked by eccentrics.

I consider that eccentrics would limit the noise of an ordinary tappet valve engine almost as well as the eccentrics working the sleeves on the "Silent Knight" engine.

I am not aware whether any designer of high speed engines has attempted to operate the valves by eccentrics, but perhaps Mr. Craig could enlighten us on that point. With regard to combined inlet and exhaust valves, I believe that the Parsons valve is solely used for paraffin. It is a valve in which the heat of the inlet valve, which is kept hot by its situation, is relied upon to partially vaporize the charge.

The great tendency or aim of all designers is to keep the inlet valve as cool as possible, so that the charge, on its way to the cylinder, does not become attenuated by heat, since weight of charge, as well as volume, is important.

Any combination of exhaust and inlet valve would probably fail for the reason that the charge would be so heated that a considerable loss in weight would result.

With regard to the three-ported inlet valves mentioned in the paper, I have had some vivid experiences in the old days, when valves were not cottered as carefully as they should have been, the valves frequently falling right into the cylinder, from which they could only be extracted with great difficulty.

With regard to very large valves, there is another item to which attention should be called, and that is the trouble with springs.

In one type of engine the exhaust valves, which were very large, frequently gave way when they got hot through retarded ignition or full throttle work, the strong springs pulling the stem away from the lead.

With regard to rotary valves, Mr. Craig points out that these have not been thoroughly successful on gas and oil engines. Crossley's fitted this type of valve on one class of their stationary gas engines, but they never repeated the experiment.

There was a type of steam car, the "Reading," the engine of which had a rotary valve, but the difficulties were so great, even on the steam engine, where the heat of the working fluid is low, that it was found to be impracticable. It is impossible to lubricate the rotary valve effectually if exposed to the heat of a charge.

There is another interesting point that I should like to draw attention to. On the first successful gas engine that we have any knowledge of, *yiz.*, Brown's, which came out about 1824—and for the manufacture of motor cars fitted with this engine a company was formed, even at this early date—a slide valve was used. The early steam engines, on the other hand, were all fitted with tappet valves. All Boulton and Watts' engines had tappet valves.

For about a hundred years therefore honours have been equally divided between the slide, piston, and tappet valves, and the same result will, no doubt, hold good in the development of the internal combustion engine.

The ever extending use of super-heated steam seems to point to the fact that the tappet valve will alone be used on steam engines in the future, as it has been found impossible to lubricate any form of slide or piston valve, and neither the cylinders of steam engines nor their valve chests can well be water cooled.

MR. C. LORENZEN: In the Author's paper it is the last described type of motor which I have specially studied, and it may interest you to learn about a motor of this kind, which I invented about three or four years ago, Fig. 17. I actually built first a small single cylinder on this principle which worked very satisfactorily, and then a 30-40 h.p. four-cylinder, but before I could finish the experiments with this engine I became interested in flying machines, which I am building now. I have, however, recently had the large motor sent to this country, and will put

it on the market. I should like to show you how I have overcome

Fig. 17.

the difficulties of excessive friction, and prevented leakage by providing an automatic tightening device.

Fig. 18.

The rotor chiefly consists of a hollow cast iron body, rotating on ball bearings, and provided with suitable ports for the passage

of the gases. To ensure gas-tightness a casing in two halves somewhat resembling bearing caps is slightly pressed by springs against the valve, but in order to minimise the friction, and to concentrate the pressure where it is mostly wanted, that is, round the cylinder ports, the latter have projections or ribs round them which alone press against the rotary valve in the same way as piston rings do against cylinder walls. The cavities between these projections form a useful lubrication reservoir. The lower shell is also provided with extensions in the shape of pistons (Fig. 18) fitting into a central bore in each cylinder, and made tight by means of piston rings. The central part of these pistons form ports to allow the passage of the gases, widened, however, on the valve side to nearly a rectangular shape, with an area of about the same size as is the area of the piston part on the under side. In consequence of this arrangement part of the gas mixture will be compressed and exploded in this widening, thereby counterbalancing the pressure of the exploding gases on the under side of the shell, which latter will therefore be pressed against the valve with the constant pressure of the springs only. In practice, however, it has been found desirable to have a slightly greater pressure tending to keep the shell against the rotor during the explosion stroke, and thus ensure gas-tightness, and by varying the ratio of the two areas to one another, any desired pressure of course can be obtained.

