MOTORCYCLE ENGINEERING—23

HEAD FIN DESIGN

The Theory Behind Modern Practice

By PHIL IRVING

BEFORE commencing to design the fins of such a complex casting as an air-cooled cylinder head—or, for that matter, the water jacketing of a liquid-cooled example—it is first necessary to lay out the positions of the valves, seat inserts (if any), ports, sparking plug and the bolts used for attaching the head to the barrel or crankcase.

Enough metal must be provided around each of these localities to cope with the mechanical and thermal stresses likely to be involved, not merely from the aspect of sheer strength, but more with the idea of eliminating deflection or distortion, either of which may lead to blown head-joints or leaking valves.

One should studiously avoid skimping the weight of metal used in highly stressed areas on the score of cost. In any case, the finished article will weigh several pounds and the small percentage saving achieved by carving off an ounce or two of material here and there may make all the difference between a mediocre article and one which will withstand full power for long periods without distress. "Penny wise, pound foolish," must be the designer's motto here.

Obviously, there are many vital details such as the valve angles and diameters, plug location and so on which need very careful consideration before they can be finally settled, and some compromises may have to be made in order to obtain satisfactory locations for the head bolts. Four of these are quite sufficient if they are correctly disposed, although five or even six have been fitted on occasions, usually because the porting or the valve-gear layout has demanded it.

However, in conventional two-valve heads the general disposition and proportions of the ports do not vary very greatly and can be taken as substantially constant for the purpose of this exercise, which is to discuss the general design of the fins. On the other hand, the method of operating or enclosing the valve gear does vary significantly from one design to another and may have a very marked bearing on the effectiveness or otherwise of the cooling.

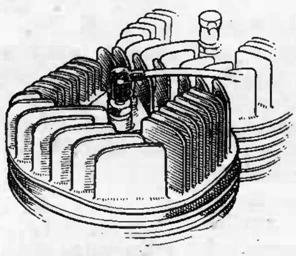
As an example, in the early days when valve-gear was exposed and lubricated scantily, if at all, it was common practice to keep the rockers well clear of the head and mount them either on slender posts or between side-plates. which were often liberally pierced to assist air-flow. The general obstruction to air-flow over the fins was then far less than it is in some later fully-enclosed push-rod designs, or with an overhead camshaft, and the matter became largely one of putting on fins wherever they could be accommodated, provided that moulding and casting were within the existing capabilities of the foundry. Even then, some avoidable mistakes were made which led to lack of stamina, cracked valve seats, burnt or broken valves, and a general state of what is now known as "customer dissatisfaction."

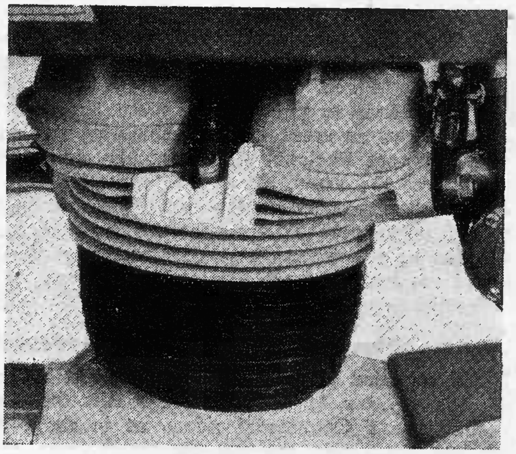
Air cooling is a complex process involving the absorption of heat by the internal surfaces, the transfer of that heat through the metal by conduction to the external surfaces and to the fin-roots, and finally its transfer to the air. There is also the matter of conduction across the mating surfaces of the valve guides and seat inserts (if used) where the fit, though close, nevertheless constitutes a heat-break, and the areas where less intimate contact occurs, namely the valve seats and the portions of stem within the guides.

To give some inkling of the principles involved, it may be worth noting that a hot metal surface dissipates its heat in two ways —by radiation and by convection.

In the radiation process, heat is transmitted through the surrounding air *without warming it up*. The heat does not reappear until it strikes some other body—for instance, a tiny frozen hand held, even at some distance, in front of an electric fire.

Radiant heat behaves in a very similar manner to light; it travels in straight lines, and is reflected by a polished surface and absorbed by a dull black one. The latter process is reversible, and therefore a polished surface emits less heat by radiation than a black one. The rate of emission from a polished copper surface is approximately half that from the same surface covered with a thin film of lamp-black, and the emissivity of a cast-aluminium surface is increased about 10% by a *thin* coating of black paint.





Deflector-type finning directs air towards the plugs on the racing MZ twin two-stroke (above) and the 250 c.c. touring A.M.C. engine (right). In the second case, it also aids cooling of the shielded area between the rocker-boxes.

Radiation takes place only at right angles to the surface. Even if that surface is somewhat rough, as in commercial sand castings, the general direction of the total heat being given off is square to the main surface.

