MOTORCYCLE ENGINEERING—28

THE TIMING GEAR

Where the designer has many alternatives

by PHIL IRVING

THE correct functioning of a four-stroke engine depends very largely upon the precision with which the mechanism controlling the motion of the valves is designed and made. This mechanism, referred to under the generic heading of "timing gear" may embody spur gearing, bevel gearing, chains and sprockets, or even some form of eccentric drive, either singly or in combination—the choice resting on many factors besides the predilection of the designer for any particular system.

As with many other things, the relative importance of these factors varies with conditions.

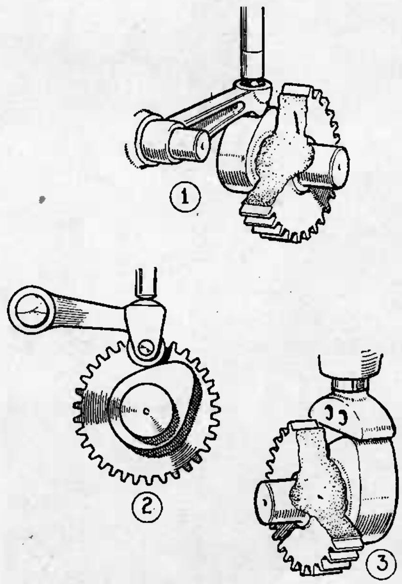
For racing, accurate operation irrespective of speed or load is a prime consideration and freedom from friction is also very important, but noisy operation and high manufacturing cost are not of much moment, provided the first two aims are achieved. For inexpensive touring engines, low cost becomes the chief item, provided that reasonably accurate operation and a moderate degree of silence is obtained; while for road-going sports engines a combination of all three attributes is required, coupled with ease of maintenance, as so many engines of this type are cared for by their owners.

Fundamentals

The simplest form of valve timing gear consists of a pinion mounted on the main-shaft; a gearwheel, with twice as many teeth as the pinion, fixed to a single cam; and a pair of cam-followers, oscillating on a single pin and transmitting motion either to a pair of tappets sliding in guides or to the lower ends of a pair of push-rods. The magneto can be chain driven from a sprocket carried on the end of the camshaft, and the construction lends itself to either side-valve or push-rod o.h.v. layout, since the cam-follower ends are necessarily spaced a couple of inches apart.

With only a single cam, the angular duration of opening of both valves is usually the same, and the relationship between their timing is determined by the angular disposition of the respective cam-followers. If different durations are thought to be necessary, it is possible to make one follower with a plain radius on the foot, and the other with two radii joined by an arc of the same radius as that of the cam base-circle.

However, good results can be obtained without resort to expedients of this nature, as evidenced by the Ariel "Red Hunter," a comparatively modern example which, besides being extremely simple, has the merit that the cam and followers are very wide. This benefits the latter from the wear point of view, but does nothing to help the cam, which has, in effect, twice as much work to do as if it were one of a pair.



Types of cam follower: (1) the simple lever, (2) the roller-foot lever, (3) the direct-acting "mushroom."

Despite its simplicity, the single-cam system places limitations on design which are not always acceptable. In fact it is far more common to use two cams, either on a single shaft in conjunction with lever-type followers, or on separate shafts, in which case direct-acting sliding followers or tappets are commonly employed.

With lever followers, the push-rods can either be located close together and housed in a single tube or tunnel, or be spaced one or two inches apart and enclosed in separate tubes or in holes drilled through the cylinder jacket. The last arrangement, if properly executed, interferes less with barrel cooling and permits shorter and lighter overhead rockers to be used, but there is little to choose between the systems on either score.

As far as possible, however, followers should always be designed so that the major stress in the steel is compression, rather than bending. They can then be made quite light without danger of fatigue failure, which occurs only in the presence of bending or tensile stresses, but never under simple compression loads.

