ELEMENTS OF CAM DESIGN

How to plan and produce simple but efficient cams for petrol engines and other mechanisms

By Edgar T. Westbury

CAMS IN SOME FORM or other are essential to the operation of many kinds of mechanical devices. Their best-known application is in the valve-operating gear of internal combustion engines, but they play an equally important part in industrial machinery, from printing presses to reaping machines.

In general, a cam can be defined as a projection on the face of a disc or the surface of a cylinder for the purpose of producing intermittent reciprocating motion of a contacting member or follower. Most cams operate by rotary motion, but this is not an essential condition and in special cases the motion mav be semi-rotarv. oscillatory or swinging. Even straight-line motion of the operating member is possible, though the term cam may not be considered properly applicable in such circumstances.

Most text books on mechanics give some information on the design of cams and show examoles of cam forms plotted to produce various orders of motion. Where neither the operating speed nor the mechanical duty is very high, there is a good deal of latitude in the nermissible desien of the cam and it is only necessary to avoid excessively steep contours or abrupt changes which would result in noise, impact shock, and side pressure on the follower.

But, with increase of either speed or load, much more exacting demands are made on the cam, calling for the most careful design and, at very high speed, the effect of inertia on the moving parts is most pronounced, so that the further factors of acceleration and rate of lift have to be taken into account and these are rarely dealt with in any detail in the standard text books.

The design of the cam follower is also of great importance and bears a definite relation to the shape of the cam itself. This is because the cam cannot make contact with the follower at a single fixed point. Surface contact is necessary to distribute load and avoid excess wear, thus the cam transmits its motion through various points of location on the follower, depending on the shape of the two complementary members.

The cams for operating i.c. engine valves present specially difficult problems in design. In the case of racing engines, both the load and speed may be regarded as extreme, because in many engines the rate at which the valves can be effectively controlled is the limiting factor in engine performance. In some respects, cam design of miniature engines is simplified by reason of their lighter working parts (and consequent less inertia) but on the other hand, working friction is usually greater and rotational speeds are generally considerably higher than in full-size practice.

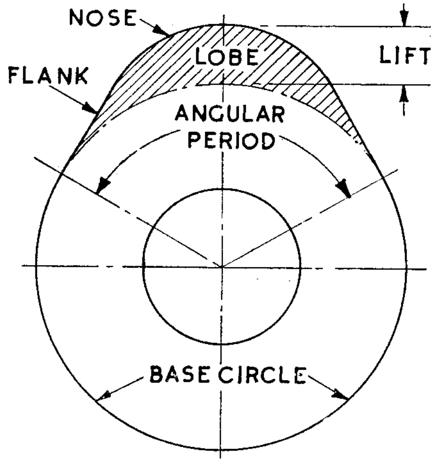
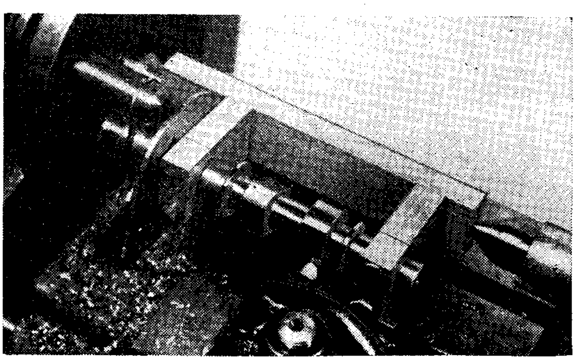


Fig. 1: The essential features of a valve-operating cam

In the many designs for small four-stroke engines which I have published, I have sought to simplify valve operation and to provide designs for cams which can be simply and accurately produced with the facilities of the amateur workshop. Numerous engine designs which have been submitted to me by readers have contained errors in the valve gear and particularly in the cams and in view of prevalent misconceptions in the fundamental principles of these items, I am giving some advice on the matter which I trust will help individual designers to obtain the best results from their engines.



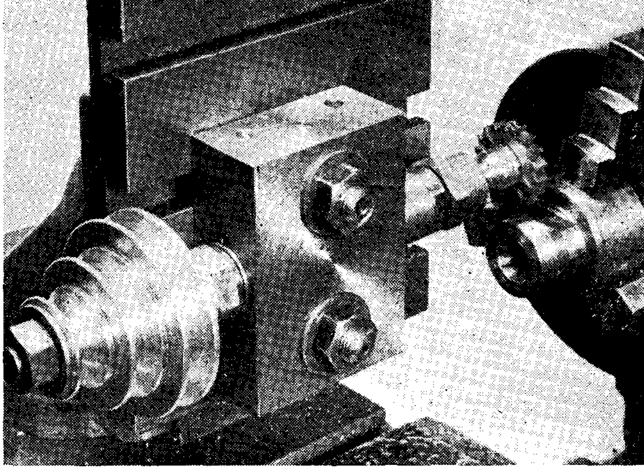
Machining a set of cams in an eccentric fixture

Getting away with it

There have been many engines built with cams of thoroughly bad design but which, in spite of this, have produced results more or less satisfactory to their constructors. It may be said that within certain limits of speed one can get away with murder-but in no case can an engine perform efficiently with badly designed cams, or indeed errors in any of its workmg details.

