MOTORCYCLE ENGINEERING—19

Choosing the Valve Layout

The relative merits of s.v., o.h.v. and i.o.e.

by PHIL IRVING

THE first four-stroke motorcycle engines used mushroom or poppet valves for controlling the flow of gas to and from the cylinders. Since then, despite shortcomings which have prompted the invention of many other types, the poppet valve has maintained its top position in the popularity poll, and today it is unchallenged in the automotive field.

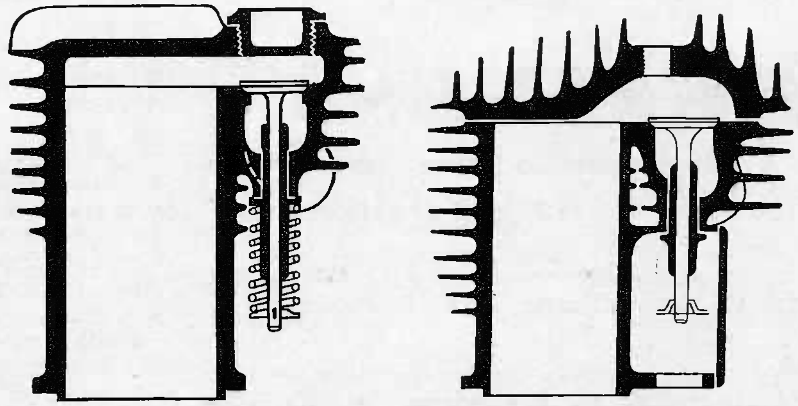
The ways in which these valves may be installed and operated, however, are legion, and from time to time almost every possible arrangement has been tried. At present, inclined overhead valves operated by push-rods and rockers are practically universal; but it was not ever thus. For quite a number of years, the side-valve engine held pride of place, and the inlet-over-exhaust arrangement has been used on several very successful engines.

Especially in the formative years, when it was hard enough to make a reliable engine at all without bothering about combustion efficiency or high specific power, the simple side-valve was often the designer's first choice. In this scheme (see sketch) the valves are located parallel (or approximately parallel) to each other and alongside the cylinder barrel, which can be made as a complete unit by casting a lateral extension wherein the valves operate, and which includes the inlet and exhaust ports.

Originally, screwed valve-caps were provided to permit assembly of the valves and their lower faces were approximately level with the upper surface of the combustion chamber, which extended right across the bore about half an inch above the piston crown at t.d.c. This shape was adopted partly because it assisted in machining the blind-ended bore, and partly because it was not then realized that it was about the worst possible shape from the detonation point of view—a fact which called for a skilful and knowledgeable hand on the manual ignition control lever, which was almost as important as the throttle.

On the credit side, as the valves were opened by short tappets operated either directly by the cams or through lever-type followers, the mechanism was about as simple, light and direct as it was possible to be, and was potentially capable of running at very high revolution rates, as witness the 250 c.c. J.A.P.—produced *circa* 1920 and reputed to be capable of 8,000 r.p.m.

However, this layout is fundamentally better suited to the low-speed, "slogging" type of power unit than to a high-speed one, because the breathing ability falls off badly as the engine speed rises, particularly if a high compression ratio is used. This is so because although the actual ports can be made with the smooth curves and easy contours conducive to good gas-flow, the ingoing mixture has to undergo *two* changes of direction after it negotiates the valve-seat and before it can enter the cylinder proper. Also there is a considerable interference with gas-flow through the proximity of the combustion-chamber wall and "ceiling" around and above the valve-heads; any endeavour to raise the compression ratio by reducing the clearance volume causes greater interference and reduced volumetric efficiency, so that beyond about 8 : 1 the loss from one source cancels out the gain from the other.



The early fixed-head side valve (left) was detonation-prone and irregularly cooled. Far better combustion chamber shape is provided by the detachable-head layout on the right.

