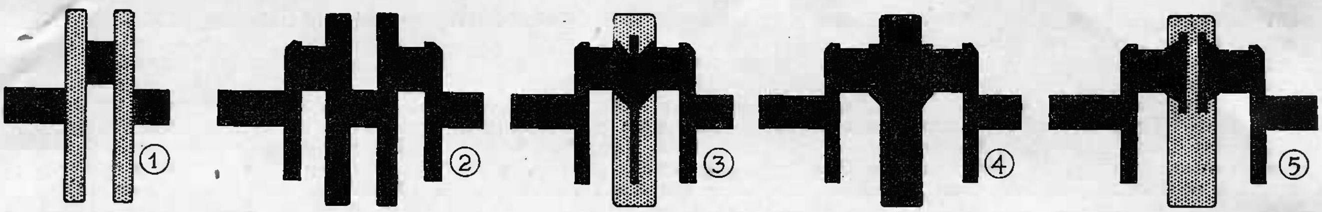


Classes of crankshaft : (1) Single-cylinder, built-up. (2) Twin, integral, with centre bearing (e.g., A.M.C.). (3) Twin, built-up, central flywheel ring bolted-on (B.S.A., Triumph). (4) Twin, integral (Royal Enfield). (5) Twin, built-up, flanged big-end journals bolted to flywheel (Norton " Dominators ").

The Bottom End

Part One—The Crankshaft Assembly

By PHIL IRVING, *M.I.Mech.E., M.S.A.E., M.I.P.E.*

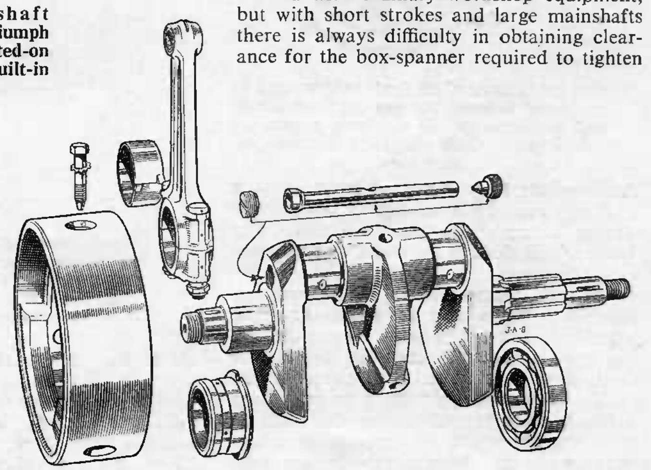
THE reciprocating motion of the piston is converted to rotary motion by means of a crank and connecting-rod mechanism enclosed in the crankcase. A flywheel also is required to smooth out the power impulses (especially with a single-cylinder four-stroke) and to keep the engine running at slow speeds; the larger the number of power impulses and the higher the minimum speed likely to be used, the lighter the flywheel effect may be.

There are, broadly, two systems of disposing these " bottom end " components: (a) the " inside flywheel," in which the wheels form part of, or are bolted to, the crank assembly within the crankcase, and (b) the " outside flywheel," in which the crank is formed from two webs or small discs, with the flywheel outside the case, though usually fully enclosed.

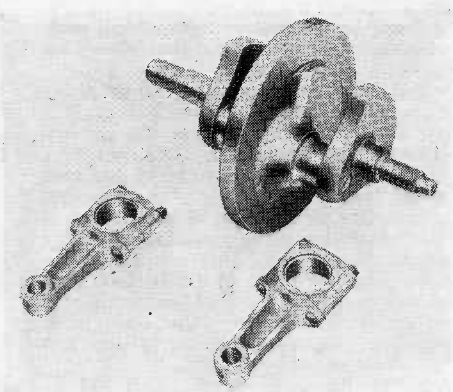
" Inside Flywheel " Systems

In the " inside flywheel " system, the case has to be enlarged to accommodate the wheels, which are usually 7 in. to 8 in. in diameter and, in most single-cylinder designs, are steel forgings, though high-quality cast iron is still in restricted use. The flywheels are united by a crankpin and the mainshafts are usually made from steel bar and retained in the wheels either by press-fitting or by nuts.