This article is concerned mainly with the design of cams for operating the valves of i.c. engines and, in order to avoid any confusion of terms, Fig. 1 shows the various parts of a cam of this type and explains their functions. The circular, concentric portion of the cam, which has no operative effect, is known as the base circle: the humv of the cam (shown shaded] is known as the lobe, and the flanks on either side rise from the base circle to the nose, which is usually rounded.

Lift may be defined as the difference between the radius of the base circle and that of the nose. and the anele enclosed between the points where the flanks join the base circle is termed the angular 'period, representing the proportion of the full cycle during which the cam operates the valve gear.



Machining a tangent, cam by circular milling in the lathe

In Fig. 2, typical examples of cams used in i.c. engines are illustrated. The tangent cam, A, has dead straight flanks-which as the name implies-form tangents to the base circle. This type of cam is easy to design and produce, the simplest method of machining being by a circular milliig process forming a concentric surface on the base circle and running straight out tangentially where the flanks start and finish. It can also be produced by filing and I have in the past described how to make it with the aid of a roller filing rest in the lathe, in conjunction with indexing gear to locate the flank angles.

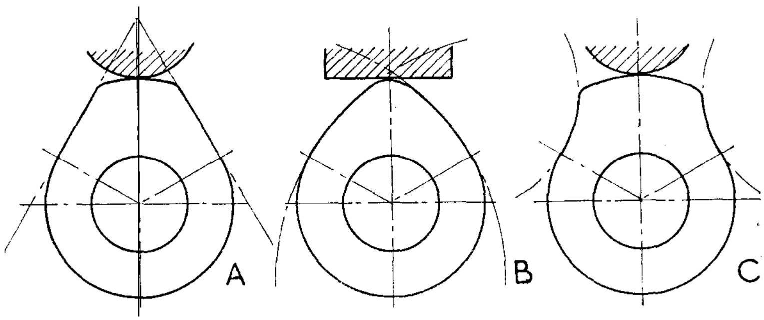


Fig. 2: Typical examples of cams and their followers

Tangent cams can only work efficiently in conjunction with a convex curved follower, as this is the only way in which the flank can be brought progressively and smoothly into action. Some time ago an engine was described having tangent cams in conjunction with flat followers. This was not intended for extremely high speed and very likely produced all the power required of it, but it is quite clear that the flat face of the tangent cam. on engaging the flat tappet-over the full length of the flank all at once, must produce an abrupt slapping action which is noisy, ***inefficient*** and destructive in the long run.

Rollers are often used as followers with tangent cams and are satisfactory in respect of their shape, but the idea of introducing rolling motion at this point is not as good as it seems at first sight, because it merely transfers the sliding friction to a much smaller area--that of the pivot pin. It is possible in some cases, however, to use a ball or roller race for the follower and this, at any rate, has the merit of distributing and equalising the wearing surface.

Tangent cams have been used with a certain degree of success for high-performance-engines and were at one time popular on racing motorcycle engines, though usually with some slight modification of shape-often " designed " by the tuner with the aid of .a Carborundum slip! Their more common application, however, has been on gas and oil engines running at relatively slow speeds, where they work well in contact with rollers attached to the ends of the valve rockers.

Cams with convex flanks are extensively used in motor cars and other mass-produced engines. One important advantage in this respect ***is*** that they are suited to manufacture in quantity by a copying process from accurately formed master cams. The fact that hat-based tappets can be used also favours quantity production and they can be designed to work fairly silently.

The contour of the flank can be plotted so that violent changes in the acceleration of the cam are avoided and, more important still, the tappet will follow the cam on the return motion without any tendency to bounce or float at quite high speeds. In such cases, it may be necessary to introduce compound curves which are extremely difficult to copy on a small scale, but cams made with flanks formmg true circular arcs will give reasonably efficient results, and are very easily produced in any scale:

Concave-flanked cams

Comparatively few examples of concave-flanked cams (Fig. 2c) are to be seen nowadays, though they have been used extensively in the past with the idea of obtaining the most rapid opening and closing of the valves. Theoretically, they can be designed to produce consant- acceleration, but in practice they render valve control very difficult at high speed and their fierce angle of attack produces heavy side pressure on the tappet. The concave flank must always have a substantially greater radius than the follower, or a slapping action like that of a tangent cam on a flat follower is produced.

The shape of the nose in most types of cams is dictated mainly by the need to decelerate the follower as smoothly as possible. It is one thing to design it in such a way that ideal conditions are obtained, and quite another to ensure in practice that the follower retains close contact with the cam. If the radius of the nose is too small, the follower will bounce and come down

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heavily on the return flank of the cam and,. if too great, valve opening efficiency will be reduced.

Of the three types of cams, A, B and C, which all have identically equal lift and angular period, the lobe of B encloses the smallest area, and on first sight it might appear that it is the least efficient in producing adequate valve opening, or mean lift area, but owing to the use of a flat based tappet, its lift characteristics are not very different from those of a tangent cam with round-based tappet, and not necessarily inferior to those of a concave-flank cam.