The discovery by Harry Ricardo that "pinking," or detonation, arose through uncontrolled and instantaneous combustion of the last portion of the charge within the cylinder head considerably altered the side-valve picture. Ricardo's solution was to concentrate the greater part of the clearance volume over the valves, leaving a flat portion of the head extending over most of the bore diameter, with only a very small clearance over the piston crown, which was also flat.

In the Ricardo layout, the space between crown and head is so small, and the surfaces so cool in relation to combustion temperatures, that the gas trapped in this "quench area" does not detonate. This, however, is only one of the merits of this head, which was so effective that the side-valve engine was able to hold its place against the overhead-valve in the car world for many years.

The additional advantages are: (a) more space and smoother internal contours can be provided round the valve-heads, giving better breathing; (b) the stream of gas "squished" out from the quench area at the end of compression creates a violent turbulence in the charge which promotes rapid, thorough burning and permits a moderately high compression ratio to be used without the excessive juggling with ignition timing which the older sort of head demanded. However, the restriction on breathing created by reducing the clearance volume, and also the area of the throat between the cylinder itself and the combustion space, still limits the highest useful ratio to about 8 : 1. The designer is in a somewhat similar predicament with valve sizes; if these are increased for better breathing, either the heads are masked by the walls or the ratio has to be lowered.

Owing to the difficulty of boring and

hpning a cylinder right up to a square corner, the Ricardo design necessitates a detachable head, with its attendant gasket and several studs; but this proved a blessing in a very thin disguise, because it did away with the old valve caps which, except in the case of the J.A.P. aluminium "fir-cone" variety and its imitators, were built-in hot-spots. It also opened the way to aluminium heads with deep diagonal finning for better cooling. Maintenance became easier.

Unfortunately, however, it did nothing to eliminate the main defect of the air-cooled side-valve cylinder, which is extremely difficult to overcome and which, in the last analysis, sets a limit to the power that can be obtained for any length of time. This is the fact that the area between the cylinder wall and the exhaust port receives heat from both sides and is almost impossible to cool effectively, even if a fan and cowling are fitted. In the days of belt-driven, clutchless models the self-generated cooling air speed was to some extent proportional to the throttle opening, except when hill-climbing —an exercise which brought on a loss of power loosely attributed to "overheating," but actually caused by cylinder and valve-seat distortion which at times was severe enough to cause temporary seizures.

The first man to detect this Achilles' heel was J. L. Norton, who attacked the problem by separating the exhaust port from the barrel wall and providing an air space between them so that cooling was a trifle better and there was far less likelihood of the port pulling the cylinder out of round. This feature alone went a long way towards explaining the outstanding success of his B.R.S., 16H and "Big Four" engines. Blackburne and some A.J.S. engines employed detachable heads with integral ports.

Cooling difficulties became even more acute with the advent of geared transmissions and heavier machines, and were even accentuated by some later developments aimed at enclosing and lubricating the valve gear which, when run open, suffered from too little oil on the stems, leading to rapid wear, and too much oozing out of the tappets, leading to a messy exterior.

The English system of enclosure was to cast a box, with a detachable cover, on the side of the barrel—an expedient which cured the lubrication problems, but at the expense of placing an air-blanket over a quarter of the barrel arc, which manifestly is a bad idea. There were, it is true, efforts by some designers to reduce the ill-effects in minor ways, but the better system was that developed in America, whereby the operating mechanism of each valve was enclosed in a tube which did little to impede air-flow.

Transatlantic designers also took the sensible course of swinging the exhaust port well away from the cylinder instead of keeping it in a plane parallel to the centre-line of the machine. Some American side-valve engines are capable of very high sustained speeds thanks to this attention to basic principles—and also, of course, to a desire to hang on to the type, although it had ceased to have much attraction in England after the advent of o.h.v. designs which were just as reliable and silent but developed much greater power.

There could still be a field of application for the side-valve, however, in water-cooled form, where the local overheating problem can be solved by correct design of the water-passages. The LE Velocette is the only example of the type now in production, but it is possible to envisage a very neat, compact in-line 500 c.c. four, producing about 20 b.h.p. at 5,000 r.p.m., which would be small enough to mount transversely—even, possibly, just in front of the rear wheel, scooter-fashion, and with the radiator built into the leg-shields.

