MOTORCYCLE ENGINEERING—20

For Better Burning

Design of the valves, ports and combustion chamber

by PHIL IRVING

THE previous article made a brief comparison between the merits of side-valve, inlet-over-exhaust and overhead-valve arrangements. The conclusion was a majority verdict in favour of the o.h.v., but a wide field of choice remains, for there are many ways in which the valves may be installed or operated while still coming under this general heading.

For instance, a clear majority of the car engines which use this kind of valve gear have all the valves located in a single row, usually offset by a small amount from the centre-line of the cylinders. The valves are vertical and operated by rockers and push-rods from a long camshaft carried in the block near the base of the cylinders.

This is, in essence, the same layout as that employed on the old "90-bore" J.A.P. Vee-twin of hallowed memory, except that in the latter engine the cylinder heads were non-detachable and were virtually merely plates or discs cast integrally with the barrels. The ports and valve-guide housings were formed in a separate casting bolted to the flat outer face of the head, an arrangement whose sole merit was that it made the job of casting the cylinders much simpler.

It might, of course, be argued that it was better to have a poor design which could be manufactured rather than a much superior design which could not be made at all, and in fact that position has always existed in engineering. The designer, especially in commercial work, is always limited to what the available materials will stand and what the available methods can accomplish.

In experimental and racing work, the more forceful type of designer tends to override these limitations, thereby spurring the metallurgist on to develop better alloys and the machine-shop and foundry to employ techniques of a more advanced nature, almost irrespective of their cost. Once the practicability of a special technique is established, it is the province of the production engineer to reduce the cost to an acceptable figure and rarely does he fail, although the process may take several years.

For example, the modern die-cast high-strength aluminium-alloy cylinder head, now accepted as commonplace, would have been an impossible dream not many years ago, but it has come into being through the racing designers' insistence on light metal heads at all costs and the foundryman's skill in eventually evolving methods by which they have become a commercial proposition. However, this is not strictly germane to the issue, which is the design of the valve gear and combustion chamber.

To return to the vertical overhead-valve layout—the combustion chambers of the early air-cooled engines resembled a boot-polish tin in general shape, and detonation, though not so serious as on contemporary side-valvers, was a problem which severely limited the usable compression ratio. The development of "squish" heads, following Ricardo's pioneering work on non-detonating side-valve heads, largely cured this trouble. The scheme was to locate the valves in a recess and machine the head so that portions of it were separated from the piston-crown at t.d.c. merely by the thickness of the gasket. Towards the end of compression, mixture was "squished" out from the narrow gap into the recess, thus creating the amount of turbulence necessary for rapid combustion, while the quenching effect of the cool surfaces in close proximity to each other eliminated detonation in the unburnt gas lying farthest from the plug.

Great—and sometimes exaggerated—claims were made for some of the head shapes developed along these lines for car engines. While they did permit the use of moderately high compression ratios with excellent economy and high torque at low and medium speeds, their breathing ability was restricted by the 90° bends in the ports and the close proximity of the valve-heads to the combustion-chamber walls, so their high torque could not be sustained at high r.p.m. and their maximum power development was therefore limited.

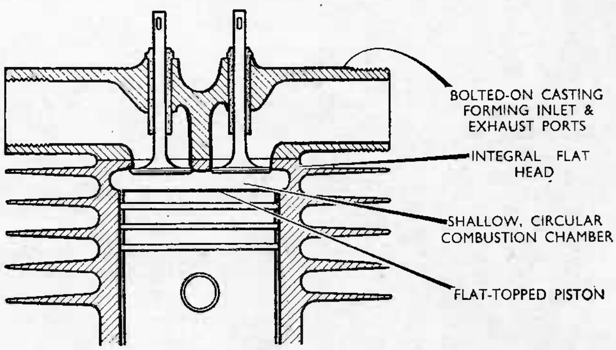
Nevertheless, from the production point of view, application of this head to an in-line multi-cylinder engine produced a layout so simple and straightforward that, with slight variations between makes, it is almost standard practice on cars today, excepting high-performance models. But the mechanical situation is different on engines with only one or two cylinders.

In such cases, where the camshafts are quite short and the cylinder heads are usually individual castings, there is not much extra work involved in inclining the valves at a considerable angle, although it is a little more expensive because the size of the rockers and rocker-boxes is increased and any such increase must add to weight and therefore to cost.