In an earlier article it was stated that the amount of heat given off by radiation increases as the fourth power of the temperature. This rather loose statement needs amplification.

Strictly speaking, when a body is very hot in relation to its surroundings the radiation varies as the difference between the fourth powers of the absolute temperatures concerned. When the difference in temperatures is only a few degrees, Newton's law of cooling applies and the rate of heat-loss is then directly proportional to the temperature difference between the body and its surroundings. However, in practice this still means that the loss by pure radiation is low at low cylinder temperatures, but increases very rapidly if the cylinder gets much hotter than it should be.

Since air takes no part in the process, radiation goes on just the same whether there is any wind present or not, so it is of most value as a safety-valve at zero air-speed. Under normal circumstances it accounts for only one-sixth to one-tenth of the total heat loss and cannot be greatly increased by the addition of fins, whose only effect is to increase the effective radiation area from that of the bare head and barrel to that of the general outside shape enclosed by the fin-tips.

This is so because adjacent fin surfaces merely radiate heat from the hotter one to the cooler, or not at all if both are at equal temperatures. The effective radiating surface is perhaps doubled or trebled by the addition of fins, whereas the area of surface in direct contact with the air may be eight to 12 times that presented by the bare components.

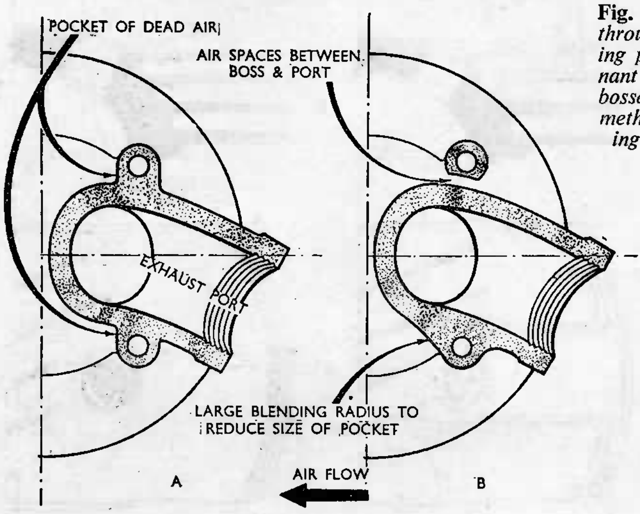


Fig. 1 (A) *Section through head, showing pockets of stagnant air behind bolt bosses.* (B) *Two methods of improving this condition.*

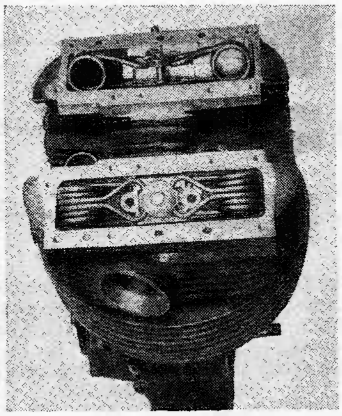
But there is a second source of heat dissipation which *can* take advantage of this increase in area—convection. It consists of a direct transference of heat to the layer of air in immediate contact with the surface; this layer then expands, becomes lighter and, under natural conditions, rises and is replaced by cold air which is heated in its turn.

Air is an extremely poor conductor of heat, its resistance being some 3,500 times that of iron, and little heat would be removed were it not for the setting-up of these convection currents, which to quote a homely example again, can be felt rising from a hot-water room-heater (incorrectly called a "radiator," whereas "convector" would be a more descriptive term).

The greater the surface in contact with air, the greater the heat-dissipation will be, provided that the air movement is sufficient. Even if the fins are substantially vertical and unshielded (as on a B.M.W. flat-twin) natural convection, though a distinct help when the model is at a standstill, would be insufficient at high power; and, of course, it can scarcely be of any benefit at all on a vertical single-cylinder or twin engine with horizontal fins.

It is therefore necessary to rely on the forward speed of the machine to provide a forced circulation, or in the case of those with enclosed engines, to employ a fan. The fan has the advantage that its air-delivery bears some sort of relationship, even if a rough one, to engine speed and power output.

Without a fan, the air velocity over the cylinder is totally unrelated to engine speed, to power or even to road speed, because a strong side or tail wind will alter both the rate and direction of the resultant wind; nevertheless, under most circumstances this will be blowing from the front and in a horizontal direction, unless seriously deflected by some external fitting.



(*Below*) *With careful design, the bulky enclosures of hairpin valve springs do not prevent adequate cooling of a light-alloy head. The example is a 1949 350 c.c. T.T. Velocette.*

To take full advantage of this type of flow, the fins on a vertical barrel should be horizontal—or reasonably so, for there is reason to assume from the behaviour of V-twins and singles with sloping cylinders that an angle of inclination of up to 25° from the vertical detracts little, if at all, from the effectiveness of the fins, and may even be of some assistance at very low air speeds in permitting natural convection currents to form between each fin.

