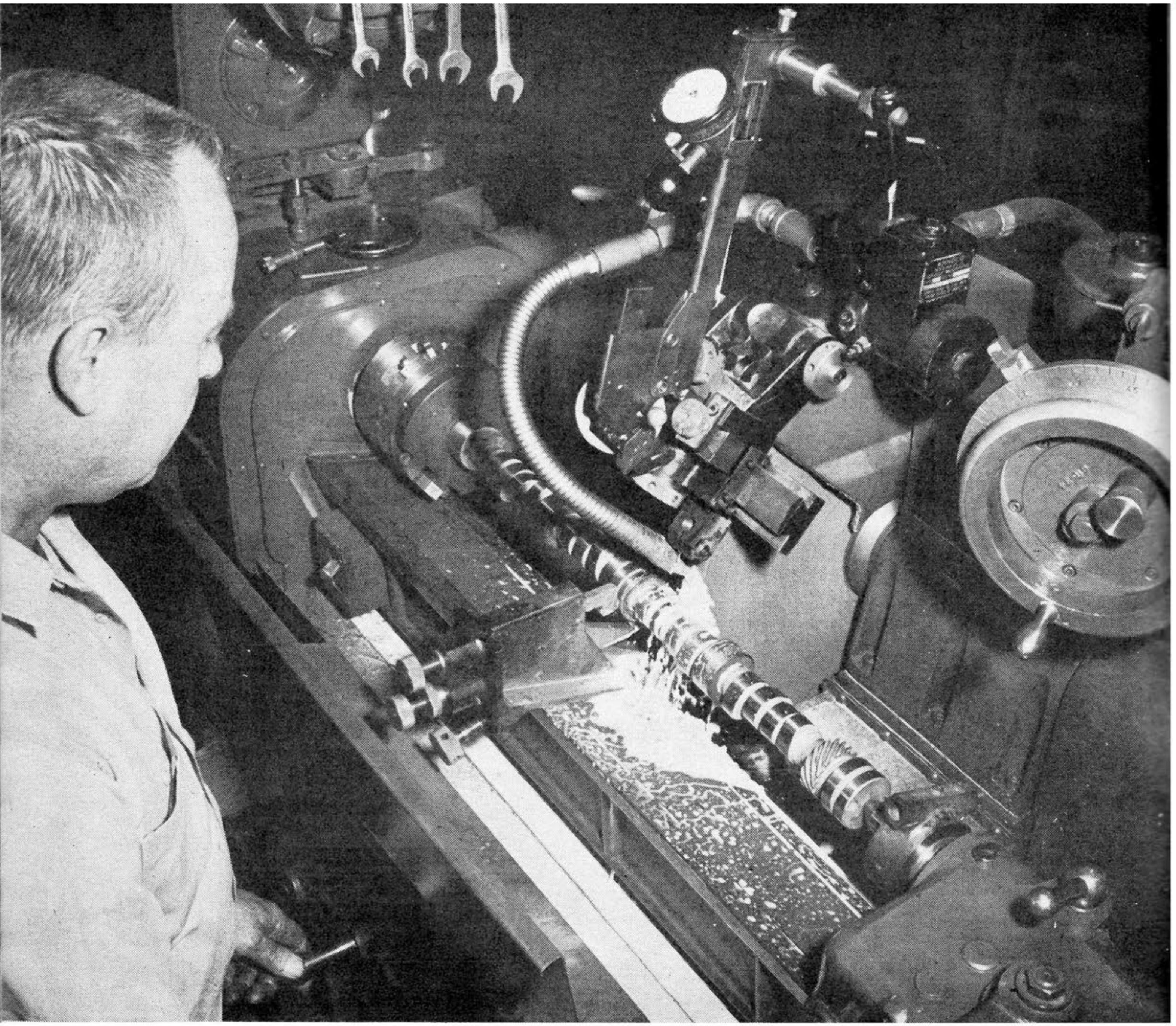
PLAIN TALK ON FANCY CAMS

A down-to-earth discussion of the cam designers' dilemma



PHOTOS BY ERIC RICKMAN, CLAY SMITH ENGINEERING, AL PALACY

By BOB PENDERGAST

Never having been inside a four-cycle internal combustion engine while it was running, I don't really feel qualified to say *anything* about them as if it were the absolute last word. On the other hand, I don't know anyone, with or without engineering degree, who has inhabited a combustion chamber while it was in use, so as far as practical experience along these lines is concerned we're all in the same boat. Although that might be considered a handicap when writing an article of this nature, it hasn't stopped anyone else so I'll just go ahead and have my say, too.

If you ever suffer from insomnia, a sure cure is to try and read what's currently available in the way of information on cams—sines, cosines, tangents, etc., are so far ahead of counting sheep in this department it's surprising that anyone can make a living peddling sleeping pills. Having no difficulty in falling asleep (ever), I conked out earlier than most.