Another type of valve gear, which had a considerable following for many years, is the "inlet-over-exhaust" (i.o.e.), with its inverted alternative, "exhaust-over-inlet."

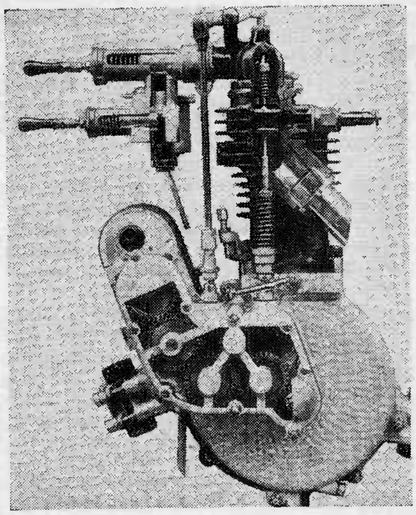
In its earliest versions, the i.o.e. had a cam-operated side exhaust valve, with an automatic inlet valve located coaxially and vertically above it; the inlet valve was contained in a cage and the exhaust valve could be extracted through the opening left when the cage assembly was removed.

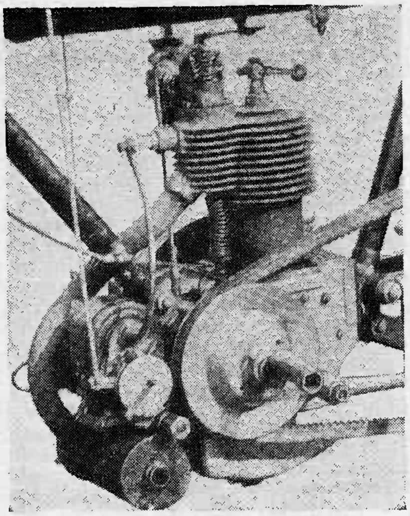
From this rudimentary scheme it was but a short step to adding a rocker and push-rod to operate the inlet mechanically, and a very worthwhile engine resulted. The Rudge which won the 1914 Senior T.T. was a good example of the type, which the firm retained until discarding it in favour of the four-valve o.h.v. model. Other famous users were the Swiss M.A.G. and the American Harley-Davidson, one of which was the first machine officially to attain 100 m.p.h. at Brooklands. [D. H. Davidson, 100.76 m.p.h. over the flying kilometre on April 28, 1921.]

Advantages of this layout as compared to the s.v. are that quite large valves can be used without unduly increasing the volume of the combustion chamber, and the cylinder cooling is better because the airflow between the barrel and the now-isolated exhaust port is greater than it can be when both valves are at the side. For somewhat the same reason, the degree of skill involved in moulding and casting the cylinder is less.

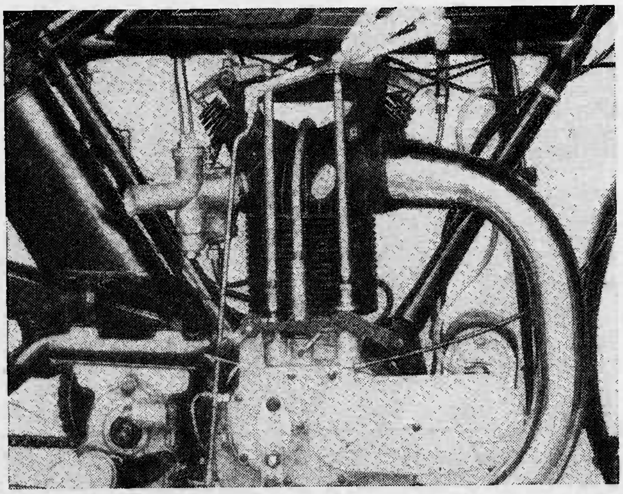
Another advantage is that the valve chamber can be narrower than the cylinder. This factor was of value for in-line four-cylinder engines such as the automatic-inlet F.N. as far back as 1910, and the later American Ace, Henderson and Excelsior.