Great accuracy is required in manufacture, as the shafts on final assembly should run true to each other within .001 in. and there may be upwards of a dozen diameters or faces involved, the slightest error in which will affect the alignment. Fortunately, however, all the machining operations are straightforward, and can be done on regular machine-shop turning and grinding equipment with little difficulty.



(Right) Crankshaft assembly of the Triumph T21 twin, with bolted-on flywheel ring and built-in sludge trap.



(Left) The Norton "Jubilee" crankshaft is a single-piece Meehanite iron casting with integral flywheel, on the flanks of which are supplementary bob-weights.

Under severe conditions, the crankpin is subject to alternating piston-inertia loads with peak values of 2,000-3,000 lb. and gas-loadings which may well be over two tons in a high-performance single. Though these factors cancel each other to some extent on the power stroke, nevertheless the resultant loads are very heavy.

In order to balance, as far as possible, piston inertia loads and also the centrifugal force arising from the big-end itself, the wheels are counterweighted. This may be done either by thickening them on the side opposite to the pin or by forming recesses, or drilling holes, on the same side as the pin. Either way, the effect is to move the centre of gravity of the wheels away from their axes, and the resultant centrifugal forces act substantially in the plane of each wheel.

The result, beside achieving partial balance, is to lessen the inertia loads on the main bearings, and also their bending effect on the crankpin, although this is still so great that the main bearings (usually of ball or roller type) must be kept as close as possible to the cylinder centre-line without making the flywheels so thin that they will constitute another source of flexure.

Clearly the pin itself should be of large diameter—$1\frac{1}{2}$ in. is advisable for a 500 c.c. single—and very firmly anchored in the wheels. There are several methods of anchorage. The pin may have tapered ends pulled in by nuts, or parallel ends pulled up against square shoulders by nuts, or it may simply be made a very tight interference fit in the wheels, which must, in this method, be of steel and not of cast iron.

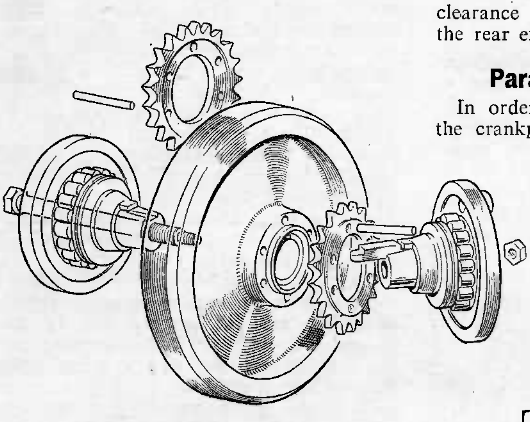
The usual method in large four-strokes is the " parallel-pin with nuts," which has the advantage that dismantling can be performed with ordinary workshop equipment, but with short strokes and large mainshafts there is always difficulty in obtaining clearance for the box-spanner required to tighten the usual hexagon nut. This has been overcome in " Manx " Nortons by using recessed nuts, with splines instead of flats, and a castellated spanner, while the 7R A.J.S. employs special nuts which, after tightening, are cut off flush with the wheels (these nuts cannot be removed without destroying them).

In single-cylinder Velocettes, the main bearings are closer together than usual because of the extremely narrow primary chain-line and no nuts are employed. The pin is ground with a very small amount of taper on each end and is forced with 3-4 tons pressure into the wheels until these are hard against the shoulders provided by the central portion of the pin, which forms the track for the caged roller bearing.

The Guzzi "Lodola" employs a somewhat similar construction which, however, is more commonly found on two-strokes, where it is essential to avoid odd spaces in which "dead" mixture can accumulate.