MR. F. S. BENNETT: Mr. Smith asked about the working of valves with eccentrics, and I can answer him as far as a single cylinder goes. On a single cylinder it works with remarkable success because it gives three very important facilities; it gives a variable lift, at all events, in the machine I am speaking of, variable timing and variable compression. I have never had any experience of eccentrics in four-cylinder engines, but in single cylinder engines they are simply remarkable, and while at high speeds high compression is obtained, at low speed the compression is low, and the pulling is remarkably powerful.

MR. D. J. SMITH: I believe the single cylinder engines that Mr. Bennett alludes to were comparatively slow-speed engines.

MR. BENNETT: We ran up to 1,350 revolutions per minute.

MR. CRAIG, in replying to the discussion, said: I am extremely glad Mr. Knight is here, and it is very proper that he should have opened the discussion, though I believe I should have been right

in leaving out any mention of his engine altogether, for, is it not a valveless engine, and therefore outside the scope of my paper? However, we have received a valuable contribution from Mr. Knight. I believe lubrication is at the bottom of the whole proposition, and it requires very careful attention indeed. We are not afraid of sub-dividing our lubricating systems if we are to get a supply from one common source, returning it to the same receptacle. With the present-day method of forced lubrication it is quite safe to carry oil to various points as long as it can be brought back again to the container from which it was drawn. The lubrication system should be carefully considered in all slide valve engines; the poppet valve puts up with practically no lubrication.

In regard to what Mr. Max Lawrence said as to the limit of torque, I suggest, in my paper, that the limit is proportional to the heat value of the charge that can be got into the cylinder. Even if a perfect vacuum is obtained in the cylinder there can only be, say, 15 lb. per sq. in. actual pressure to drive the charge in, but, as a matter of fact, it is much less than that; for the expulsion of the charge, on the other hand, there is the whole momentum of the moving parts available. Therefore, at high speeds, torque falls off for want of charge, and I believe that some of those engines which are designed for a very big compression ratio are working on quite ordinary compressions when running at very high speeds, because they do not get a full charge. Mr. Lawrence wants more of my experience. I do not know in what form I can give it, and perhaps the best way is to try to answer his questions. He referred to the Otto cycle and the possibility of development in other directions, and with other cycles. I agree with him that this subject is well worthy of study, and should be glad if our scientists, who have not to worry about manufacture, would give some attention to it. If they will, we shall be ready to make things in accordance with the results of their investigations. Mr. Lawrence complains of my omission of the Lanchester valve. This valve is very interesting, like most of the things that Mr. Lanchester does; one valve is used to let the gas out, and another to steer it when it gets out either into the exhaust passage or the inlet passage, so that nothing is gained beyond having a particular valve opening into the cylinder cooled by the passage of the new charge.

Mr. Smith also mentioned this point, but it is a very question-

able practice; you do heat up the charge, but you also get a less weight of charge into the cylinder.

As Mr. Lawrence says, the Phillips and the Martineau valves adjust themselves to the time at which the pressure falls. It does not matter when the valve opens. He has tried opening quite late, and finds very little difference in the result; I can agree with him, I think we are better without that combined automatic mechanical device, because it is a disadvantage in the matter of quietness. The opening of the admission valve a little later, or even considerably later, does not cause a great falling off in power except so far as it reduces the average opening. That brings me to the point that Mr. Lawrence commented upon when he says the quick opening does not give power. By quick opening I mean using a certain portion of the total opening for raising the valve so as to leave a similar amount for valve closing again, and a certain amount of dwell on full opening. If you refer to the diagram for a cam drawing on page 279, you will see the opening that these cams give plotted out on a straight line base. The rectangle there shows the average opening. That is a thing of importance, and that is the real valve area. If you are endeavouring to obtain a very easy opening or to use half the movement for opening, and the other half for closing without any dwell, you are doing it at the expense of valve area. I think a great deal of the noise of the valves is due to the rollers jumping off the cam. That simple figure in the paper, which was founded upon actual tests, took a great many hours to get out; the roller *does* jump from the cam. If the cam is at all abrupt you can get a velocity up to 10 ft. per sec., and an acceleration up to 10,000 ft. per sec. per sec. That is no uncommon thing; if you consider the kinetic energy that must be destroyed or absorbed by the spring, you can easily understand that unless the change of velocity is very gradual, the roller will leave the cam, and that is a very fruitful source of noise. Mr. Lawrence thinks that 0.008 in. clearance is far too much, and that 0.002 in. is ample. I could guarantee that if Mr. Lawrence goes round his works with a set of feelers he will find at least 0.008 in. clearance in the exhaust valve stem on all the engines. You have to allow for expansion under heat, and there must be a certain amount of clearance to meet this. He says that large port area may be bought too dearly; I quite agree with him. I believe that engines which are actually running on the road do not need