With the dawn came a dual awakening—besides consciousness, I also regained my common sense, and decided to go talk to people designing racing cams, technicians testing the results of these designs in engine dynamometer tests, and some of the more successful competitors who have credited cam "juggling" as one of their "open secrets." This not only kept me awake, I found, but also improved my grasp of the subject to the point where I felt the readers of HRM would appreciate sharing in my new-found knowledge.

When asked what an engine's camshaft actually *does*, most of us are inclined to look bright and say "it opens and closes the valves, dummy." But this is gross oversimplification—the fact that the cam opens and closes the valves is meaningless without some serious consideration to *when*, how *high*, and in what *manner*. You can't just refer back to the explanation of the operating principle of the four-stroke engine and let it go at that—and here's why.

Since the four-stroke engine's cycles of operation are Intake, Compression, Power, and Exhaust, the cam must actuate the valves in such a way as to make these operations possible. On the Intake stroke, the intake valve must be open. During Compression and Power strokes, both valves must remain seated at least part of the time so that the cylinder is sealed, otherwise these operations cannot be accomplished. Clearing the cylinder of the products of combustion after the Power stroke requires the exhaust valve to be open during the Exhaust stroke.

It seems that those cute little drawings illustrating internal combustion engines' four strokes of operation that you find in the high school auto shop textbooks aren't quite literal—in the interests of clarity they've greatly over-simplified things. Most of the illustrations picture the intake valve opening at Top Dead Center (the upper limit of piston travel) and closing at Bottom Dead Center (lower limit of piston travel). Since one full stroke of the piston requires but half a revolution of the crankshaft, valve timing such as this would give an intake duration (length of opening) of but 180 degrees.

A similarly unrealistic view of things is presented on the Exhaust stroke. After having been closed during the Compression and Power strokes, both valves are shown at rest at the beginning of the piston's upward travel on the Exhaust stroke, at which point the exhaust valve is represented to be just now opening. At Top Dead Center on this same stroke, the exhaust valve is now shown to be closed, for this marks the beginning of the Intake stroke of another full cycle of four strokes. Timing such as this would result in an equally short exhaust duration, once again of 180 degrees.

You don't have to crawl inside anyone's engine to know that they just don't *work* that way.

Since the intake valve must be opened before Top Dead Center ("Early"), and must be kept open after Bottom Dead Center ("Late"), obviously we're going to have more than just 180 degrees of intake valve duration—this is where we take leave of those diagrams we mentioned and transfer from theory to fact.

In actuality, the *intake* valve is opened before Top Dead Center of the *Exhaust* stroke—and the *exhaust* valve is held open somewhat into the *Intake* stroke. That's what's known as *overlap*, and there are several good reasons for its existence.

A lot has been written about gas flow at sonic speeds, acoustic pulsations, elasticity of the air column within the ports, etc., and frankly I can't prove or disprove any of it, except to say