In conventional designs, the position of the engine-sprocket is determined by the necessity to move the primary chain out far enough to clear the rear chain and to provide space behind the clutch for the inner wall of the primary chaincase—which may result in an undesirable degree of overhang from the main bearing. To combat this, a second bearing can be added very close to the sprocket, and in rare instances an "outrigger" bearing has been employed—a system which is even more effective, but adds to the problem of machining all the main bearing housings in alignment.

With two bearings on the drive side, the mainshaft is very well supported, but this



Central flywheel of the Scott twin two-stroke is located between the two crank-chambers and the bosses of the overhung cranks are bolted to it. Only two main bearings are necessary.

does nothing to relieve it of torque-loading and may even increase local bending loads due to flexure of the crank-assembly. The fixing of this shaft in the wheel thus becomes very important.

The best method would be to make it integral. While this is sometimes done when the crank-web is small, forging difficulties are encountered when the flywheel is large, and it is more usual to make the shaft a semi-permanent fitting by employing a heavy press fit and locking the shaft in some manner which will prevent its subsequent removal. After that, the crankpin hole is bored and faced true to the shaft to eliminate any errors introduced during the fitting of the shaft: it is at this stage that the greatest care must be taken in machining, to avoid scrapping a valuable component.

On the timing side, there is usually one roller bearing, but on occasion a plain bush is used, oil being fed directly to the bush and thence up drilled holes to the big-end. Alternatively, either oil is fed into the end of the shaft via a quill, or a bronze bush is located in the timing cover to steady the end of the shaft and also to act as retainer for oil which is supplied to the blind end of the bush.

There is not much oil pressure involved when roller big-ends are used, because these offer little resistance to flow, nor do they need pressure feed as do plain bearings. So long as enough oil is supplied to the mainshaft, the centrifugal force generated in the radial oil-way will ensure that it goes out through the big-end.

V-twins

The general construction of V-twins duplicates that of singles, and the rods can be accommodated either on the "fork-and-blade" principle or by mounting them side by side.

On J.A.P. engines, the forked rod is fitted with a sleeve which runs on rollers on the crankpin, while the blade rod oscillates on the outside of the sleeve. This construction permits the cylinders to be in the same plane, and the overall width is less than when the rods are side by side, as in the Vincent. However, the offset of the Vincent barrels provides slightly better airflow over the rear one and is also a help in obtaining clearance between the two heads to permit the rear exhaust port to face forwards.

Parallel-twin Four-strokes

In order to obtain even firing impulses, the crankpins on parallel-twin four-strokes are in line and, naturally, the whole crank assembly is twice as long as in a single. Undesirable flexure would occur owing to this great length unless adequate precautions were taken, which may consist of adding a centre bearing, as in A.J.S. and Matchless products, or the usual practice of making the centre portion extremely rigid either by bolting the flywheel to a heavy integral flange (Triumph), sandwiching it between the flanges of a two-piece shaft (Norton) or making an integral assembly, cast in high-tensile iron (Royal Enfield).

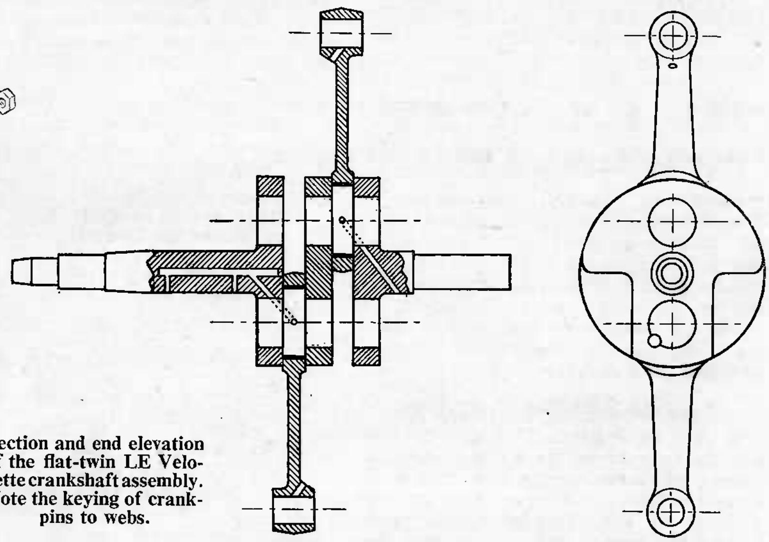
Split big-ends with their accompanying bolts are necessarily heavier than the plain eyes used with roller big-ends, and high-tensile aluminium forgings are used. This material also forms a good bearing surface and can be run directly on to the pins, but it is usual to fit renewable bearing shells of thin steel lined with white-metal or, for very arduous work, with indium-coated lead-bronze, sometimes called "tri-metal."