Even then, followers lead a very strenuous life, especially in engines which are carelessly permitted to run with excessive tappet clearances, and should be made from a high-quality nickel-chrome steel, heat-treated to give a tough core, with the wearing surface case-hardened to a depth of .040 in. The case obtained with nickel-chrome steel is not likely to "spall" or flake away from the core, and it does not soften quite so quickly as the case on mild steel under the influence of the high temperatures which may be generated if the lubrication is insufficient.

Roller Followers

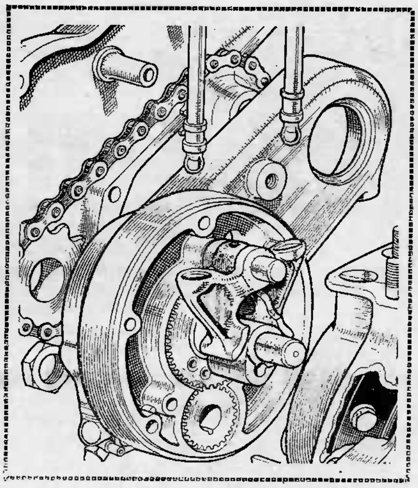
Some designers prefer to eliminate rubbing contact by using rollers instead of solid feet, in spite of the objections that the overall weight of the follower is increased and that the rollers sometimes develop flats through skidding on the cam-surface.

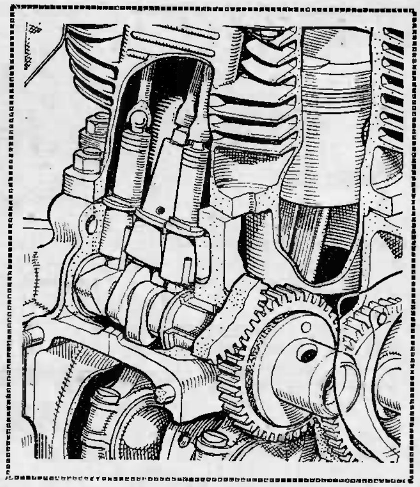
A roller does not rotate at constant speed, but is spinning faster as it passes over the nose of the cam than it is when in contact with the much smaller base circle, and the force necessary to accelerate or decelerate the roller tends to promote momentary skidding. For that reason, a cam used in conjunction with a roller follower should have a large base circle radius to reduce the percentage difference between it and the nose radius; if the followers are solid, on the other hand, the overall size of the cams should be as small as possible in order to reduce the rubbing speed.

Direct-acting followers are usually of the "mushroom" type, with flat contact surfaces, disposed slightly off-centre to the faces of the cams so that they will rotate and thus distribute the wear evenly; there must, of course, be room to accommodate the large-diameter followers, as there is if two separate camshafts are used, as in the A.M.C. singles. As the reaction to any force applied to a body acts at right angles to the surface concerned, there is very little side-loading to contend with and the diameter of the tappet stem can be quite small. There is *some* side-thrust present, of course, partly due to the load being applied eccentrically and partly through friction, which acts along the line of the contacting surface; but wear from this cause is not serious and it is quite practicable to run a mushroom or cylindrical follower direct in the metal of the timing chest, as, in fact, is done in the small Triumph singles.

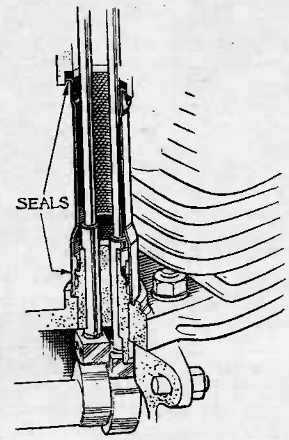
Flat followers are used in conjunction with "harmonic" cams, i.e., those with contours composed of three (sometimes more) circular arcs. Though this type of cam furnishes highly satisfactory results and is very simple to design and make, some designers prefer to utilize curved follower-feet, which provide a little more latitude in the selection of the most suitable cam contours and enable a pair of cams and followers to be accommodated in a relatively small space. This is a matter of importance in some engines; a good example of compact design is to be seen on Triumph twins, in which pairs of followers are carried side by side in common bushes spigoted into the cylinder base-flange.