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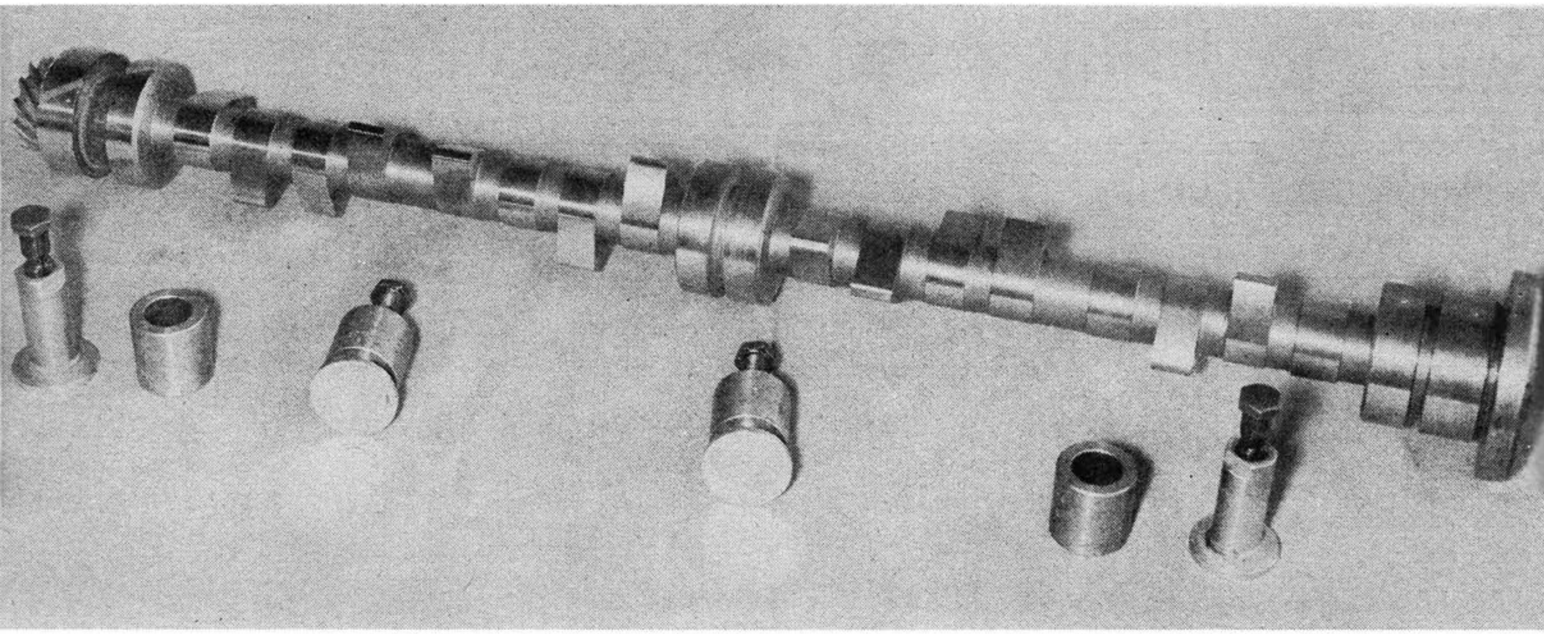
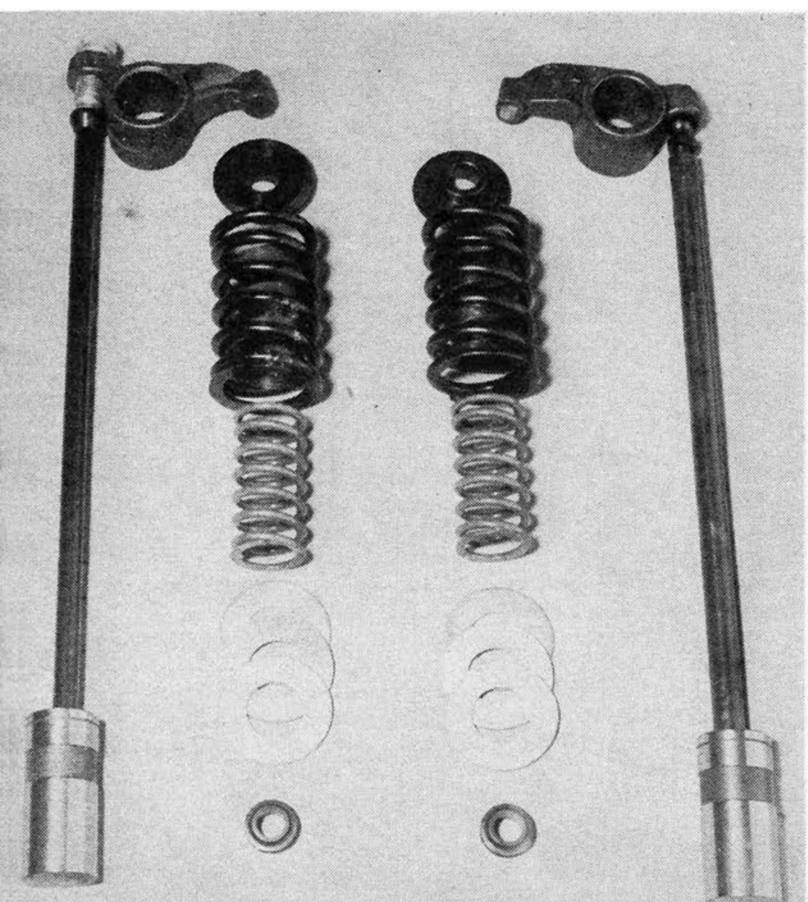
OPPOSITE—Frank McGurk, well-known cam grinder and speed merchant, practicing the art in his Gardena, Calif. shop. Actual grinding of cam is a relatively simple machine operation compared to preparatory design work that must be done.



Rapid action of typical Ford-Mercury flathead "Track Grind" required tappets with larger than standard diameter. Cam and tappets shown are from Clay Smith "270-X" kit. Use of this cam with standard 1 inch diameter tappets would cause ruination of both.



Valve train components for use with racing cams in Ford products furnished by Clay Smith Engineering include either adjustable or non-adjustable rockers and pushrods, special dual springs, surge dampers, height shims, pushrod seats, mechanical lifters.

that the portion of my bedtime reading I found so conducive to sleep included a goodly portion of books on these somewhat voo-doo like topics. But—whether or not you believe in them, it's good common sense to start lifting the intake valve before the actual start of the Intake stroke. Here's why:

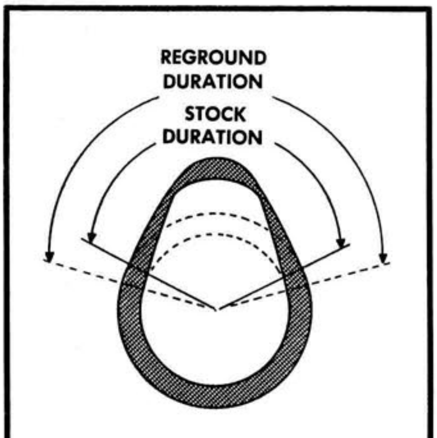
Take an engine with a four-inch bore, three-inch stroke, having an intake valve two inches in diameter lifting .400 inch (maximum). With 270 degrees of duration, the timing of this cam is: Intake opens 30 degrees before Top Dead Center (BTDC), closes 60 degrees after Bottom Dead Center (ABDC). The reason for starting to open the intake valve before the start of the piston's downward travel on the Intake stroke is simple after you give it a little thought; look at the difference in the sizes and relative movement of the intake valve and the piston—here you are, trying to fill a cylinder four inches across and three inches deep through a hole only two inches in diameter —and with a lid on it yet!