However, the necessity of a cage for the inlet valve was a hindrance to obtaining smooth internal contours for easy gas-flow, while cylinder distortion due to unequal





Two pre-First World War examples of i.o.e., both with full mechanical operation—the 327 c.c. NSU of 1912 and the 293 c.c. Velocette which appeared in the following year.



The engine which did so much to put "o.h.v." on the map —the original "Big-port" A.J.S. Large, inclined valves and light rocker gear were its most significant features.

metal sections and differing local temperatures was still a problem. This was attacked by one or two makers by placing the exhaust valve overhead and the inlet valve below (e.g., the Martinsyde "Quick-Six"), while ex-R.F.C. types may recollect the V-eight R.A.F. engine which employed this valve arrangement and looked remarkably like a collection of motorcycle cylinders bolted to a common crankcase. It is interesting to note that possibly for reasons of accessibility, each sparking plug of the R.A.F. was fitted to the valve chest on the side remote from the cylinder—and about all one can say of this location is that, however hard you tried, you could not choose a worse one.

There are a few examples of i.o.e. engines still extant in the car world, and one or two conversion sets are available to convert a s.v. to i.o.e. with a sizeable increase in power, but these all make use of a detachable head and relatively large inlet valves located over, or nearly over, the bores. This method of construction suits a four- or six-cylinder engine, but if it is applied to an air-cooled single the result is more complicated than a side-valve and less efficient than an overhead-valve, so it is not surprising that there are no examples of i.o.e. or e.o.i. engines in production today for motorcycles.

Since an internal combustion engine operates by converting energy in the form of heat into mechanical energy, the less of the former that is lost during the process by being absorbed into the surrounding metal, the more efficient the engine will be. In simpler words, the smaller the surface area of the combustion chamber, the better.

This fact was recognized very early, and put into practice by inverting *both* valves, seating them directly in the head above the cylinder and operating them by means of rockers and push-rods. However, the first examples of this type, now commonly referred to as o.h.v., did not necessarily prove to be much faster than rival s.v. or i.o.e. engines, because they all suffered from identical limitations in other directions, such as inefficient port shapes, poor cooling, "slow" valve timings and detonation due to the wrong shape of combustion chamber and incorrect plug location.

In addition, vertical valves seated directly in a fixed head were necessarily less than half the bore in diameter, whilst they could be larger than that in either of the other types. This limited their breathing ability, but a worse defect was the ever-present bogy of a wrecked engine resulting from failure of the exhaust valve—a frequent occurrence before the development of high-hot-strength valve steels, and not unknown even today. When the exhaust valve is located in a pocket to one side of the cylinder, its decapitation is rarely attended by serious mechanical consequences, but these could be disastrous in an o.h.v., especially one with a fixed head and a cast-iron piston, even to the extent of wrecking the whole top half of the engine beyond redemption if the catastrophe took place in the heat of battle.