With tappets or followers of the Triumph or similar types, it is logical to use ball-ended push-rods running direct from the top of each follower to the appropriate overhead rocker. In the days of exposed valve-gear, it was the practice, even with lever-type followers, to fit tappets running in reasonably oil-tight guides between the followers and the lower ends of the exposed push-rods, but these became unnecessary when push-rod enclosure came into use. The push-rods could then run directly from the followers to the rockers, thereby eliminating all frictional drag and effecting a worth-while reduction of weight—a matter of vital importance in valve gear, since at high speeds the inertia forces generated will amount to several hundred times the weight of the components concerned.

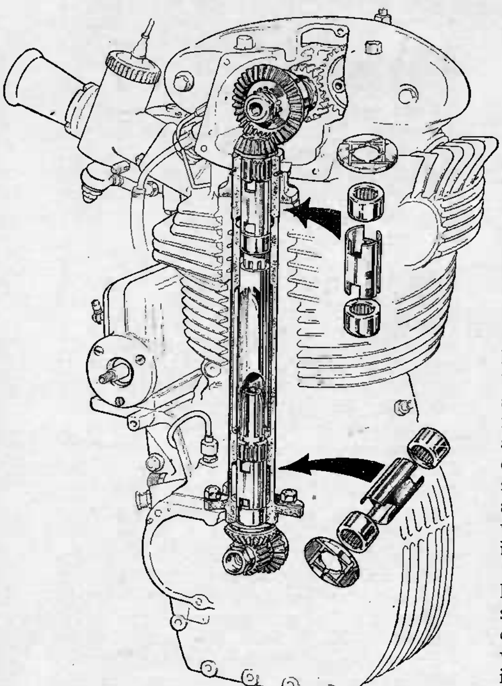




(Left) Single cam and "double" follower on a single-cylinder Ariel. (Right) All valves are operated from a single rear-mounted camshaft on the B.S.A. twins.



On Triumph twins, pairs of followers are carried side by side in common bushes spigoted into the cylinder base flange.



Classic example of the bevel-driven o.h.c.—the "Manx" Norton.

The extra length of the direct-acting push-rod is, however, a disadvantage. A push-rod is, in effect, a long, slender column loaded in compression and it has a tendency to fail by buckling which increases as the square of its length. Even if a rod does not actually fail, it can whip laterally, an action which is fostered by the fact that each end is moving in arcs which themselves are different, and as a result the actual valve-motion will not agree absolutely with the motion which the cam theoretically imparts to it.

To a certain extent this is bound to happen, due to the cumulative effects of springing or flexure in every one of the components from the camshaft up to the valve, and allowance has to be made for it when developing high-speed cams; but whereas it can be reduced in most places by attention to stiffness and rigidity of mounting, push-rods must of necessity be kept light.

The solution is to employ light-walled steel tube, $\frac{3}{8}$ in. diameter by .030 in thick, or high-tensile aluminium tube of the same diameter, but approximately .060 in. thick, with very light ball-ends or cups sweated to the steel tubes or pressed into aluminium. Ball-ends need not be of large diameter—$\frac{1}{4}$ in. is ample, and $\frac{3}{16}$ in. is sufficient for small engines—and there is no necessity to locate the cups hollow side up to retain lubricant. Provided there is some oil or oil mist present, the oscillating motion of the rod will ensure that enough enters the cup to prevent wear, especially if the diameter is kept to the sizes given and the actual amount of relative sliding movement is therefore small.

The High Camshaft

The "high-camshaft" idea, introduced on the M series Velocette engines, overcame the disadvantage of long push-rods by interposing an idler wheel between the mainshaft pinion and the cam wheel, thus raising the camshaft centre almost to the level of the base of the deeply spigoted cylinder so that the push-rods were short and therefore both light and stiff.