True, you have *lifted* the lid (intake valve)—but only a measly .400 inch at full height of the cam's lift, which lasts only a fleeting moment. Actually, with a conventional contour, a 270 degree duration cam will have lifted the valve to its maximum height approximately 135 degrees after it begins its lifting process; in the case under discussion, this would put the point of maximum lift at 105 degrees *after* Top Dead Center since our timing calls for the intake to begin opening 30 degrees *before* Top Dead Center.

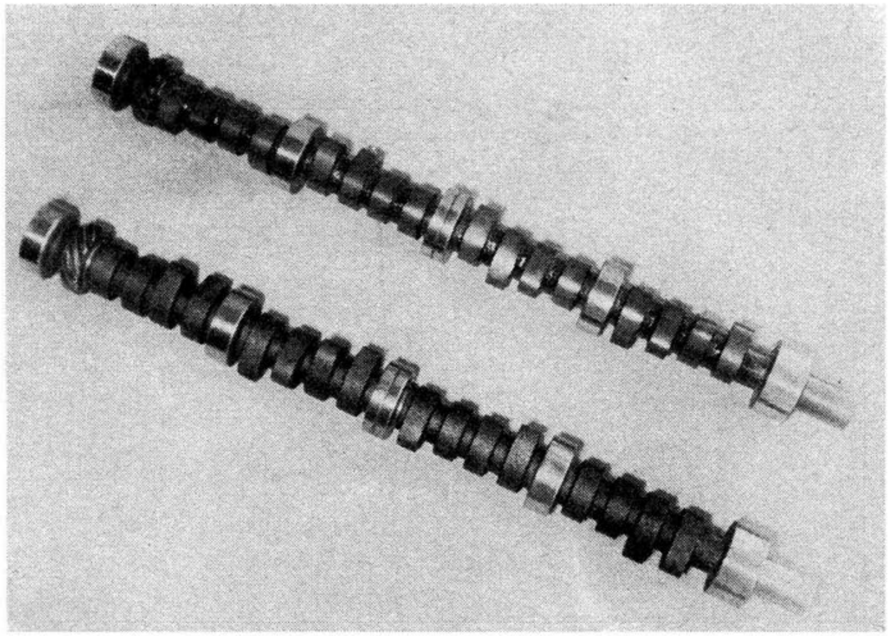
At 105 degrees after Top Dead Center, the *crankshaft* has revolved more than one-quarter of a complete revolution, and the piston (depending on the length of the con rod and its resultant angle) will have gone a considerable distance down the bore; certainly more than half-way in an engine of this bore-stroke ratio.

So what does all this mumbo-jumbo about degrees boil down to? Just this—you are *racing* the piston with the intake valve, actually attempting the impossible—imagine thinking you could fill that big cylinder through that little valve! But wait—we're not through yet—we can "fudge" by holding the intake valve open *beyond* the "theoretical" end of the Intake stroke. Here's how:

Remember when we told you that although the intake valve opened 30 degrees *before* Top Dead Center, it didn't reach



How regrinding stock cam can produce a "fat" lobe where there was a "skinny" lobe is diagrammed here. Reduction in heel diameter that results is considered one cause of rapid camshaft wear.



Latest development in the cam field is the cast iron billet which, when flame-hardened, is metallurgically compatible with stock lifters. Offered by many of the leading cam grinders, the un-ground (bottom) and ground (top) billets shown above are Clay Smith's for ohv Ford products. Wear characteristics of these cams inspired a one-year guarantee.

maximum lift until 105 degrees *after* Top Dead Center? Well, the same thing applies going the other way—If you want the intake valve to be anywhere near maximum lift at Bottom Dead Center you're going to have to use a cam with enough timing so that the valve won't actually be back down on its seat until well after BDC. That's why the timing of the exemplary engine we're referring to calls for an intake *closing* point that's a full 60 degrees into the Compression stroke. This is why racing cams are frequently of longer duration than stockers—but just how *much* more intake duration we require in a given engine depends on many variable factors, including several that are usually varied by the hot rodder himself when modifying an engine for competition. Most important of these are carburetion, piston displacement, and compression ratio. The advance curve of the ignition is also a related factor.

Here's how they enter into it—The more carburetion added to an engine over what it came with, the more "cam" (intake duration) you can use. The more piston displacement is increased over stock, the bigger the cylinders become in proportion to the ports in the head or block as the case may be, so once again additional intake duration becomes attractive.

Now regardless of how well the increased carburetion and displacement fit in with more cam, the greater the intake duration (all other factors being equal) the poorer the low speed torque and "lugging" power of the engine will become *in relation to what would result from using the stock cam in an identically modified engine*. However, the higher the rpm rises the less this will be true, until, at some point approximately midpoint in the engine's rpm range, the "hot" cam takes over and is superior in performance to stock the rest of the way up.