The stresses in the drive-side crank-web are considerable. In particular, the explosion load from the timing-side cylinder is applied several inches away from this web, so subjecting it to a twisting action in addition to the loads imposed merely by the transmission of torque. Consequently, should a failure occur, it will almost always take place through fatigue in this region; it is fortunate that such failures are rare, because they can be followed by the most disastrous consequences.

Outside Flywheel Designs

The presence of inside flywheels naturally makes the crankcase large, which is undesirable in a two-stroke because it reduces the pumping efficiency of the crankcase. Hence, the diameter of the shaft assembly is reduced as much as possible and the required weight is supplied by an outside flywheel, a convenient system because this component can then be utilized as part of a flywheel magneto, or even a starter-motor.

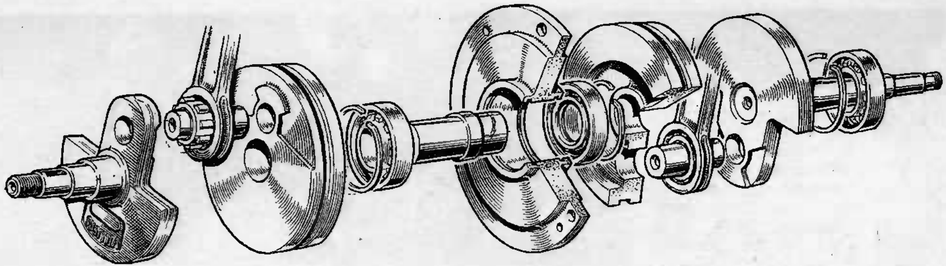
The crank-webs can either be disc-shaped in order to fill up the maximum amount of space, or be made simply as webs with crescent-shaped balance weights, which is the usual Villiers system and is an assistance in forging the drive-side web and shaft in one piece. Press-fit, nutless crankpins are usual, though not universal, those in the Villiers being hollow and fitted with expander plugs which are driven home after lining-up the assembly.



Section and end elevation of the flat-twin LE Velocette crankshaft assembly. Note the keying of crankpins to webs.

Since a flywheel magneto is large in diameter and must be run free from oil, it is not feasible to enclose it in the primary chaincase, but instead it is often carried on the "idle" end of the crankshaft and protected simply by a light weather-proof cover. One disadvantage of this scheme is that under very rough conditions involving severe changes in (or even reversal of) the drive load, the inertia of the flywheel tends to pull the assembly out of line, and a very secure method of fitting the crankpin is necessary, this being particularly important in moto-cross engines.

In the flat-single Guzzi, which has an



Crankshaft assembly of the Villiers 2T twin two-stroke is supported in the centre by a pair of bearings, with seals, installed in a central wall.

outside flywheel, the primary drive is taken through dogs on the face of the flywheel bars to the pinion, which is otherwise a free fit on the shaft. Thus all transmission "snatch" loads due to rapid flywheel-speed fluctuations are absorbed at the source and have no effect at all on the crankshaft assembly.

In small two-strokes, an overhung crankpin is sometimes used. This system is the simplest possible and avoids all the trouble of building up a composite assembly accurately in line, at the expense of placing very heavy loads on the main-bearing nearest to the crankpin. To reduce this, and also to minimize bending loads in the mainshaft, the big-end and crank-web must be made as narrow as possible consistent with adequate strength.