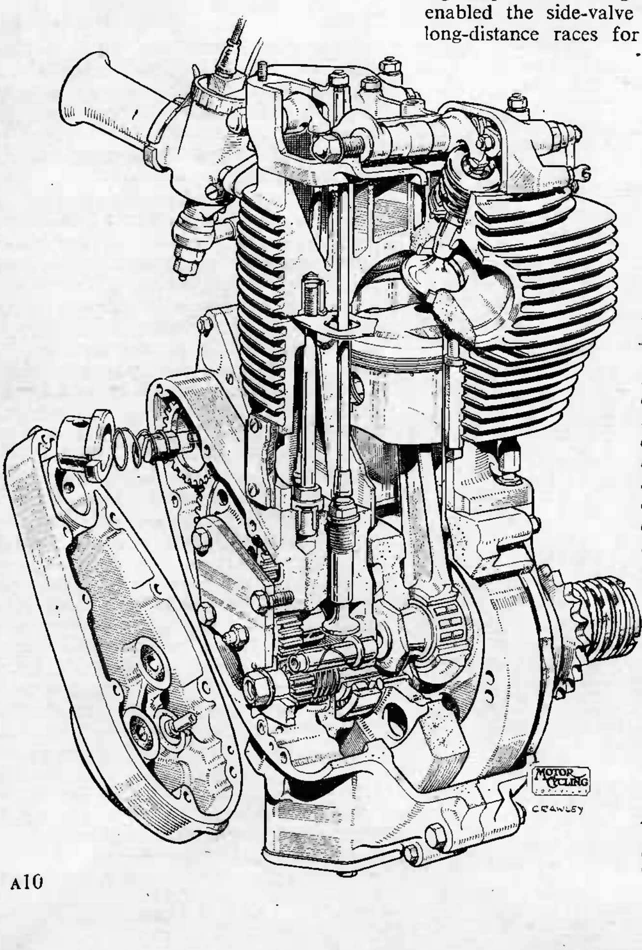
Because of this weakness, designers were loath to employ strong valve-gear, so the inherent ability of the o.h.v. engine to maintain a high volumetric efficiency at high r.p.m. was largely lost. This fact enabled the side-valve to continue to win long-distance races for far longer than it should have done (the last major victory was the Sunbeam's Senior T.T. win in 1920), while the o.h.v.'s lack of reliability frightened off the man-in-the-street to a degree which militated against any manufacturer being game enough to stake his all by restricting his range solely to o.h.v. models.

Credit for ending this situation must go largely to the Stevens Brothers of Wolverhampton, who produced the "big-port" A.J.S.—which, thanks to its nickname, is remembered more for its one bad feature than for its good ones, of which the large, inclined valves and light rocker gear are the two most noteworthy for the purposes of this article. With only 350 c.c. to play with, this little giant-killer was able to vanquish any contemporary engine up to twice its size, and did so with such regularity that the superiority of the o.h.v. principle was established beyond argument.

The reasons for this are not difficult to see, yet it has taken many years of painstaking work by knowledgeable technicians to realize all their implications and to translate them into physical form. Briefly, the use of inclined valves permits the valve-head size to be considerably larger than half the bore whilst making the combustion chamber approximate to the desirable part-spherical shape which has the least surface-to-volume ratio. Further, the contours of the inlet pipe and port can be of a shape favourable to gas-flow, the sparking plug can be placed in a situation which does not tend towards detonation, and (a most important point from the reliability aspect) waste heat inevitably absorbed by the exhaust-port walls does not affect the cylinder barrel, which can be a simple, symmetrical component with good all-round cooling and no built-in hot-spots.

Whilst not *absolutely* essential with this layout, a detachable head is desirable in the interests of easy assembly and maintenance. Although there may be more total work required to manufacture a two-piece head and barrel than a single component, the operations involved are simplified and subsequent repair work such as reboring is facilitated by the ability to handle each part separately. Foundry work is considerably simplified and there is no necessity to use the same metal for both parts; instead, the barrel can be made from an iron with outstanding wear resistance, while the head can be made from an iron possessing specially good fluidity when molten, or of aluminium-bronze or high-strength aluminium alloy with inserted or cast-in valve seats, according to the designer's own ideas on the matter.

With one or two exceptions, the o.h.v. engine has been developed with the accent on speed and power—a circumstance which has given it a reputation for roughness that is not really deserved. Whatever may be said in favour of alternative arrangements, the fact remains that the o.h.v. is capable of out-performing them in *any* particular—power, fuel economy, flexibility and even long life—provided that the design is correct in the first place and directed primarily at whichever of these attributes is the main aim.



Modern o.h.v. practice in a high-performance single. This view of a 500 c.c. B.S.A. "Gold Star" engine shows clearly the large valve area, advantageous combustion chamber shape and relatively clear porting obtainable with a good inclined valve layout.

NEXT WEEK: COOLING PROBLEMS