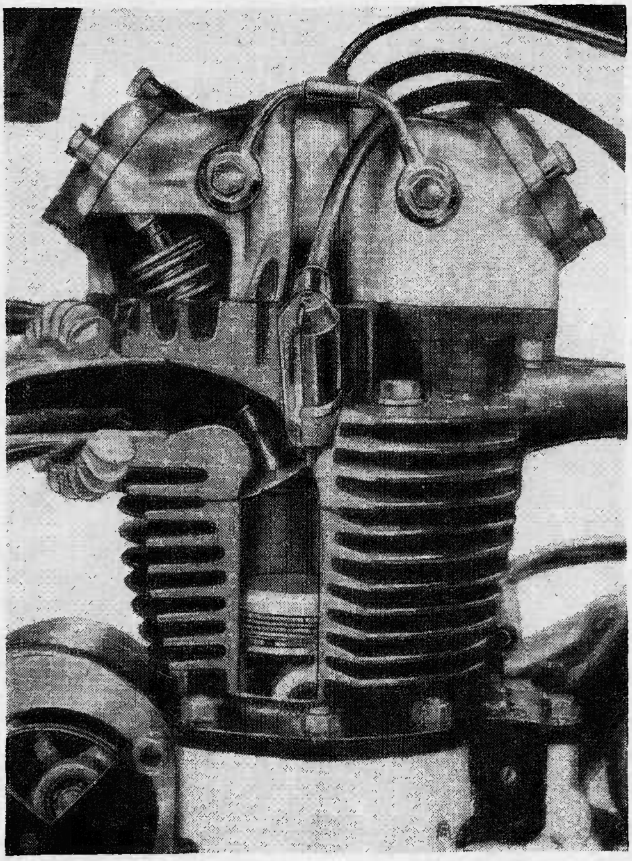
Inclining the valves confers a number of benefits, in addition to permitting larger diameters to be used without exceeding the confines of the cylinder bore. The bend in the induction port is less acute, which is beneficial to good cylinder filling, and the exhaust port can be short and smoothly contoured, which helps in getting the spent gas away.

Possibly of even greater value is the reduction in the amount of waste heat absorbed by the walls of such a port as compared to a long, square-cornered port in which the gas flow is erratic and turbulent. It has been estimated by research workers into cooling problems that about 45% of the total amount of heat absorbed by the head is picked up by the exhaust-port walls. Clearly, everything possible should be done to reduce this effect, as it leads to local high temperatures in the region of the valve-guide boss and causes the valve to run excessively hot, even to the point of failure.

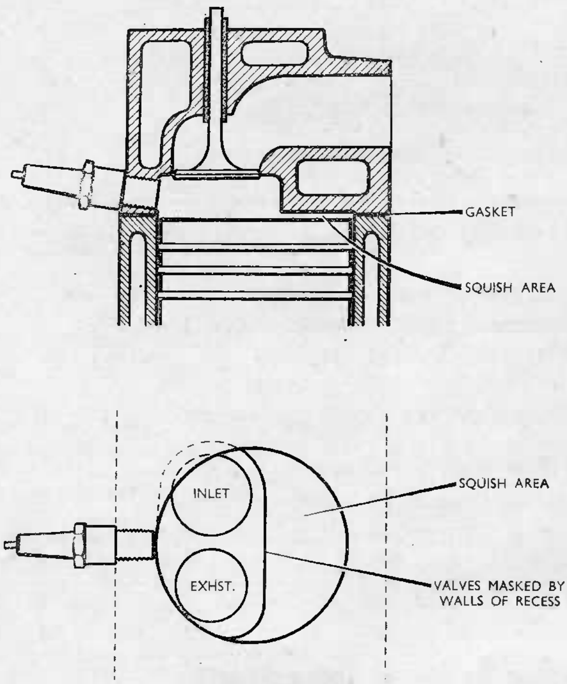
Another advantage of inclined valves, especially in conjunction with aluminium heads, is that each valve is, or can be, disposed along an axis which is radial to the spherical portion of the combustion chamber. Presupposing that each valve is



Layout of a typical early o.h.v. design with parallel valves and integral flat head. Inefficient combustion chamber shape set a severe limit upon compression ratio.



(Right) Modern o.h.v. layout exemplified by a part-sectioned B.S.A. "Star Twin" engine of 1954. Clearly seen are the exhaust port contour, combustion chamber shape and plug position.



(Left) A water-cooled o.h.v. head of the type employed in many car engines, showing how the valves are masked by their proximity to the step which forms the "squish" area.

accurately in line with its seat when assembled cold, it will remain so when the whole head is at running temperature, because thermal expansion takes place substantially equally in all directions. If, however, the valves are parallel to each other, the seats, which are located in the hottest portion of the head, will move apart under the influence of thermal expansion and will thus become out-of-line with the valves, which are guided from a cooler area.