The twin-cylinder Scott is a good example of this construction. By placing a crankpin at each end of the shaft and the flywheel in the centre, the number of main bearings is reduced to two and the problem of isolating the crank-chambers from each other is very neatly solved—but, of course, the drive also has to be taken from the centre, which is not convenient when a conventional type of gearbox is to be used.

Twin Two-strokes

The general system with twin two-strokes is, therefore, to put the sprocket at one end of a two-throw assembly which is supported in the centre by a pair of bearings and seals installed in a centre wall. This construction, though sound, is not easy to put into concrete form, and necessitates a "semi-permanent" arrangement, as on the Villiers twin, which cannot easily be dismantled without special equipment, or the use of a sliding-fit crank-web on the drive side (the Excelsior method) which permits access to a draw-bolt holding the two halves of the centre portion together. In the second system, the drive-side shaft must be mounted in two bearings, in order to maintain it in true axial relationship despite the lessened rigidity occasioned by the sliding fit of the adjacent crankpin.

Flat-twin Shafts

Flat-twin shafts are always built-up assemblies, the easiest method being to form the pins in one with the centre-web, which can then be less than ½ in. thick. By this method, together with the use of narrow roller-bearing big-ends, the cylinder centre-lines can be kept close together, which is desirable both for balance and for rigidity. The outer webs, formed with balance weights, can be either pressed onto the pins or retained by nuts. There is, however, a tendency to twist the drive-side pin in relation to the web which is not present in a single-cylinder layout, and for that reason the pins may be keyed to the webs as a precautionary measure.

(To be continued)

The Bottom End

Part Two—The Crank

By PHIL IRVING, *M.I.Mech.E., M.S.A.E., M.I.P.E.*

THE crankcase has one obvious duty to perform, namely, that of acting as a container to keep oil inside and mud and water outside. Less obvious, though more important, functions are to act as a mechanical connection between the cylinder and the crankshaft bearings, to provide a firm foundation for the cylinder block, to accommodate the oil-pump and timing gear and, in some instances, to act as a frame member as well.

A further function in two-strokes is to act as a pump in transferring mixture from the carburetter to the cylinder. So, in one way and another, a great many points have to be borne in mind at the design stage to obtain a component which is neither too heavy nor too difficult to machine, and yet is not so flimsy that undue flexure will occur under operating loads.

With one or two exceptions (notably the Barr and Stroud single-sleeve-valve units in which the barrels were cast integrally with the upper crankcase halves) crankcases are made in light alloy, either as sand-castings or die-castings, and, except for those of flat twins, are usually split vertically into two components, spigoted or dowelled together.

The foundry work entailed in this construction is quite simple, demanding the minimum number of cores, chills or loose pieces in the pattern equipment, and the castings can be easily and rapidly machined on turret lathes without expensive tooling. After part-machining, it is necessary to assemble the halves before milling and boring the cylinder register, and, of course, great care must be taken to ensure that the main-bearing housings are accurately in line, especially when there are more than two.

In a single-cylinder or V-twin engine, the construction is quite straightforward. The crank-chamber is in one compartment and the timing gear in another, closed by its own cover.

Parallel-twin Problems

Complications begin to creep in with a parallel twin, partly because the camshaft or shafts must be housed within the crank-chamber so that they can operate the drive-side valve gear, which means that they, too, are carried in bearings in each half (unless an overhead camshaft layout is used). Further, the span between the main bearings is so wide that some designers prefer to incorporate a centre bearing, which must be carried in some fashion that permits of easy assembly.

In modern A.M.C. twins, the solution is to carry a split plain bearing in a plate sandwiched between the two case-halves. Their predecessor, the "Porcupine," had a similar scheme, but the crankcase was in one piece. The crankshaft, with the centre-bearing attached but without the rods, was slid in through one end of the one-piece case and, after adding the drive-end cover, the centre bearing was pulled up against the bored inner surface of the case by bolts reaching down from the cylinder base. The rods were assembled after this operation, the big-end nuts being accessible through the cylinder-base mouths.

