MOTORCYCLE ENGINEERING—24

COOLING THE BARREL

Problems of Correct Cylinder Finning

By PHIL IRVING

CONSIDERED as an engineering proposition, the cylinder barrel (or block in the case of some multi-cylinder engines) comes into quite a different category from that of the head because the duties which each has to perform, and the thermal and mechanical stresses to which they are subjected, are completely distinct. Although the head has much the smaller internal area, the amount of heat absorbed both internally and through the exhaust-port walls in an o.h.v. four-stroke is, as a first approximation, 80% of the total heat absorbed from *all* surfaces and, with the exception of a small amount which may be removed by oil flowing through the valve-spring housings, all this heat must be dissipated through the fins; the head has, as it were, to stand on its own feet in the matter of keeping itself cool or at least avoiding becoming too hot. On the other hand the barrel of the same type of engine has only to get rid of the remaining 20% of the rejected heat and a sizeable proportion of this need not be handled by the fins at all but can be removed internally, either in the lubricating oil or by the air-displacement which can occur if a large breather pipe is fitted; another path for waste heat can be provided, in spigoted barrels, by conduction to the relatively cool crankcase.

Avoiding Distortion

But the head has only to maintain gas-tightness of the valves and, provided the design is good, it can achieve this end even at temperatures which are high near the exhaust valve and low near the inlet; the barrel, however, has to remain round and straight under all conditions if blow-by past the piston-rings or the upward passage of oil into the combustion chamber is to be avoided; also, any severe distortion, especially if accompanied, as it usually is, by local hot-spots, is prone to cause piston-seizure unless excessively wide clearances are used, with resultant noisy running. Barrels which are distorted when hot always wear unevenly, and after reboring will not work well until they have again developed the unequal wear which is necessary to provide some semblance of circularity under running conditions.

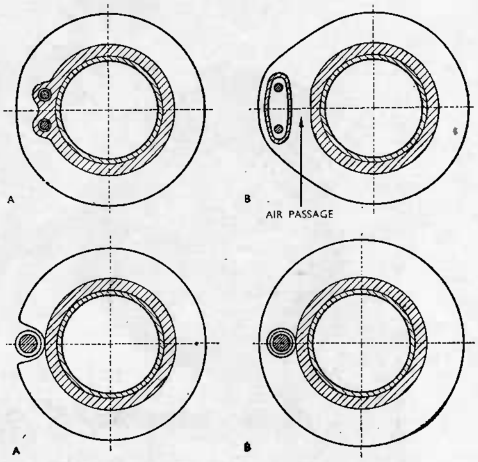
Resulting from the absence of actual inlet and compression strokes as such, which means, in effect, that the cylinder always contains hot gas, the heat-loss to the walls of a two-stroke is much greater than in a four-stroke; it is not actually doubled on that account, because the gas-temperatures, in general, are lower; the actual increase is of the order of 70%—an amount which is sufficient to make the cooling of a two-stroke something of a problem which is further complicated by the presence of ports and passages in the lower half of the barrel. The exhaust port (or ports) naturally absorbs heat in much the same way as its counterpart in a four-stroke, and the shorter it can be kept the better; even so, the exhaust side of the cylinder is bound to be hotter than the side containing the transfer ports, and usually the induction port also. This, in conjunction with the unavoidably irregular metal thicknesses in that region, predisposes the cylinder towards distortion which is especially unwelcome because, for optimum performance, a piston which also acts as a valve must run at the closest clearances possible. The smaller the bore, the less the actual departure from true circularity will be. For that reason and also because the ratio of cooling area to heat rejected to the walls becomes more favourable with decrease in cylinder size, two-strokes give better performances in small capacities, whereas four-strokes are not quite so sensitive to dimensions.

On vertical—or near-vertical—cylinders, plain circular barrel fins are the simplest to manufacture and afford the most effective cooling at high speed. When inclined to the air-flow, as in V-twins or sloping engines, their cooling efficiency is actually increased at low and medium speeds, though this effect diminishes as the fin-spacing is decreased; sloping fins are also a help when the air-speed is down to nil, because natural convection currents can then form between the fins to provide an amount of cooling which, though limited, is at least something on the credit side. In this respect horizontal, transverse cylinders are the best of the lot, since they can take full advantage of either speed-induced draught or natural convection. Moreover they are not hampered by frame components or tanks which may interfere with air-flow from the front, or oil tanks or battery boxes which can have a surprisingly large adverse influence by hindering the freedom of exit of heated air from the rear; this last point is one which is not always given sufficient attention when laying out the installation.

Circular fins would not be very effective on a forward-facing uncowled horizontal cylinder at speed and hence such cylinders are usually equipped with radial fins, although some very small two-strokes, capable only of low road-speeds, have worked well enough with circular fins.