The general direction of the head fins should be either horizontal, or vertical and parallel to the centre-plane. They should be disposed in the manner best calculated to allow moving air to penetrate right down to the fin-roots and to eliminate pockets of stagnant air which, if undisturbed, acts as an insulator instead of a heat-remover.

Head-bolt bosses in close proximity to ports sometimes create such pockets. The effects can be made less serious either by separating the bosses from the port wall, even though this may be a tricky job for the foundry, or by going to the opposite extreme and using very generous fillets between boss and port which in effect, fill up the unwanted pockets with metal (Fig. 1).

The areas below and behind a steeply offset exhaust port are other badly cooled places. It is in such localities that aluminium scores over cast-iron, as, although it is only two-fifths the weight, its thermal conductivity is double, so that generous sections can be employed without a serious weight penalty in order to conduct the heat out to a region more exposed to the air-flow.

Heads have occasionally been designed with a bank of vertical fore-and-aft fins lying between the valves. This arrangement is bad in two respects. One is that the ventilation is bound to be poor and deepening the fins makes matters worse, if anything. The other is that differential expansion of the hot head-metal between the valve seats and the cold fin-tips sets up stresses which have been known to create valve-seat distortion and gas leakage.

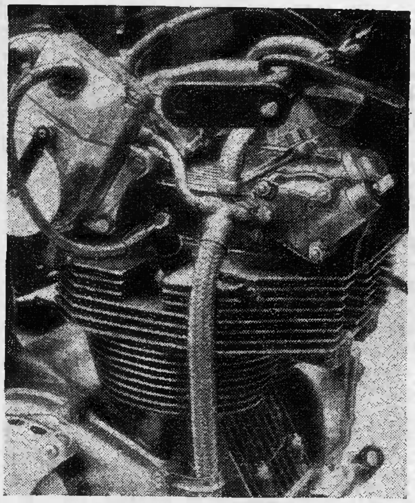
One palliative is to cast a transverse slot through the bank of fins, partly to assist air circulation and partly to remove any restraint on free expansion of the head, but a better solution is to arrange the fins at an angle so that air is collected on one side of the head and guided through to the other. On vertical twins, especially those with integral or bulky bolted-on rocker-boxes, inclined fins may materially assist in feeding air through into the badly ventilated area behind and between the two cylinders.

On the Exhaust Side

Since most of the heat extracted from the exhaust valve is transferred to the head via the guide, it is essential to pay particular attention to this region, although it is not always easy to achieve anything like perfection. The space taken up by hairpin valve springs necessarily cuts down the area of finning close up to the guide, whilst prominent fins springing from a long exhaust port do little more than handle the heat absorbed in the port itself.

Any heat which escapes in the exhaust gas is simply a waste product and as such should be dismissed down the pipe as soon as possible and not allowed to embarrass the head any more than is absolutely unavoidable. To that end, the port should be short and of the smallest diameter consistent with good power production.

Largely on the score of weight, but also in some cases because it was a refinement added to an existing open-valve design and later retained for manufacturing reasons, valve enclosure on cast-iron heads is frequently carried out by using a bolted-on light-alloy rocker-box with separate oil-tight housings for the valve springs. Some of these devices are well clear of the head



Vertical fore-and-aft fins between the valves of the 125 c.c. Honda racer are pierced and air is directed towards them by a sheet-metal deflector (not shown).

and do not interfere too greatly with air flow; the J.A.P. design is good in this respect, though others are not so happy.

The bevel-box and housing of a single overhead camshaft can create a much more serious situation, especially with an engine which is so tall that the cambox must be kept close down between the valves in order to fit into the frame. But the whole picture is altered when light alloy is used, because then it becomes possible to cast the cambox and head in one unit without excessive weight, and to employ copious lubrication without smothering the cylinder head in oil. Either coil or hairpin springs can be used; even the bulky enclosures required to house the latter are not so detrimental as they might appear, since the high-conductivity material will transfer heat quickly to fins applied to the spring-box walls.

Probably the outstanding examples of this construction were the "works" 350 and 500 c.c. Velocettes, which were notable for their enormous fins—approximately 10 in. square in plan view—as well as the unit camboxes.

The size and shape of these fins were developed not only to furnish a larger area than the conventional circular outline, but also to get their tips out into fast-moving air. Experiments prove that at high speeds a region of comparatively dead air, extending as the speed rises, exists behind the shelter of the front wheel and forks; this can lead to the cooling becoming progressively worse instead of better.