The problem becomes more acute with two-strokes because of the necessity to seal each chamber individually, and achieving this inevitably introduces complications or difficulty in assembly.

In the present Villiers system, a central circular casting containing a roller bearing and double-acting seal is assembled on a spindle to which the adjacent crankwebs are pressed. The disc is spigoted into the case on the split-line to centralize it, and slots are provided in both half-cases to clear the con.-rods which are, of course, non-detachable. The upper ends of these slots are closed by what appears to be, but actually is not, a full-width compression plate. In the Jawa twin a somewhat similar idea is used, but the slots are closed by a light metal block.

The difficulty with this method is that the central bearing or seal can only be renewed after pressing off one of the inner crank-webs, which requires special equipment. Fortunately the job is not one which needs to be done very often.

In the Excelsior twin two-stroke, a three-part case is employed, split on each cylinder axis. The drive-side crankweb, being only a sliding fit on its crankpin, can be withdrawn with its part of the case, after which the two-piece central portion can be divided and removed. These systems make sure of the inter-crankcase sealing, but whichever is used satisfactory results are more difficult to achieve than in a four-stroke.

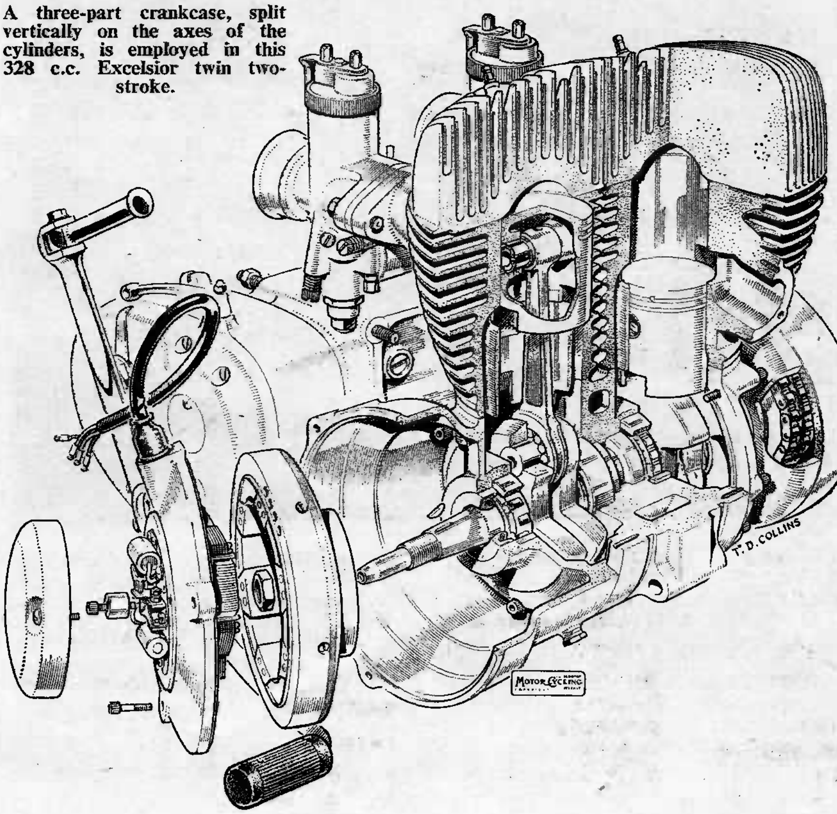
Horizontal Split

Another solution, more favoured abroad than in England, is to split the case horizontally instead of vertically, along the axis of the crankshaft. The shaft can then be built up, complete with rods, bearings and seals, and placed in position in one half before bolting the other in place.

From the manufacturing angle, this still means preliminary machining in halves, followed by final machining after joining together to form a unit, but it is probably simpler overall than the vertical-split method. If the gearbox is made integral (as in the Japanese "Suzuki") the split can be continued right through and the gearbox shafts arranged with their bearing centres on the line of the split.

Occasionally four-stroke units have been made in this way. In fact it was the only

(Continued on page 727)



A three-part crankcase, split vertically on the axes of the cylinders, is employed in this 328 c.c. Excelsior twin two-stroke.