This effect leads to lack of gas-tightness and also accentuates any tendency towards valve breakage, because the heads do not seat squarely and the stems are consequently subjected to continual bending loads which, in time, they may fail to withstand. It is, of course, affected considerably by dimensions—the larger the cylinder, the worse the effect. Though it may not be very great in even the largest cylinders likely to be used in motorcycle work, nevertheless it can exist, and where engines of high power output are concerned it is best to eliminate it by disposing the valves radially. This was done in the very successful four-valve Rudges and the "Mechanical Marvel" Excelsior, about the only four-valve engines which ever managed to vanquish the conventional two-valver in road racing, where stamina is an essential attribute of success. However, the special aspects of heads with more than two valves is a wide subject which will have to be deferred.

Reference has already been made to the necessity for turbulence or "swirl" in the mixture to ensure rapid combustion. This is so because the rate of travel of a flame starting from a single point in stationary or quiescent mixture is so low that complete combustion could never be achieved in an engine operating at speed, but the process is speeded-up enormously if the mixture is in a state of violent agitation, preferably of an orderly kind which can be controlled in direction or intensity by the detailed configuration of the head or ports.

"Squish" Turbulence

In "squish" heads, the size, position and minimum width of gap between the areas concerned are the main factors determining the amount of turbulence. Each of these can be modified easily in the experimental stages to obtain the optimum results, but in hemispherical heads with only one inlet valve, reliance is placed upon the angle of entry of the inlet gas-stream to establish a rotary "swirling" action of the whole charge.

It has been clearly proved that once this induction-directed swirl has been established, it will continue in being for the whole of the three remaining strokes. As the rate of rotation of the mixture may be several times as fast as that of the engine itself, it is difficult to see how the swirl could possibly die out before the exhaust valve opens, though, of course, by that time its intensity has been considerably reduced.

The intensity of this mass turbulence depends mainly upon two things—the speed of the ingoing gas (which at full throttle is approximately proportional to engine speed) and the angle and direction at which the stream enters the cylinder. The least swirl—and, incidentally, the best volumetric efficiency—is given by a port lying in the plane of the valves (that is to say, directly fore-and-aft in a conventional single) and with a large down-draught angle. Conversely more swirl is afforded by offsetting the port so that the gas enters tangentially to a greater or lesser degree according to the angle of offset, the amount of down-draught and the internal contours of the port; a "flattish" shape has more effect than one with a curve which brings the general direction of flow more in line with the axis of the valve.

In addition to this mass effect, local turbulence is set up by eddy-currents created by the ingoing gas tripping over its own feet as it passes the edges of the port and

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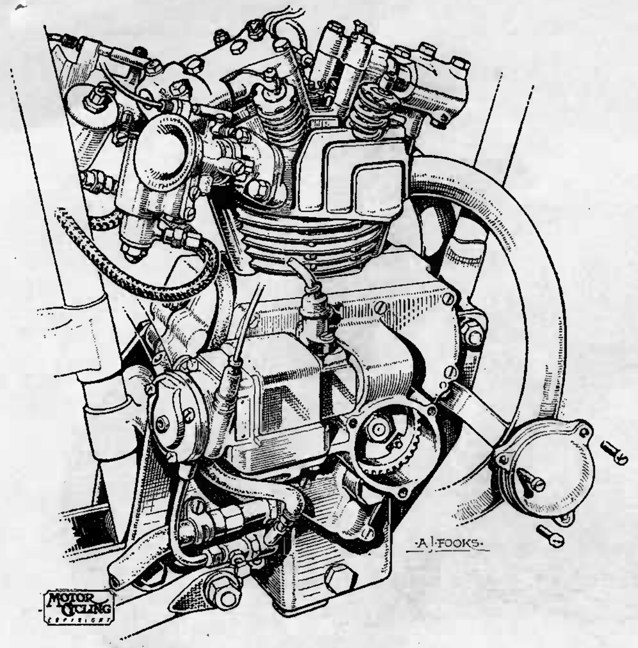
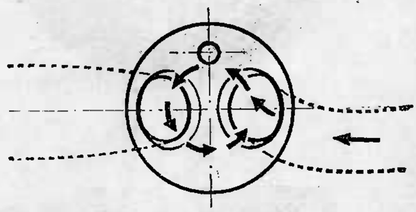


(Left) Four radial valves and twin carburetters on splayed inlets—the Excelsior "Mechanical Marvel" of 1933.



(Right) Plan view of a cylinder head, showing how swirl can be produced by offsetting the angle of the inlet port. The exhaust port in this example has no offset.