We mentioned that the ignition's advance curve was also a related factor because the poor low speed performance associated with conventional racing cams comes from downright lousy cylinder filling at slow rpm, due to the prolonged intake valve opening beyond bottom dead center on the intake stroke causing a portion of the incoming charge to reverse its direction of flow and back-up into the induction system. Remember, you don't start compressing *anything* on the compression stroke until the intake valve closes because you don't have a closed cylinder until it *does*. The later the intake valve closes, the less stroke you have left for *effective* compression. The engine's *compression ratio* is merely a misleading figure on paper which incorrectly assumes that compression begins at the bottom of the compression stroke, which we now know to be a false assumption.

Because of the cam timing influence on *actual* compression, ignition advance is irretrievably tied in with valve timing—if you install a cam with a *later* effective intake valve closing, you've lowered your low rpm compression, and thus need to re-tailor the advance curve of your distributor for additional "lead" in this range to compensate.

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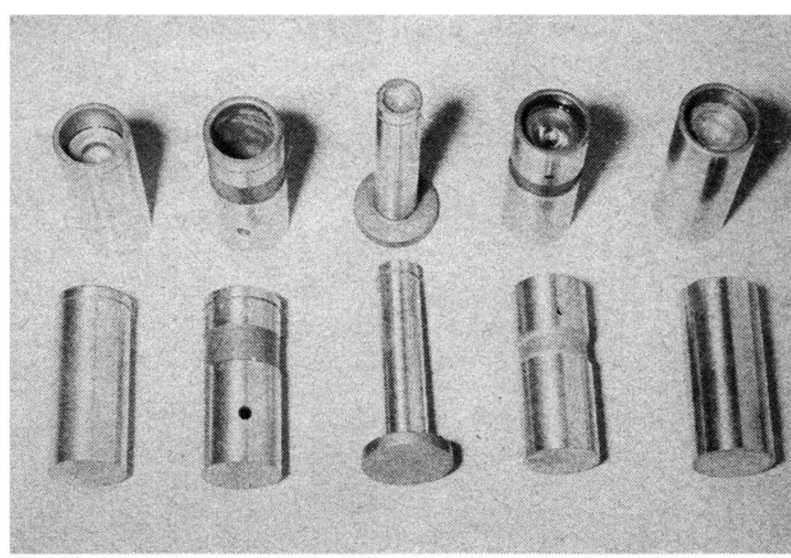
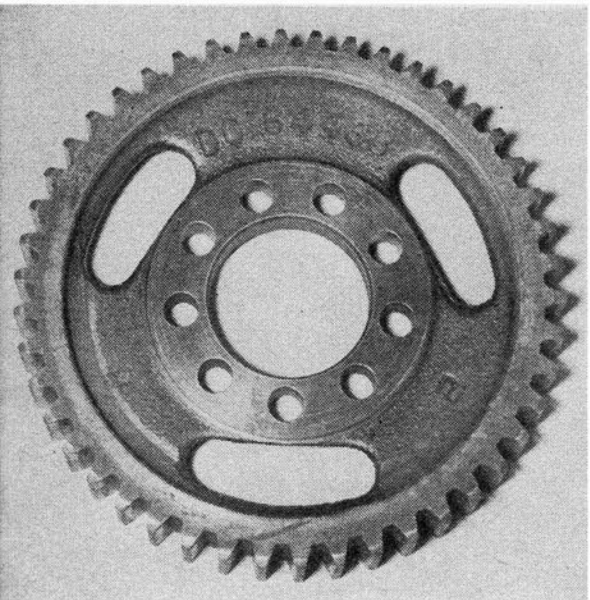
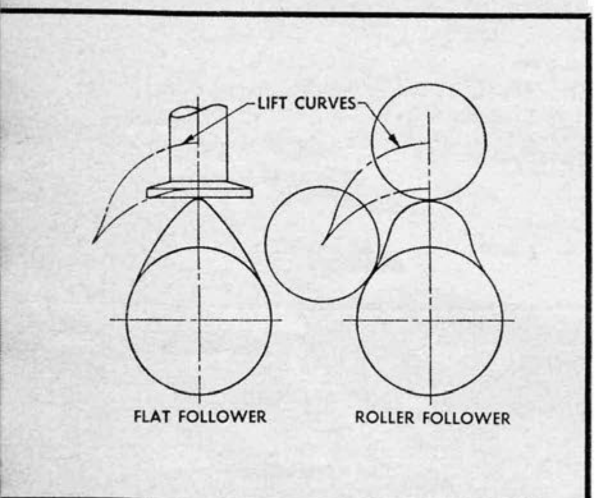
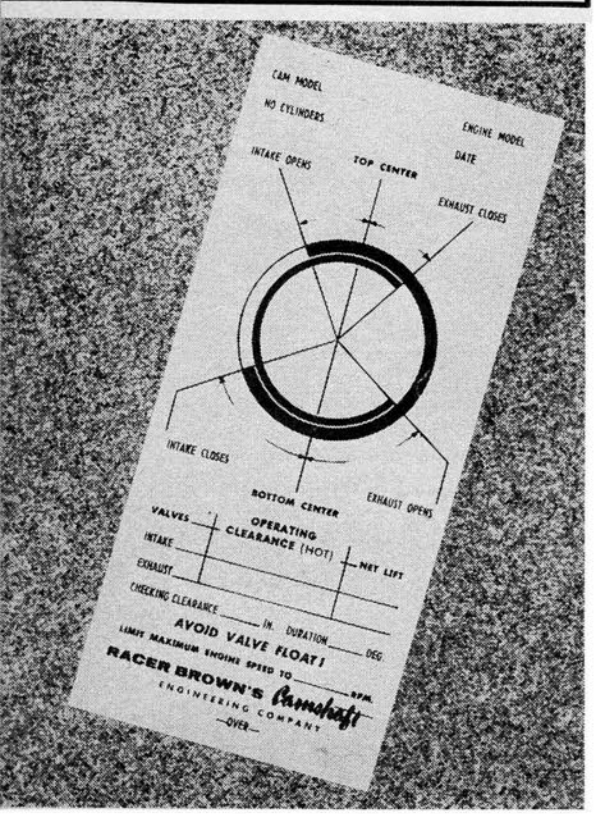