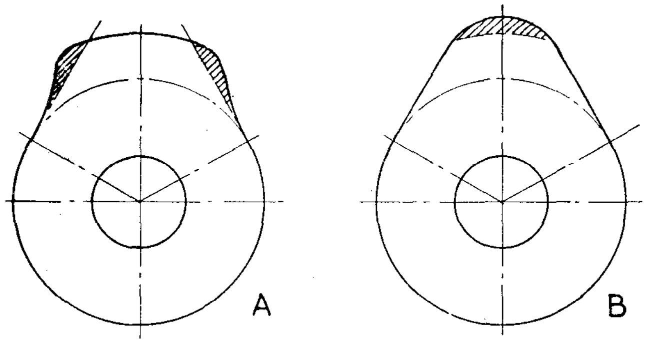

Fig. 4 : Comparative lift efficiency of cams with dwell and maximum lift

Unsymmetrical cams

It is not common to make the two flanks of a cam of different contours to produce some particular result which the designer may consider desirable. In some cases, the object is to produce rapid opening and gradual closing, but sometimes the opposite effect is preferred. When all things are considered, however, most attempts to monkey about with cam forms lead to complications which may actually defeat their own object, at least at really high speeds.

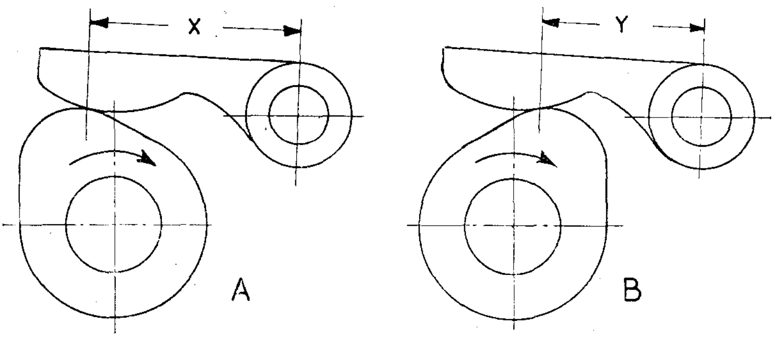

Fig. 3: Illustrating the variable lift characteristics produced by a pivoted follower

In many engines, particularly those of motorcycles, the cams operate the valves through levers or rockers which move in an arc instead of in a straight line, as in the orthodox motor car tappet. This may be mechanically efficient, but it modifies the lift characteristic of the cam, as the point at which the latter transmits motion to the follower varies in relation to the radius of the lever arm, (Fig. 3).

With the cam rotating in a clockwise direction, the effective length of the lever will be greater in the position A during valve opening than in position B during closing, as indicated by dimensions X and Y. This amounts to the same as using an unsymmetrical cam, and in the example shown, would result in slow opening and rapid closing of the valve, or vice versa if either the direction of rotation of the cam, or the relative "hand " of the lever, is reversed. The shorter the lever, the greater the discrepancy in the rate of movement,

Neither the unsymmetrical cam form nor the pivoted lever is condemned as bad design, but I have sought to avoid them in most of the engines I have designed because they are a complicating factor in what is already a very involved problem, and by keeping to fairly simple cams and straight-line tappets, one can be assured that there are not too many snags.

The employment of cams with flanks of true circular arc has enabled me to devise means of producing them on the lathe without elaborate attachments and, what is more important still, to produce an entire set of cams for a multi-cylinder engine in correct angular relation to each other by equally simple means. There is no doubt whatever that these methods have enabled many engine constructors (some without previous experience) to tackle successfully a problem which would otherwise have been formidable, to say the least.

Many designers have attempted to improve valve efficiency by designing cams which hold the valve at maximum opening for as long a period as possible. This is done by providing dwell or, in other words, making the top of the lobe concentric with the cam axis over a certain angular distance in the centre of its lift. To do this, however, it is necessary to make the flanks excessively steep, thus producing heavy side thrust on the tappet, and making control at high speed more difficult, (Fig. 4A).

A little consideration, however, will show that the same result can be achieved, with much less mechanical difficulty, by lifting the valve somewhat higher at an easier rate, as shown at B. This avoids the need for sudden acceleration and deceleration of the tappet and promotes flow efficiency of the valve. The shaded portions of the two cams show the differences in the area of the lobe, showing that nothing is really gained by the dwell.

Factors in **efficiency**

High valve lift is a desirable feature, but only if it can be obtained without making extra dificulties in controlling the valve. The maximum port area of a valve is obtained when the lift is equal to one-fourth of the seat diameter, but owing to the baffling effect on the valve head, a higher lift is better for flow efficiency-if it is practicable.

Large diameter valves will obviously release and admit gas efficiently but they are more difficult to control and keep cool at high speed than smaller valves. Another point is that the exhaust valve is required to open against a high cylinder pressure, and the larger it is the more the load imposed on the cam, quite apart from the spring load.