By this token it surprised me somewhat to find them employed on the prototype horizontal-engine "works" Nortons recently described. Not only would the barrel-fins appear to be likely to fail in their primary purpose but the top one also effectively throttles the air-flow through the head-fins which are otherwise correctly disposed for a horizontal draught although somewhat shielded by the bulk of the cam-box. It is of course highly possible that, in the final design, a scoop or cowl might have been employed to deflect air vertically through the fins; it is also possible that the designer utilized an existing component suitably modified in detail in the early stages.

At first sight radial fin arrangement appears to be much superior to the circular one because the air-space between adjacent surfaces becomes greater as the fin depth is increased and any one fin does not become blanketed by its mates on either side which happens when circular fins are made of excessive depth. But, while this is true, it is not such a real advantage as it may look. For one thing, you can only apply a certain *total* length of fin, measured at the roots, to the curved surface of the barrel regardless of which way the fins go and for any given thickness of root, there is a maximum depth of about eight times this thickness above which there is no gain in cooling, provided that the *whole* fin is exposed to the air-blast.



(Top) Providing for push-rod operation: (A) Holes drilled in solid bosses. (B) Cast-in tunnel. (Bottom) Camshaft vertical drive through (A) break in fins and (B) drillings in fins of larger diameter.

Circular fins have the added and very real advantage that they provide a high degree of circumferential stiffness and thus resist any tendency towards ovality, as long as they, themselves, do not distort appreciably; being so much deeper radially than the cylinder wall, the fins are the real masters of the situation. For that reason they should, so far as possible, be continuous; for instance, if long holding-down bolts are used as mentioned in Part 21 of this series (January 28 issue) holes should be drilled for them instead of casting deep slots into the fins. This latter process has been carried out on occasion and invariably leads to piston trouble through the barrel assuming a four-sided shape, not necessarily during running, but even after a pit-stop of a duration sufficiently long to allow the cylinder to cool off, which it does unequally due to the vertical gashes in the fins.

A detail design feature worth mentioning in passing is that small, flat bosses should always be added to the tapered flanks of any fins which are to be drilled; unless this precaution is taken, the drill has a tendency to wander, especially where iron fins are concerned, and the holes will not be true. If the bolts are so located that they are almost touching the actual wall, as they often are with thick aluminium jackets, it is better to employ cast-in bosses so that the drill goes through solid metal all the way; the bosses need be very little larger than the bolts (as an occasional break-through into air will not matter) and will cause only a little more obstruction to air-flow than the bolts on their own.

Camshaft Drives

The housing containing the overhead camshaft drive, whether it be by shaft, chain or gears, is another encumbrance, as it always entails some reduction of fin area and loss of symmetry, more especially in large engines where the drive has to be kept relatively close in order to avoid making the whole thing too wide.

The deep slot in the fins, which is necessary to clear a vertical drive-shaft is clearly undesirable and one way out is to make the fins bigger still and either cast-in a tunnel or drill a large hole for the drive-housing; these expedients cause less reduction in area than the slot, but the main advantage lies in maintaining equality of circumferential stiffness.

Push-rod enclosures can also be a nuisance, though to a somewhat less degree, and do nothing towards improving the appearance. Some makers, notably B.S.A. and Royal Enfield in England, provide tunnels cast integrally with the fins, in which case the tunnels should be either tight in against the jacket, with plenty of fin on the outside, or kept sufficiently far away to allow air to flow through and then the outside wall of the tunnel can be supplied with just enough fin-depth to give a smooth appearance. In the first method there is not a great deal of reduction in cooling efficiency, especially with aluminium; with iron there is a possibility of a hot streak being caused down the barrel. In the second method, overcooling of the outer tunnel wall may give rise to differing amounts of thermal expansion causing undesirable internal stresses and a chance that the whole barrel may even bend slightly, hence the endeavour to keep the temperatures equalized by making the visible fins short.

Because the breeze on any cylinder other than one which faces horizontally forward must, of course, impinge mainly on the front side, the rate of heat dissipation is bound to be greater on this side than at the rear, and it may even be slightly higher still at the sides. Experiments on cylinders placed in a direct airstream and heated uniformly by internal electrical elements, described in the N.A.C.A. Report No. 488, entitled "Heat Transfer from Metal Cylinders in an Airstream," indicate that the difference in temperature between fin and the air in front, at the sides and at the rear, given a speed of 58 m.p.h., was of the order of 95°, 140° and 130° F. respectively, with tapered fins of .3-in. pitch, 1.32 in. depth and .13-in. average thickness; these are about average proportions for motorcycle work and it is interesting to find that thinner fins of closer pitch created a greater variation—55° F. as opposed to 35° F.—while thicker fins of coarser pitch caused about the same variation, but the average temperature went up at air speeds from 30 to 150 m.p.h.