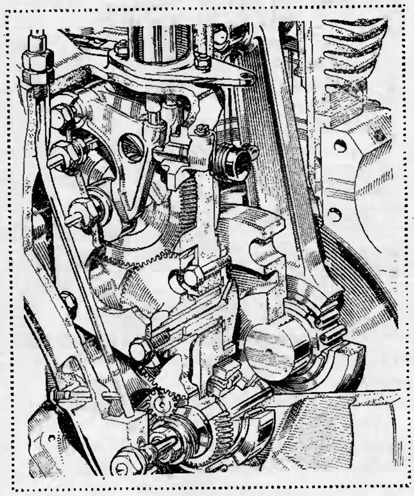
This scheme was also adopted on Vincent engines, but in these an unconventional rocker arrangement permitted the rods to be so short that there was little to be gained by making them tubular; instead, they are of stainless-steel rod, .280 in. dia., with integral, work-hardening ball-ends. In engines of this marque modified for sprint work, solid aluminium-alloy rods are found to work satisfactorily, running direct in the steel cups; the weight saved is only of the order of $\frac{3}{4}$ oz. per rod, but even this is worth losing if it can be done without sacrifice of strength.

It is possible to operate all four valves of a parallel twin from a single camshaft, as on the B.S.A. products, using a train of only three gears, but the general rule is to use one shaft at the front to operate the exhausts and another at the rear for the inlets, so introducing an extra gear-wheel which may, however, be used to drive the generator and thus eliminate a chain drive.

An alternative scheme is to use a "triangular" chain-drive to both shafts, as on the Ariel twins, but in this particular design it has been necessary to resort to two extra pairs of gears, one set to drive the generator and the other to drive the magneto, so that any benefits the chain-drive might have conferred in the way of silence are largely lost, and the design would have been much simpler if a single idler wheel had been used, as in the A.J.S. twins.

Chain drive is frequently used for magnetos, and it is undoubtedly a cheap and effective way of transmitting motion between shafts which are some distance apart. However, there are grounds for thinking that the slackness or play which must be provided in the chain to allow for centre-distance variations at differing temperatures, plus the inherent springiness in the whole drive, may permit inconsistency of spark-timing to occur. This, though of little importance in a touring engine, might be detrimental in racing engines which are much more sensitive to ignition timing than they are to valve timing.

It was said that the Rudge engines with chain-driven magnetos were slower than their counterparts with gear drive; and although the most successful English racing single has always had its magneto chain driven, some pains have been taken in the 7R A.J.S. to provide gear drive to this component,



The Velocette "high camshaft" gear; a detail from the 350 c.c. "Viper" engine.

while retaining a chain for the overhead camshaft. In general, it has been found that centrifugal automatic-advance devices function best with gear drive; in fact they cease to operate with a chain should it by any chance become tight, and the trend with touring engines is therefore towards gear drive.

Because of the irregular torque required to drive a shaft with only one or two cams, obtaining silent running is something of a problem, aggravated by the fact that the gears are usually made of steel with a rate of thermal expansion much less than that of the aluminium timing-case.

This means that the running clearances between the teeth must be greater when hot than when cold. Moreover, the severity of the effect is entirely a matter of the total distance between the centres of all the gears in the train. The increase in backlash between one pair of gears is exactly the same as the combined increase which would occur if three or more smaller gears were arranged along a common centre-line, and less than if they were not arranged along this line, as then the total centre-distance length would be increased.

Teeth cut with $14\frac{1}{2}°$ pressure angle are less sensitive to backlash increase than those with 20° pressure angle, but it must be remembered that obtaining silence is rather like trying to score a "bull" with a rifle—the best you can do is hit it, and an error in any direction will lose points. Similarly, any departure from perfection may lead to noise in gears subjected to irregular torque; if too tight, they whine, and if too loose, they rattle. If they are eccentric or out-of-round, they may do a little of both.

Noise will also result if the tooth-form is incorrect or the shafts are subject to flexure—as, for instance, when the mainshaft pinion is overhung a fair distance from the nearest bearing and alters its position at every firing stroke.

