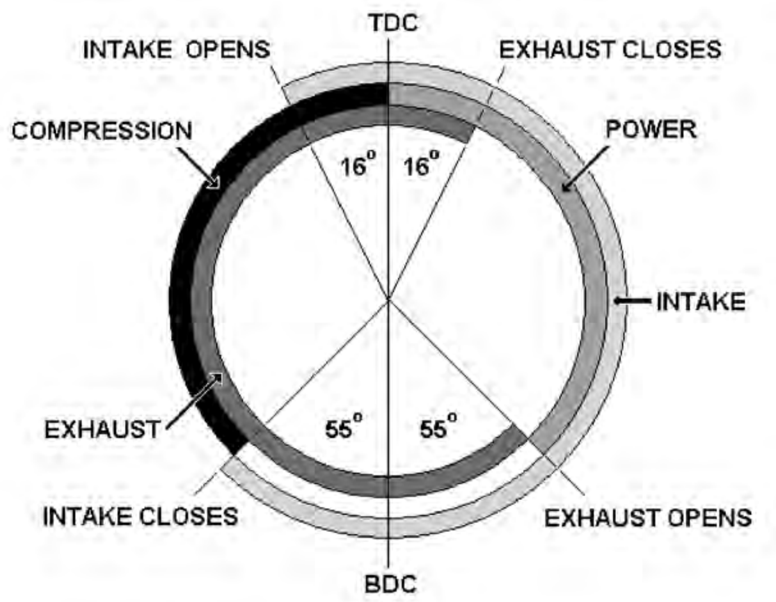
BY GARY LEWIS



Notes on Camshaft Selection

Proper selection of a camshaft has never been easy. You need to know what you want in the way of performance and what you're ready to give up in the way of compromises…

In camshaft selection, there are always compromises. For racing, power is the objective and there is little concern with idle quality or low speed response. For the street however, it would be nice if the engine were to idle at something close to specified RPM, especially with an automatic transmission. It would also be nice if there were sufficient vacuum for power assisted brakes.

Vacuum is especially important if dealing with computerized engine management. As an objective, if we can keep vacuum characteristics somewhat close to that of the original engine, the OE electronics will work without unforeseen glitches.

When we change camshafts, we're dealing with changes in the four valve "events". By this we mean intake opening and closing and then exhaust opening and closing.

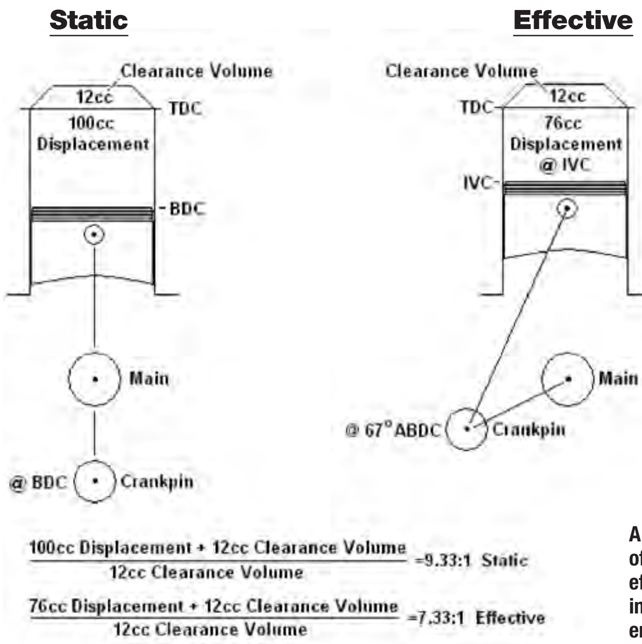
Take a look at the typical valve timing diagram pictured above and the following list of concerns when tampering with these events.

1. **Intake Valve Closing (IVC):** The point of intake closing determines the effective compression ratio. If closed too early, cylinder pressure will be excessive and the engine will be subject to detonation under load. If closed too late, cylinder pressure will be low and there is a reversion of pressure back into the intake manifold especially at low RPM. In all engines, closing the valve well past BDC improves volumetric efficiency because cylinder pressure remains low through this range of piston travel.
2. **Exhaust Valve Opening (EVO):** The point of exhaust opening marks the end of the power stroke. If opened too early, the length of the power stroke is shortened by the loss of expanding gases with a resultant loss of output and fuel efficiency. If opened late, exhaust gases are pressurized in the cylinder and evacuation is incomplete. By opening the valve at just the right time, the "blow-down" effect of high cylinder pressure promotes efficiency of the exhaust stroke.
3. **Intake Valve Opening (IVO):** The point of intake opening marks the end of the exhaust stroke and the beginning of the "valve overlap period." If opened early, exhaust pressure dilutes the incoming intake charge. If opened late, the effective length of the intake stroke is reduced and efficiency reduced. Ideally, the intake opening occurs when cylinder and manifold pressures are equal.
4. **Exhaust Valve Closing (EVC):** The exhaust closing occurs after the start of the intake stroke and marks the end of the "valve overlap period." If closed too early, exhaust gas is trapped in the cylinder and the rise in pressure forces exhaust into the intake manifold. This is referred to as "pressure reversion." If closed too late, vacuum is applied to the exhaust port, the scavenged gases diluting the incoming air and reducing vacuum.