THE BOTTOM END - *Continued*

sensible method with a "straight" four, and it presents the possibility of making the sump as a steel pressing which, on removal, would disclose split big-ends and perhaps the gearbox internals as well.

This idea would not be practicable with a two-stroke, since when crankcase compression is utilized it is necessary to reduce "idle" spaces to a minimum. Hence the practice of using disc crankwebs which clear the machined surfaces of the case by only half a millimetre in some engines.

On a four-stroke, it is better to allow a generous clearance to reduce the drag resulting from the large amount of oil present, and at one point only to provide a scraping edge by which oil adhering to the wheel rims is directed into a small sump, where it can become quiescent before being drawn into the scavenge pump. In the early days of the dry-sump system, trouble with faulty scavenging was encountered due to the pump having to handle a great mass of froth instead of liquid.

Oil as a Coolant

If circulated at a rate of 30 or 40 gallons an hour through external pipes to a dark-coloured tank, oil can be used to remove a lot of heat and can exercise a great effect in keeping the piston cool.

In order to eliminate the separate tank and its plumbing, some designers prefer to cast the tank integrally with the crankcase, still retaining the dry-sump system if there is insufficient room below the case to allow the oil simply to drop in by gravity. This is usually the position with a largish vertical single, but it is possible to use the sump system if the crank assembly is small, as in the B.M.W. twin and M.V. four.

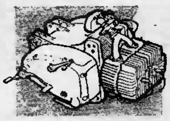
While oil is good at collecting heat, it is very bad at getting rid of it again, because the layer directly in contact with a cool surface increases in viscosity and simply stays there, acting as an insulator and effectively preventing heat being dissipated from the hotter oil in the interior. Ribbing a sump which contains a quantity of oil is not very effective unless there are some internal ribs also to conduct as much heat as possible from the body of the oil, but ribs placed on areas against which hot oil is violently thrown by centrifugal action can be made to radiate a lot of heat.

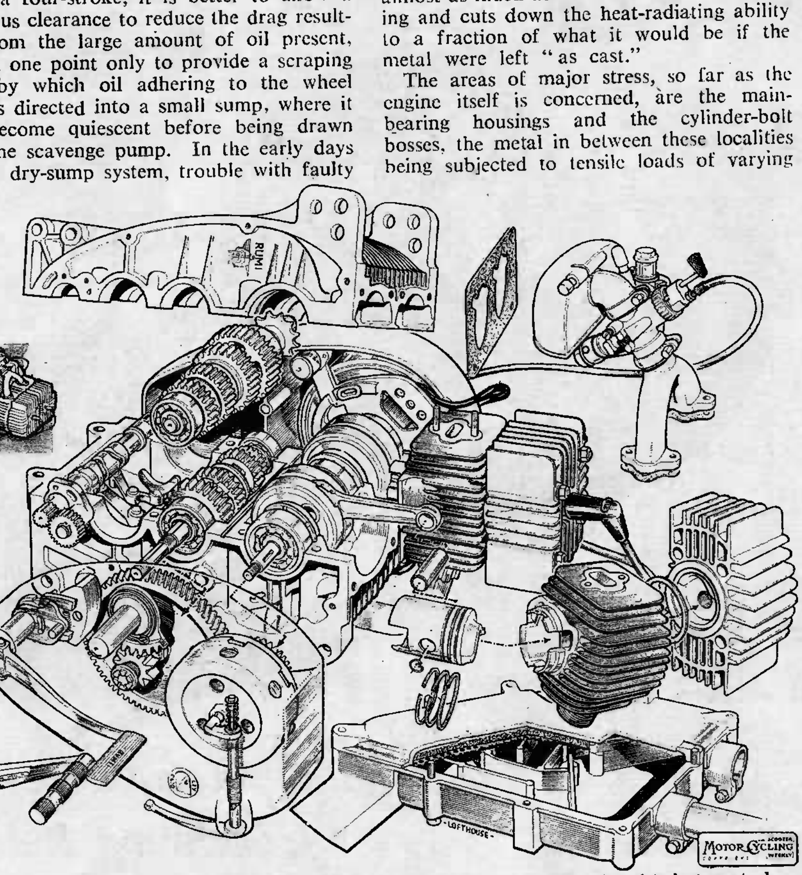
In this connection, the polishing of crankcases, though pleasing to the eye may cost almost as much as the whole of the machining and cuts down the heat-radiating ability to a fraction of what it would be if the metal were left "as cast."