Incidentally, a comparison between the head assembly of pre-war push-rod Velocette, the K.T.T., and the post-war aluminium component with integral rocker boxes provides a very good example of the way in which design progresses by utilizing ideas from every source available. The later example is lighter, simpler to make and better cooled than the original version and, moreover, it can be die-cast in permanent moulds which, besides reducing the component cost, furnishes cleaner and more accurate castings and increases the strength of the material, in this instance Y-alloy.

Fin area is sometimes lost through having to provide clearance for the sparking plug and the push-rod tubes or cam-shaft drive; these gaps cause discontinuities in strength or conductivity which are best avoided. If, say, the head has several horizontal fins, it may be possible to adjust the plug angle so that, while the firing points remain in the correct position, the top fin need not be cut away much, if at all, to miss the body and give spanner clearance (Fig. 2). A long-reach plug thread helps the situation, as the boss can be in direct contact with one or even two fins.

On the push-rod side it is possible to cast a tunnel up through the barrel and head fins, provided that there is space for air to pass through behind the tunnel. Rudimentary fins may be applied to the visible side for the sake of appearance, but overcooling in this region can do more harm than good, the ideal being to aim for equality of temperature all round. However, this is entering the province of barrel design and poaching upon the next article.

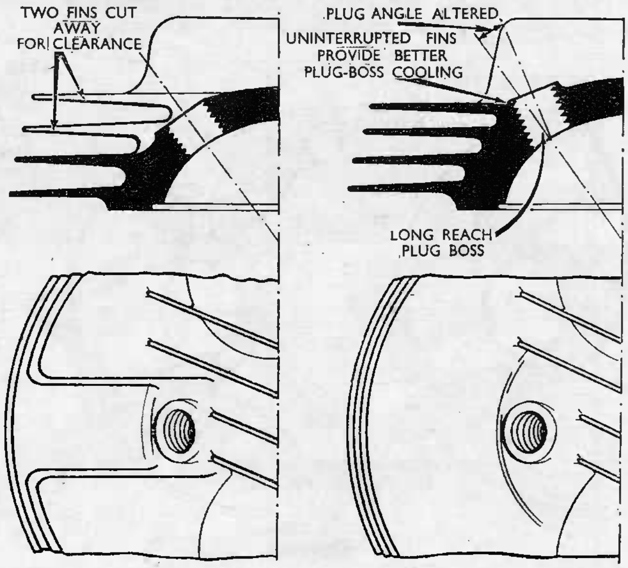


Fig. 2 *(Left) Section and plan of head with two fins cut away to provide plug clearance. (Right) Use of a long-reach plug at a modified angle provides uninterrupted finning with the same firing point.*

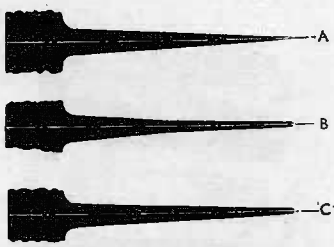


Fig. 3 (A) *Ideal fin section for constant temperature gradient.* (B) *Double-taper section, a practical form of* A. (C) *Conventional single-taper fin. The root fillets play an important part in providing a heat path.*

In practice, fins are usually of plain tapered section, spaced somewhere between $\frac{3}{8}$-in. and $\frac{5}{16}$-in. apart. Although this shape was adopted simply because it is the easiest to make in the pattern and foundry stages, it is, by a happy chance, a very efficient section on the basis of weight in relation to heat dissipation when the air-speed is low and its direction is erratic.

Ideally, a fin should have concave sides and sharp tips and be blended into the base metal by circular fillets. Such a shape is difficult to make, but a good approximation can be attained by using a double taper on the sides (Fig. 3) and rounded tips $\frac{1}{16}$-in. wide.

The fillets present no difficulty, though they are sometimes inadequate in size, or even omitted, because their value in feeding heat into the fin-roots is not fully appreciated. The limiting factor in casting is the depth of fin in relation to the pitch, but fins up to 2½-in. deep can be sand-moulded in aluminium by specialists in the art.

Lately, die-casting has become a serious rival to sand-moulding for production models where the design is sufficiently well established to warrant the high initial die cost. Excellent examples of this class of work are to be seen on Triumphs, and even the Japanese Honda racing models have die-cast heads and barrels.

With die-casting, there has come about a tendency towards using a larger number of thinner fins than is customary, or even expedient, with sand-casting, though this is by no means general. Some makers, though adopting die-casting for production reasons, have maintained the fin dimensions previously used for sand, a procedure which has much to commend it on machines cooled only by normal draught. When fan cooling is employed high-speed air can be directed by cowls which embrace the fin-tips closely, and for these conditions the ideal is a large number of thin fins.

Anyone wishing to delve still further into the relative merits of various fin sections can find much to interest them in a paper written by P. V. Ramarque, issued by the Institution of Automobile Engineers' Proceedings, 1942-43, and entitled "The Design of Cooling Fins for Motor Cycle Engines."

NEXT: BARREL COOLING