The timing of the intake closing point is perhaps most critical. It is this event and how well we fill the cylinder that determines compression and cylinder pressure. If compression and cylinder pressure are too high, detonation is likely. If too low, we give up power and efficiency. ➤

TECHSIDE

BY **GARY LEWIS**



A comparison of static and effective ratios in the same engine.

What are the limits for compression and cylinder pressure? Before getting into specific numbers, the fuel and it's resistance to detonation is the primary factor. Here, we will assume pump gasoline with octane not over 91.

So, what is the connection between intake valve closing and octane? To get to the connection, we need to understand the difference between "static" and "effective" compression ratios. Static ratios are the ones we know from specifications. They are calculated by dividing displacement plus clearance volume by clearance volume. With effective compression, we need to substitute displacement measured using the stroke length from BDC to TDC with displacement measured with the piston positioned at the point of intake closing, a much lower number. (The diagram above should help visualize this.)

As pictured above, the engine on the left has a static compression ratio of 9.33:1. On the right, using the displacement at intake valve closing, the compression ratio is 7.33:1. Most production engines run ratios similar to these. A production engine with these numbers will likely run on low octane fuel. With volumetric efficiency at 100 percent or more, as we see in performance engines, higher octane fuel will be required as a safeguard against detonation.

In regard to detonation, there are a number of factors that enter into the picture besides compression.

Some of these include:

1. Aluminum cylinder heads help dissipate the heat from combustion.
2. Cold air induction cools the chamber during overlap and the intake stroke.
3. Short power runs build less heat than running under sustained load.
4. Rich fuel mixtures under peak loads absorb heat in the combustion chamber.
5. Lower engine operating temperatures help resist detonation (but increase wear and may not be compatible with computer engine management systems).
6. Shifting the torque curve upward even 500 RPM lowers cylinder pressure (BMEP) significantly.
7. Carburetors and distributors require adjustments to fuel mixture and spark timing as altitude and ambient conditions change. Failure to maintain adjustments could lead to detonation.
8. Computer engine management systems with feedback fuel mixture control, knock detection, and electronically controlled spark timing maintain proper tune and make compensations as ambient conditions change.

GLOSSARY OF CAMSHAFT TERMS

DURATION – The valve open period in crankshaft degrees. Although not so simple, longer periods open are associated with improved volumetric efficiency.

LIFT – Cam lift or valve lift measured in inches or millimeters. Up to the limits of port flow, greater lift is also associated with improved volumetric efficiency.

OVERLAP – The period at the end of the exhaust stroke when both valves are open. With split overlap, both intake and exhaust valves are open equally at TDC exhaust stroke.

BASE CIRCLE – The portion of the cam lobe concentric to the center of rotation and, when in contact the lifter or follower, the valve is closed. Because valves are on their seats during this period, this is also when valve cooling is most efficient.

RAMPS – Opening ramps serve to take up valve train slack before opening the valve and extend from the base circle to where valve opening actually begins. Closing ramps extend from the ends of the closing flanks to the base circle and serve to reduce shock on valve closing.

FLANKS – The areas on cam lobes where valve opening or closing rates are greatest.

NOSE – The valve slows to a stop on opening and slowly begins closing as it travels across the nose.

LOBE CENTERLINE – The centerline of the lobe frequently used to locate wide-open points in crankshaft degrees.

LOBE CENTERS – The separation between intake and exhaust lobe centerlines in camshaft degrees sometimes referred to as the lobe separation angle. Increases in the angle reduce overlap and decreases in the angle increase overlap.

LOBE TAPER – The taper ground into some camshaft lobes to promote lifter rotation and reduce camshaft wear.

SYMMETRICAL CAM LOBES – Lobes ground the same on opening and closing sides of lobe centerlines.

ASYMMETRICAL CAM LOBES – Opening and closing sides of lobes are ground to different contours.

DUAL PATTERN GRINDS – Intake and exhaust lobes are ground to different duration and/or lift specifications.