Top and bottom rows hold matched pairs of lifters for different views. Left to right: Ford F-8 truck (interchangeable with 317-cubic inch Lincoln), 332-cubic inch and larger Ford products, the smaller Fords, 283-inch Chevrolet, and Chrysler products.







FANCY CAMS continued

The above-mentioned facts about cams are so well-known in some circles that I'm sure at this point some of my audience have gone to sleep, but they *had* to be put down in black and white to make the rest of what we intend to kick around here make sense in case "you came in in the middle of the picture."

To wit—there are *ways* of getting around a large proportion of that bugaboo of poor low-end performance when a racing cam is installed. The one that's been with us the longest, of course, is to bore and stroke sufficiently larger during the modification process so that the finished engine is so much larger than it was originally that even though the cam hurts low-end performance *net*, the *gross* is still as good as or better than what was produced in stock trim.

In addition to this admittedly crude but oh-man-does-it-ever-work method of making up the difference we have a couple of other tricks up our collective sleeves. One is increased compression *ratio* to make up for poorer *effective* compression caused at low rpm by the racing cam. Another isn't actually a cure, but minimizes the ailment, and that's a proper reworking of the ignition's advance curve to minimize the bottom end performance loss by furnishing the earlier spark required by the poorly "turbulated" charge in the cylinder under these conditions.

Of course the best method would be to design a cam that would pull like a straight-jacketed maniac throughout the entire rpm range but that's mere wishful thinking. This theoretically "ideal" cam would substitute *lift* for *duration*; in other words, it would lift the valve so *high* that complete cylinder filling could be accomplished without lifting it *long*. Such a cam would have excellent low, middle, *and* high rpm torque characteristics—but you couldn't run it because the valves would float at a ridiculously low rpm, due to the too-radical action.

TOP—Chrysler cam sprocket with additional locating holes to allow juggling. Turning sprocket five teeth one way and sprocket one hole the other gives a differential of 1.73 degrees for each step.

CENTER—Diagram illustrates fallacy of trying to deduce cam characteristics by looking at lobes. Both cams give same lifter motion, due to different contour of both lifter and lobe cancelling each other out in this particular case.

BOTTOM—Tag furnished with racing cam contains information not to be ignored, particularly maximum rpm limit. Diagram portion clarifies late and early intake, exhaust timing discussion found in the text of the accompanying article.

But—the trend in cam design during the past few years *has* been in the direction of substituting ever-higher lifts for increasing *decreases* in duration. This trend was just starting to hit its stride and was really bearing fruit (particularly in track and drag usage) in the flathead engines when the overhead valve movement called a temporary halt because a valve action that wasn't too violent for a flathead literally assassinated the cam in an overhead.

This was due to the extra mechanism in addition to the valve and lifter themselves that the cam must actuate in an overhead—although a tubular pushrod and a stamped steel rocker arm may seem light *statically*, jiggle them *dynamically* at 8,000 rpm and the inertia they develop (and consequently exert against that long-suffering cam) is tremendous. Result: the now-infamous cam wear hassle. And that's *why* the all-lift, practically no-duration cam of the grinder's dreams will remain just that—a dream.

On the nightmare side of the ledger we have the competition engine builder's dilemma of trying to put together a mill that roars like a lion throughout the entire rpm range when he knows very well that *total* success in that direction is also just a dream.

Help is on the way, though, in the form of improved cam *contours*, for it's not just the lift, or duration, or any combination of the two that determines how much *opening* a given cam will impart to the valve it actuates.