the size of valves that are often given to them. You do not get the number of revolutions on the road that you get on the test bed, and you find it desirable to modify the carburetter adjustment. If you look at ordinary ratios of gearing the engines do not run at 2,500 revolutions per minute very often. If we are designing for other purposes where we are running up to good speeds, we must give plenty of valve area, and keep down the weight of the moving parts.

I was much interested in the form of rotary valve shown in Fig. 17, and in the provisions made for keeping it gas tight. In the Lewis engine mentioned in the paper it appeared to me that it was rather overdone, and that the whole area of the cylinder, less the port, was available to receive the pressure at the explosion stroke, and to deliver it on to the valve to keep it gas-tight. It seemed to be rather too much, although I understand that the engine has shown some very fair results in the preliminary runs.

Mr. Smith regrets I did not touch upon what he called the simplest type of valve motion in which the piston alone constitutes the whole valve gear, as used in the two-cycle engine. It is pretty common knowledge that one cannot touch on everything in a paper of this kind. The varying of the camshaft centres by an eccentric arrangement or by varying the length of the rod, or generally the throw of the crank by an eccentric sleeve on the crank pin, entails gearing that is possible but not very desirable. It is very good for engines used for laboratory experiments, and it is conceivable that with careful design they could be made to work, but I do not think they are within the range of practical politics. With regard to operating valves by means of eccentrics, there would be too much noise for engines used for pleasure car purposes. Mr. Smith touched upon the point of the heating of the incoming charge by passing it over a hot valve as in the Parsons engine; that is not confined to paraffin, but with certain modifications of design this type of valve may be made satisfactory for petrol. I think, as used at present, it has done good work as a valve for petrol engines.

Finally, as to Mr. Bennett's remarks. May I ask if he is referring to the Cadillac?

Mr. BENNETT: Yes.

Mr. CRAIG: And you are operating by eccentrics?

Mr. BENNETT: Operating the inlet valve.

MR. CRAIG: You cannot do that without considerable clearance, which involves rattle, and you may eliminate other sources of noise, and decide to put up with that source of clatter. I do not think it would be applicable to a four-cylinder engine for use on pleasure cars. However, that is a matter that manufacturers must decide for themselves. I should not expect silence, and I should not be inclined to make use of eccentrics or to expect silence from any form of valve gear which entails so much clearance between the tappet and the valve.

THE PRESIDENT: It is my duty now to propose a vote of thanks to the Author. We have had a discussion which to my mind is an ideal one. The paper was full and comprehensive, and raised points which have been ably discussed. When we meet together in this way it is for mutual information, and we are very much benefited by papers of this character which deal thoroughly with one subject rather than touch lightly upon several subjects; and to-night we have heard the views of practical men who have spent several years on the question of valves, and who have given us the best of their information. I therefore move a hearty vote of thanks to Mr. Craig for his paper.

WRITTEN COMMUNICATION.

MR. D. W. GAWN wrote: Since the power of engines is now rated generally by the R. A. C. formula, probably it would be as well if valves were to be designed in accordance with the basis of that formula. This is, of course, an assumption that the piston velocity equals 1,000 ft. per minute.

For some time I have employed a very simple rule for the determination of areas of valve passages, and find that it gives excellent results. It is based upon the piston speed mentioned, and is expressed thus:—

(1) for exhaust valves, $a = A/7$,

(2) for inlet valves, $a = A/8$,

where a = area of valve opening in sq. in., and

A = area of piston in sq. in.

The divisors may be varied to suit individual ideas or special requirements. Those given allow for a velocity through the ports of about 116·6 and 133·3 ft. per second, respectively.

FIG. 4.

FIG. 12.