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valve. This effect is quite valuable, especially at low engine speeds when the mass-turbulence is not very great, but the larger the valve the less it becomes, all other things being equal.

It will, therefore, be appreciated that, for good tractability and an ability to pull well at low and medium speeds, a small valve fed by a port with a large amount of offset is required. But if one wishes to go higher up the speed range in order to get good top-end power, larger valves and straighter ports are required in the interests of volumetric efficiency; even ports with no offset at all and the largest valves that can be accommodated will provide enough natural turbulence for clean combustion at very high revolution rates.

This is another example of not being able to have one's cake and eat it. The features which are essential for good low-speed power are in opposition to those required for high-speed power and, in practice, a compromise between the two is necessary, with a bias in either direction according to the type of performance required. In general, an offset between 12° and 18° with an inlet valve of diameter equal to half the bore and lifted an amount equal to one-quarter of its diameter, will give very good all-round results in an engine whose bore and stroke do not differ greatly.

Against Interchangeability

To keep manufacturing costs down, it is common to make both valves of the same dimensions and material, and therefore interchangeable. This scheme is of doubtful merit because, for various reasons, the exhaust can be, and should be, smaller than the inlet, and it requires a much more heat-resistant and expensive material. If both valves are identical, either the material is not quite good enough for the exhaust, or unnecessary expense is incurred by making both valves from expensive steel. Making the valves dimensionally identical but of different steels is a practice fraught with grave consequences, because inevitably someone will put a valve in the wrong place and find himself faced with an expensive repair bill, for which without doubt (but with some degree of justification) he will blame the maker of the machine.

The better method, if the most costly, is to regard each valve as doing a different sort of job and to design it accordingly. The inlet is automatically kept cool by the ingoing charge, to which it must offer the least obstruction, because for every pound of difference between the pressure in the cylinder at the start of compression and that of the surrounding air there will be a reduction of one-fifteenth in power output. On the exhaust side, the bulk of the burnt gas is expelled by its own pressure, and a pound or so per square inch of pressure on the exhaust stroke will reduce the power by only about 1%.

Exhaust Valve Problems

Being in contact with hot gas for most of the time, the exhaust valve runs very hot, even to the extent of glowing a dull red, and the surface of its head constitutes a possible source of self-ignition of the mixture before the spark is timed to occur. This feature is not wholly detrimental, as it acts to vaporize the fuel, which enters the cylinder as minute droplets, and thereby promotes good combustion. Carried to excess, however, the effect is bad, but it can be limited to an acceptable amount by reducing the head diameter to 90% of that of the inlet, using a larger stem diameter and taking care to see that the valve-seat and guide are kept as cool as possible, because it is only through those two areas that heat absorbed by the valve can be dissipated.

Exhaust valves are liable to attack by lead through the products of combustion present in the exhaust when tetra-ethyl-lead has been added to the fuel as an anti-detonant, the villain of the piece being lead bromide. Austenitic steels such as KE 965 or Jessop's G2 or any which conform to the English specification D.T.D. 49b are much more resistant to attack, which causes severe pitting and channelling across the seat, than are other less highly alloyed steels; they also possess much more strength at high temperatures, and so are safer all round. "Nimonic 80," a non-ferrous alloy, mainly composed of nickel and originally developed for the turbine blades of jet engines, is also coming into use and, in fact, is now standard equipment on the Velocette "Venom."

A view down the exhaust port of an engine under load would show the hot gas impinging on the underside of the head, then bouncing off, striking the exhaust port walls and generally tying itself in knots before issuing from the port. This is bad for the valve, bad for gas-flow and bad because the violent scrubbing action causes much heat to be absorbed by the port walls and valve guide boss, which is precisely what one wishes to avoid in the interests of valve cooling.

There is no way of eliminating this eddying entirely, but the effects can be reduced by widening the port considerably in the areas on each side of the guide-boss, so that it is actually wider than the valve throat. This is of especial value in those designs where the port has had to be kept flat in order to reduce overall height, or to give enough clearance for valve springs in a limited space.

It has been thought that the angle of offset of the exhaust port, if any, is immaterial because it cannot affect combustion conditions in the same way as offset of the inlet port. A little reflection, however, will show that if there is a large amount of horizontal swirl in the gas it will be as well to humour it by offsetting the exhaust port in the same direction; in fact experimental work has proved that this is true. If one considers the residual gas whirling past the valve-head, it must obviously object to being forced to change direction through 90° in order to escape through the port, and this may well be part of the reason why engines designed with an excessive amount of swirl fall off in power at high speed.

NEXT WEEK

THE CYLINDER HEAD IN DETAIL