We mentioned earlier in this manifesto that three of the important things to consider about any cam's manipulation of a valve were *when, how high,* and *in what manner*. The *manner* of the valve's opening and closing is controlled by the cam lobe *contour*, and as such may be said to be (metallurgical considerations excepted) the last frontier of competition cam design.

Refer to the illustrations on page 35 of this article and be sure to read the accompanying captions. You'll then see that timing and lift are merely part of a cam's description, and selecting a particular grind for *your* bomb on the basis of these two factors alone would be just as silly as sending the cops after the man who stole your car with nothing to go on but the following description: "20 years old, 5'6" tall." You've given them his timing (age) and lift (height), but without his *contour* (weight in relation to height and age) they have absolutely no idea of his physical characteristics!

A while back we touched on the subject of *overlap*, the period when both the intake *and* exhaust valves are off the seats and attempting to do a job without interference with each other. After suffering through the preceding explanation of why the intake valve must be open through 270 degrees of crankshaft rotation to sup-

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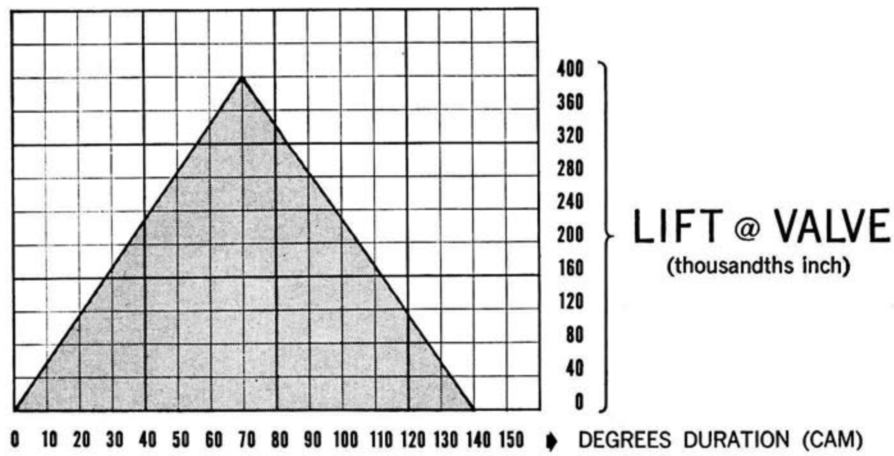
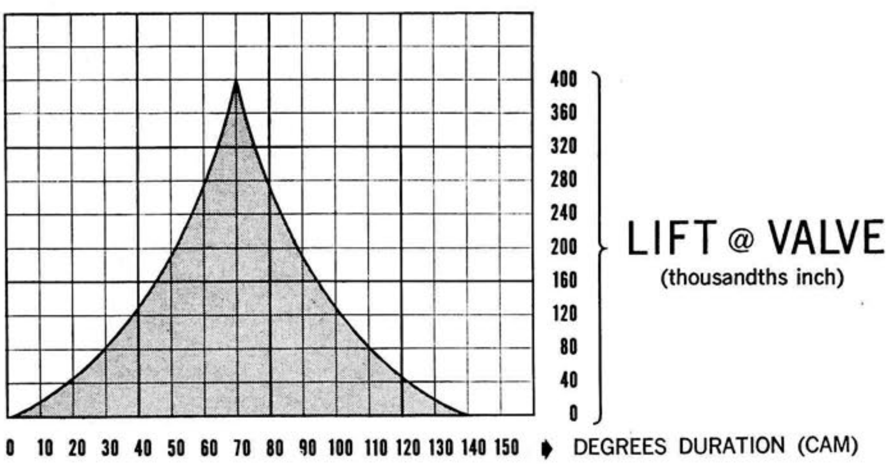
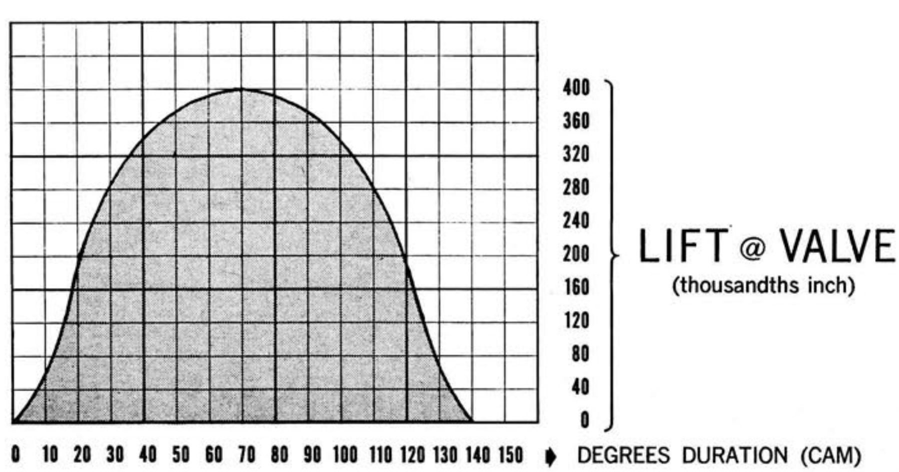
The three graphs presented on this page illustrate the fallacy of picking a cam by degrees of duration, by lift figures, or even a combination of the two. Three cams of widely varying opening and closing characteristics (ridiculously exaggerated for clarity) are shown, but all are 280° duration (crank), .400 inch lift.