Lack of space precludes the use of wide, large-diameter wheels such as are employed in car engines and consequently hardened gears are essential. Heat treatment almost invariably causes some amount of distortion or alteration in size. Subsequent grinding of the bore to bring this to an accurate diameter may do nothing to correct the position—in fact, it may aggravate it unless the bore is ground with the wheel centred on the pitch-circle by means of three rollers located between the teeth.

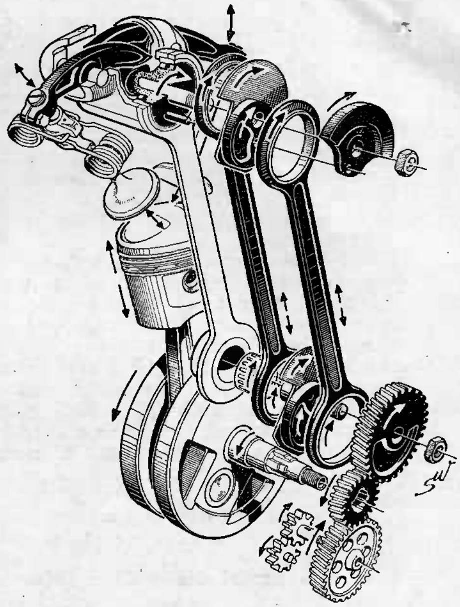
Some makers prefer to eliminate grinding and leave only one or two thou. to be honed out of the bore after hardening; but, whatever method is used, gears must be checked for concentricity before being passed to stores.

Size variation may be corrected, together with errors of form or concentricity, by tooth grinders, but this is an expensive process. The usual method is to assemble the gears selectively in sets, and/or make the final adjustment by fitting a pinion of the appropriate size.

In the Velocette design the idler gear is carried on a spindle which is adjustable for position, and thus may be set in correct engagement with both mating gears. The teeth are unusual in being very small, their diametral pitch being 48 instead of the more usual figure of 16 or 20, and are also helical. These proportions were adopted in the interests of silence, partly because helical teeth obtain continuous contact and partly because the frequency of any noise generated by the numerous small teeth is so high that it is above the range of audibility of most human beings.

O.h.c. Problems

When the valves are operated by overhead camshafts, the drive has to be conveyed over a considerable distance. The usual method is to utilize a shaft with bevel gears at each end and, if two camshafts are used, to take the drive out to each by a train of spur gears. The bottom bevels are necessarily rather small and inertia of the rest of the mechanism is high, so it is not surprising that bevel-gear failure has been known to occur, especially when the lower one is mounted on the engine mainshaft, which must deflect to some extent under the high stresses from the engine itself.



Unique eccentric drive of the NSU "Max" series embodies a spacing member to maintain constant shaft distance.

The NSU system of interposing a spur-gear reduction just before the bevel drive would seem to be preferable. On racing double-o.h.c. parallel twins manufactured by this company, designs which vary in detail have been used, but most of them employ a separate drive to each camshaft, which materially assists efficient barrel and head cooling.

Their single-cylinder "Max" engines feature an ingenious drive by means of two pairs of eccentrics, each pair being phased at 90° and coupled by links resembling con-rods with two big-ends. The lower eccentric shaft is driven at half engine speed and the problem of overcoming differences in thermal expansion between the links and the cylinder is met by providing a member between the two shafts which maintains them at the same centre-distance as the links, the variation in timing thus caused being negligible.

This form of drive is naturally very silent, a characteristic which it shares with chain drive, familiar on the 7R A.J.S. and less obviously employed on Japan's 125 c.c. twin Honda. In the latter example, the layout is extremely simple, consisting merely of a small sprocket on the mainshaft, one twice the size on the single overhead camshaft and a tensioner-pulley housed in a tunnel cast on the side of the iron block. The whole arrangement is very neat, but neatness has been purchased somewhat dearly, as the tunnel completely shields the left-hand barrel, which is virtually uncooled on this side.

The only other drive system of any significance is the train of gears favoured mainly by Italian designers for racing models. This is inherently prone to be noisy—a matter of little moment in this field—and is seen at its best on fours and twins in which the gears are carried in a central housing.

NEXT WEEK: Valve-gear Design