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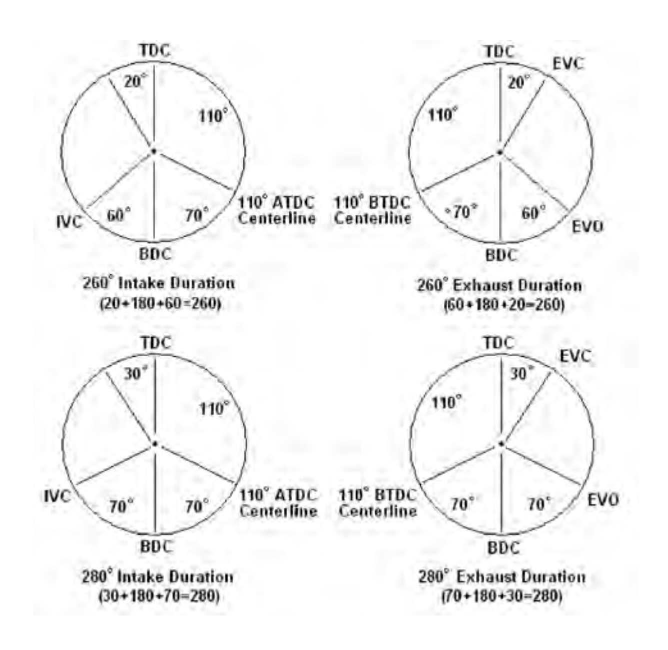
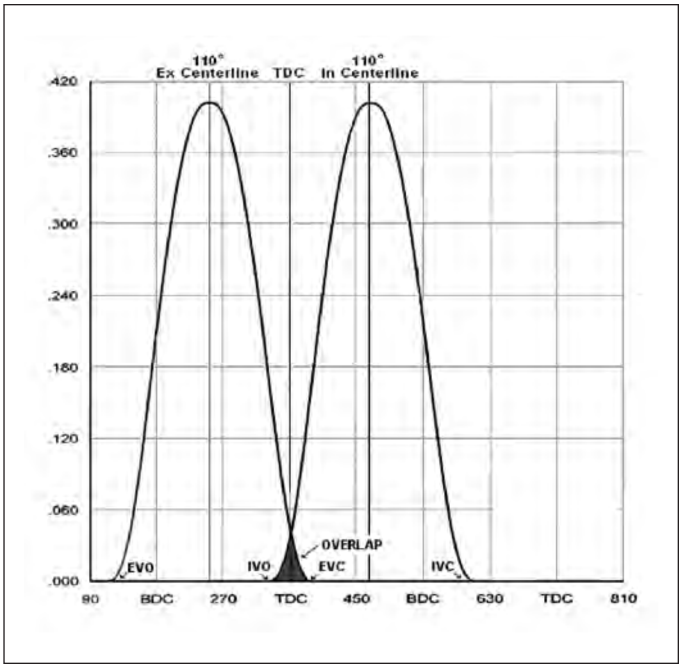


Changes in intake valve events with the same centerline timing points but with increased duration.



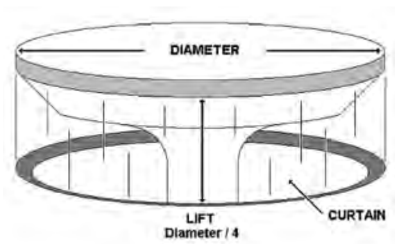
Overlaying intake and exhaust valve opening curves to show how duration effects overlap.

To improve performance, we typically begin by raising compression. However, if limited to 91-0ctane fuel, no matter how high we raise static compression, effective ratios are still limited to the range of 7-8 to 1 (using advertised duration to determine the intake valve closing point). Then where is the power gain? The answer is that the higher the static compression, the later we must close the intake valve to keep effective compression in the range. This requires longer duration and this improves volumetric efficiency and increases power (see the sidebar, "Glossary of Camshaft Terms" on previous page).

Take a look at the diagram above (left) and see what happens to the intake closing point as duration goes up.

However, when we increase intake duration, we need a proportional increase in exhaust duration. The normal relationship between intake and exhaust durations is that we need the exhaust to flow 75 percent of intake flow (80 percent or more with forced induction). In this regard, it really helps to know the flow test results for the cylinder head. If flow testing shows exhaust flow at about 75 percent, exhaust duration can be equal to intake duration. If exhaust flow drops much below 75 percent in testing, additional duration is needed, perhaps up to 10 degrees.