The areas of major stress, so far as the engine itself is concerned, are the main-bearing housings and the cylinder-bolt bosses, the metal in between these localities being subjected to tensile loads of varying intensity. There are also stress concentrations in the region of the fixing-bolt bosses, especially if the crankcase forms part of the frame—or even if, as sometimes happens, it is stiffer than the frame which is supposed to be carrying it, in which event the case may be doing more work than the frame.

In a single, the best way to dispose the metal between bearing and cylinder flange is in the most direct line, but this may imply that the wall is practically a flat disc which is likely to "pant" in and out, especially if the flywheel assembly is located laterally between the sides of the case. If there are two bearings on the drive side, they may be insufficiently supported against radial loads, especially those applied by the primary drive, and it is therefore advisable to provide a number of ribs to give additional stiffness without much weight increase.

Unfortunately, ribs, if placed externally, collect dirt and are difficult to clean, so on touring engines they are usually placed internally. If this course is adopted, plenty of metal must be left around the main-bearing outer races, otherwise they will inevitably come loose.





A clear example of a horizontally split crankcase-gearbox—the 125 c.c. Rumi twin two-stroke.

Care with Studs

Cylinder-base studs, especially in a high-compression engine, should be screwed into the metal for a distance at least *twice* their diameter, and the bosses should not be overhung from the parent metal, even if this does assist the machining operations.

The run-out at the end of a thread cut with a self-opening die-head exercises a powerful wedging action if the stud is tightened on this portion, and the boss may split. This can be avoided either by bottoming the stud in the hole, or by the simple expedient of turning a groove at the end of the thread to eliminate the run-out portion. Studs treated in this fashion screw into the end of the groove and then stop, so their projecting length is not indeterminate, as it is when the run-out is present.

Local "heaping-up" of the soft aluminium around the stud-hole can be avoided by counterboring two threads deep before tapping.

Provided attention is given at all localized high-stress points, any good-quality aluminium alloy will suffice, and the design should be such that it can be readily die-cast without too much intricacy in the permanent moulds.

When lightness is a primary consideration, magnesium alloy can be used, with a saving for equal section thicknesses of 40% in weight. For various reasons, such as thickening-up at high-stress areas or the use of steel locking plates for the main bearings, the saving may not be much more than 30%. This is worth while in bulky single-cylinder engines and is common English practice, though the Italians, who are thoroughly weight-conscious in their racing models, are not very keen on magnesium.

One reason for this is magnesium's coefficient of thermal expansion which, at .000028 in. per in. per degree C., is much higher than that of a low-silicon aluminium alloy at .000022. Even this second figure is an embarrassment, because it means that when cold a bearing of 2½ in. diameter must be fitted .003/.004 in. tight to prevent it coming loose at operating temperature.

At lower temperatures, considerable "hoop" tension is developed in the housing metal, and the additional interference necessary with magnesium alloy increases this tension to an extent which may cause the metal to stretch, after which the bearing is loose, or at least free to creep around at working temperature. For that reason, it is necessary to hold the outer rings in and prevent them from rotating by some form of retainer-plate or a flanged outer race.

The problem is not so acute if a bronze bush is used on the timing side to act as an oil-feed as well as a bearing, because the coefficient of expansion of the yellow metal at .000018 is higher than that of steel (.000012). On the other hand, such bushes should always be pegged or dowelled, because if a bronze bush does start to turn it wears away with great rapidity, though the aluminium, oddly enough, does not suffer nearly so much.