While the cam shown in the first diagram accelerated the valve open evenly, then abruptly reversed its direction without decelerating and began to close it, the cam diagrammed opposite is quite different in its action. This one has an even more impossible action at the reversal, (change of direction); less opening area.

Although of the same timing and lift as the two grinds diagrammed above, the last of this series obviously would allow the engine to breathe better. A simple comparison of the potential effectiveness of these cams is to count the squares within the shaded area representing opening, proving 280°, .400 lift means nothing.



FANCY CAMS

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ply a function that theoretically lasts but 180 degrees, the Intake stroke, you should be aware that a similar situation exists regarding the Exhaust stroke. Just as the *intake* valve was straining to keep up in its race to provide sufficient opening area to match the descending piston's demand for air, the *exhaust* valve must provide sufficient passage for the products of combustion's exit from the engine at the end of the Power stroke. By now it should be no surprise to you that to accomplish this the valve must be started up off its seat long before the Power stroke is completed —in the engine we're using as an example, a matter of 60 degrees.

The period between the start of exhaust valve opening and Bottom Dead Center of the Power stroke is known as "Blow-Down." This is one of the most literal terms used by automotive engineers, meaning that it is during this time that the pressure within the cylinder is supposed to *blow* out enough to come *down* to equal that of the surrounding atmosphere. If this is accomplished 100%, then all the piston has to do in the way of work during the Exhaust stroke itself is to clear the cylinder of its own volume of exhaust gases. If this is *not* accomplished, and the pressure within the cylinder at the end of the Power stroke is still considerably higher than atmospheric, the piston must ascend on the exhaust stroke against the remaining pressure. This takes a lot more work, and leaves just that much less of the crank's twisting force (torque) left to do whatever the engine's primary assignment may be, whether it's installed in a dragster, ski-boat or bakery truck.

Just as it was found both necessary and desirable to leave the *intake* valve open beyond *Bottom* Dead Center, it's also beneficial to hold the *exhaust* valve open past *Top* Dead Center. The reasons are the same, basically—to provide sufficient valve opening toward the end of the stroke concerned, the valve must still be a considerable distance off its seat. Although just a few degrees later you might be all done using the valve, you just can't say "vanish!" It still must be lowered onto its seat in a manner to avoid all undue shock throughout the entire valve train. Combine this with the mandatory early intake opening and you have the situation where *overlap*, long praised for a variety of esoteric reasons vaguely associated with yet-to-be-proven air flow theories, actually must exist independent of them for considerations of mechanical limitations even if for no other reason.

As a result, many racing cams have intake and exhaust opening periods of equal duration, timed appropriately. Now this works fine in a lot of engines, particularly when the cam concerned has a rather long timing, but some of the more

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FANCY CAMS continued

recent grinds have featured the use of different *contours* for intake and exhaust —intake opens *fast,* closes *slow;* exhaust opens *slow,* closes *fast.* Since the "blow-down" period of exhaust valve opening is considered to be the most important, this innovation may be more beneficial on paper than in the engine—but at least the pursuit of *improved* performance through *modified* contours is still being done; a far better situation than that of a few years back when it seemed as though the name of the game was "I can lift it higher and drop it quicker than you can."

If after slogging along with us this far you're inclined to think that designing cams is probably the best sure-fire way of getting the granny of all headaches, let me touch just briefly on some of the other things that must be considered, in addition to how the engine will *run* with a given cam. Any one of these topics could be the subject of an article in itself, so we'll just take a quick look at:

Mechanical: Considerations of cam design involving the mechanical aspects of the valve train operation may be said to be those involving the type of tappet used, since without changing cams you can change lifters and thereby modify the resultant action at the valve; the limiting fact of the rigidity (or lack of it!) in the type pushrods to be used; the rocker arm ratio, and how much in the way of "scrub" between the ends of the rocker, the pushrods and valve stems may be tolerated; and etcetera, etcetera, etcetera.

Metallurgical: Considerations involve all subjects mentioned above, and many more, for we have just scratched the surface here. At any rate it should be obvious that the reason so many cams are sold (and guaranteed) only with a "kit" these days is because the design of any one of the components mentioned has become so interdependent upon the design of the remainder of the valve train that the only insurance the grinder has that his cam will work is to sell you everything it *must* have to function properly right along with the cam.

This article was prepared at the risk of boring those who have been reading HRM since "year #1" with the idea in mind of exposing the great majority of "the faithful" to a few of the things that must be considered when one sits down at the drawing board to design a new cam for a given engine. Just as in college there are things called "Survey Courses," wherein the subject is glossed over lightly just to give you an idea of what it is like, so this article was intended to *expose* you to cam design, not to *instruct* in the practice of said art. Heaven forbid—we've enough engineers making the scene in "padded penthouses" because of those little lobes now!