Flow data is also useful in determining what valve lift allows maximum flow. Without flow data, it is safe to use one-quarter of intake valve diameter. At this lift, the area of the opening is equal to the area of the valve. This area is equal to the circumference around the valve multiplied by valve lift and is called "curtain area" as can be seen in Figure 4. When the curtain area is equal to valve area, the valve is no longer a restriction. Lift on the exhaust is typically equal or greater even though the valve is much smaller. Getting the exhaust valve well open early in the cycle is done to take maximum advantage of the "blow-down" from the still pressurized gases that exit the cylinder on valve opening.



Comparing valve area to curtain area at one-quarter valve lift.

Now we get to those compromises. All this added duration, especially on the exhaust side, also adds to the length of the overlap period with major effects on manifold vacuum. Not just lower vacuum, but vacuum oscillations caused by exhaust pressure reversions through the intake system. That "rumpity-rump" idle may sound neat but the engine will idle badly, the power brakes won't work and the onboard computer won't know what to do. In reality, static compression ratios in street engines are limited by the overlap problems created by long durations. The overlap period can be visualized in the diagram above (right).

What can be done to improve vacuum? First, because of the effect on vacuum, it best to have really efficient exhaust port flow rather than compensate by adding exhaust duration. However, if we don't have this option, wider lobe centers, as can seen in Figure 5, reduce overlap and improve vacuum. It only takes a couple of degrees to make a difference. Maybe this is why we now see production lobe centers up to 115 degrees apart?

BY GARY LEWIS

Stage 1 Base Engine — Analysis

Typical low performance: Standard 1.94 and 1.50 valves with typical port flow, OE dual plane 4bbl intake, OE exhaust manifolds and single exhaust.

Static Compression	8.25:1	Volumetric Efficiency	86.7%
Intake Duration	250 Degrees	Torque/RPM	360/3,000
Exhaust Duration	260 Degrees	HP/RPM	245/4000
Lobe Centers	110 Degrees	Effective Compression	7.13:1
Fuel	87 Octane	Vacuum	20.9 in/Hg

Stage 2 — Analysis

Mild production performance: Standard 1.94 and 1.50 valves with typical port flow, OE dual plane 4bbl intake, OE exhaust manifolds and dual exhaust.

Static Compression	9.25:1	Volumetric Efficiency	87.2%
Intake Duration	260 Degrees	Torque/RPM	373/3,000
Exhaust Duration	270 Degrees	HP/RPM	268/4,500
Lobe Centers	112 Degrees	Effective Compression	7.61:1
Fuel	87 Octane	Vacuum	21.1 in/Hg

Stage 3 — Analysis

Performance engine: Larger 2.02 and 1.60 valves and mild porting, single plane aftermarket intake and 1-5/8 x 36 in. headers with low restriction mufflers. With the increased effective compression and volumetric efficiency, premium fuel is recommended.

Static Compression	10.0:1	Volumetric Efficiency	94.8%
Intake Duration	288 Degrees	Torque/RPM	404/4,500
Exhaust Duration	288 Degrees	HP/RPM	372/5,500
Lobe Centers	114 Degrees	Effective Compression	7.55:1
Fuel	91 Octane	Vacuum	19.6 in/Hg

NOTE — In all but the last stage, "dual pattern" camshafts with increased exhaust duration were required to achieve 75 percent or better exhaust flow relative to intake. Also, note vacuum was kept within a range of 1.4 in/Hg for all three engines.

Computer simulations show what happens when we increase compression, add duration in different combinations and then adjust lobe centers using a hypothetical Chevrolet 350 engine assembled with different combinations of compression, camshafts and valve timing as a base.

To help put all this together, let's look at some computer simulations to see what happens when we increase compression, add duration in different combinations and then adjust lobe centers. We'll use a hypothetical Chevrolet 350 engine assembled with different combinations of compression, camshafts and valve timing as a base. Keep in mind that because we're looking at street engines, we'll look at not just power, but also at vacuum.

As you see in the examples above, compression ratios and duration are directly related to each other. Essentially, as compression goes up we add duration and close the intake valve later to keep effective compression within the acceptable range. Fine tuning of effective compression can be also be accomplished by retarding or advancing the centerline position of the intake cam lobe and thereby change the intake valve closing point (the camshafts were left straight up in these examples). From the baseline position, the cam lobe centerline might be advanced five degrees or retarded four degrees but not commonly outside of this range. If adjustment outside of this range is necessary, we probably ought to change duration. ■

Gary Lewis is an automotive machining instructor with 35 years at De Anza College in Cupertino, California. Gary began developing his interest in all things mechanical at an early age repairing his old cars and fabricating farm equipment. He gained formal training in an apprenticeship machining aircraft engine parts. After accumulating experience, he returned to college and earned Baccalaureate and Master's degrees from California State University San Jose. He has written and contributed to a number of automotive texts and publications including his own text, Automotive Machining and Engine Repair.