This leads to the intensely gratifying conclusion that conventional fin proportions are not very far wrong, although the results of this test are not strictly applicable; for one thing, due to the presence or close proximity of exhaust ports, the internal heating in practice is not uniform, and for another, the air-flow is not straight but largely consists of a mass of eddies, while a proportion of the front side of the cylinder is shielded from direct blast. Nevertheless, there is obviously good reason for locating the exhaust at the front, or if this is not practicable, at the rear rather than at the sides, as is done indeed on the M.Z. two-stroke. Considerable lengths have been gone to in this engine to reduce the pick-up of heat in the exhaust-ports; although there are two cut in each cylinder, they merge quickly into a single outlet, the length from bore to flange-face being only a few inches.

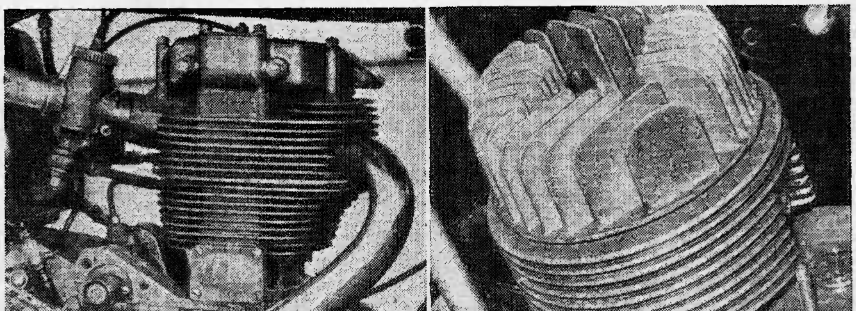
Although this design necessitates a thin piece of liner ¼ in. wide and 1 in. long between the ports and supported only on the outside by a streamlined bar, this practice has clearly been deemed to be preferable to that of using twin outlets with their inevitably greater surface area and a space between which would be bereft of any cooling whatever except by conduction to neighbouring cooler areas. This problem exists even with forward-facing twin ports.

One elementary law governing the behaviour of heat is that it always travels from a warm area towards a cooler one; the implications of this are evidently not always appreciated, as it means that if it is desired to keep an area such as the inlet port cool, it is useless to connect it to any hotter places by continuous fins, which will merely conduct heat to just where it is not wanted; an early example of avoiding this is to be seen in the de-finned inlet port of the Model P Triumph, and many two-strokes might benefit from having the barrel-fins separated, even by thin slots, from the inlet ports. Conversely, the law operates to good advantage in attaining some degree of equality in temperature all round the barrel especially if thick, continuous, circular fins are used; these then act as channels to transfer heat to whichever areas are the least well-cooled.

The better heat conductivity the more pronounced this effect will be; the conductivity (K) is measured in British Thermal Units per square inch (of area) per inch (of thickness or depth) per °F. per hour, representative figures being 2.17 for iron, 7.66 for Y-alloy and 18 for copper. So aluminium fins will conduct heat at 3½ times the rate which iron ones of the same section will, for the same temperature difference, but at only two-fifths of the weight. Put in another way, for the same *weight* they can be 50% thicker and 72% wider and will then be able to conduct heat at nearly *nine times* the rate of the smaller iron ones.

The rate at which heat is dissipated to the air is, however, practically independent of conductivity, but depends upon the surface area, the air-speed actually traversing that area and the condition of the surface. For those reasons, iron fins of the same dimensions as the very deep, aluminium ones used on racing barrels will dissipate nearly as much heat but would be prohibitively heavy and more likely to suffer from wide temperature differences at various points on the cylinder wall. If the air-flow could be induced to follow the entire fin surface instead of breaking away from the sides and merely becoming a turbulent mass at the rear, better cooling could be effected for less weight or bulk; this can be achieved to a considerable degree by fan-cooling with cowls fitting the fin tips, and can also be obtained with natural draught by partly enclosing the fins with shrouds which merge into an outlet of rectangular section, and three or four inches long. When correctly proportioned, such cowling may provide a reduction of 30% in the temperature of the rear wall and may well be worth investigating for racing machines, particularly when fitted with fairings. The scheme would not, however, be of much value for touring models.

NEXT WEEK: Cooling problems peculiar to the multi-cylinder.



(Left) B.S.A. "Gold Star" o.h.v. barrel offers an excellent example of cast-in push-rod tunnel. (Right) Completely circular M.Z. "250" 2-stroke barrel finning showing the unusual provision for the exhaust port at the rear.