CAMSHAFT CHOICES AND TUNING

VALVE TIMING BASICS

Your Honda's camshaft determines the engine's power curve. By opening and closing the valves with precise timing, in relation to the position of the pistons and crankshaft, the cam determines where in the RPM range an engine makes the most power and torque.

Of course, the cam's ability to produce power depends on the intake and exhaust tract design efficiency, i.e., how well these channels flow throughout the RPM range of the engine, as well as the pressure curve in the cylinder dictated by the motion of the piston. (See the short rod, long rod section.) The cam can't flow any more than these tracts allow. What it can do is optimize the physics of the air that is moving through these tracts within an RPM window, to best fill the cylinder with air and fuel. VTEC technology affords an advantage here by staging two cam profiles that optimize performance within two RPM ranges. The trick, that Honda engineers did so well (besides designing a system that works), is blending the profiles and engine management electronics of the VTEC to give the engine a wide and drivable power band.

The intake and exhaust tracts are accelerating columns of air and the inertia of those columns is used to increase the volumetric efficiency of the cylinder. As the piston recedes to bottom dead center (BDC), it creates a low-pressure area that is filled by atmospheric pressure (in a normally aspirated engine), pulling air through the intake manifold into the cylinder. What the manifold does is form the air into columns. When you get a column of air moving, it doesn't want to stop, so more of it packs into the cylinder. By timing the intake and exhaust valve opening and closings (let's call these "events" from now on), you can catch a little more air and fuel on the intake stroke to provide a powerful, power stroke.

The amount of air you can stuff into a cylinder per intake stroke is a measure of the engine's volumetric efficiency. If it can capture its full cubic capacity, it's said to have 100-percent volumetric efficiency (VE). By tuning the intake dimensions, head port configuration, and cam profile and timing, you can, within a certain RPM window, get more than 100-percent volumetric efficiency, depending on the efficiency of the intake and exhaust systems.

Generally, the torque peak occurs at peak VE. It should be obvious that VE of the cylinder is a primary factor in determining power output of an engine. Turbos, superchargers, and nitrous all work because they leverage the VE of your engine. These techniques literally squeeze more air and fuel into the cylinder per cycle. Technically this isn't an increase in VE, because you can have a situation where the VE is 80% but the density of the charge is doubled and the engine will flow more air than a naturally aspirated engine at 108-percent VE. The VE is a measure of volume and doesn't measure mass or weight depending on what units you're using. (Mass Density equals Mass divided by the volume; Weight Density equals the weight divided by the volume.)

Volumetric efficiency falls off as engine RPM increases because there is less time to fill the cylinders. That's why a cam is designed to work with specific intake and exhaust system flow characteristics within an RPM window. Cams that are designed to work best at high RPM have a long duration, meaning they hold the valve open longer. Holding the valves open longer gives the cylinder more time to fill, and the power band moves up the RPM range. In addition, high- RPM cams have a lot of what is called overlap. Much of the work of designing and tuning a cam concerns how the intake charge and exhaust charge interact in the "overlap zone."

THE OVERLAP ZONE

Overlap is when both the intake and the exhaust valves are open. This occurs when the piston is near TDC on

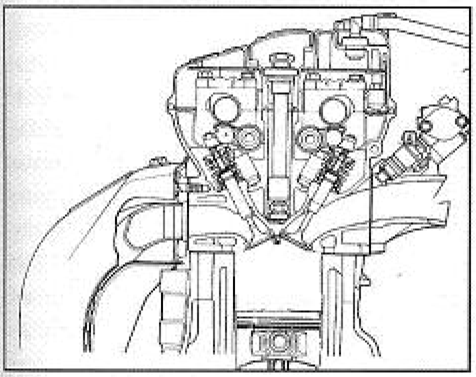


Figure 5-1. ***On the power stroke, most of the work is done in the first 90 degrees of crank rotation. As the piston gets near bottom dead center, it's not putting as much pressure on the crank to spin it. The gases are still hot and expanding, but for the most part their job is done.***

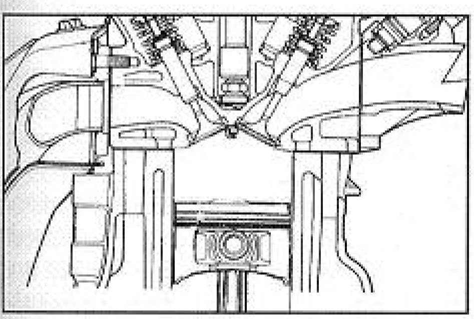


Figure 5-4. ***The dynamic compression ratio of an engine changes through the RPM range. A cam that closes the intake early and has little overlap makes good bottom-end power and idles smoothly. It also has a dynamic compression ratio closer to that of the static compression ratio. Closing the intake late lowers the dynamic compression, but you can gain high-RPM power.***

the exhaust stroke. Figures 5-1 through 5-5 walk you through the valve events of the four-stroke engine cycle and some of the reasoning behind the timing of valve events.

We mentioned that it's important to get an uncontaminated charge into the cylinder, which means the cylinder must expel the charge that was burned in the power stroke. That's what the exhaust stroke does. It forces the hot and expanding gases out the exhaust tract. However, the real exhaust cycle begins a few degrees back on the power stroke before the piston reached BDC. Because

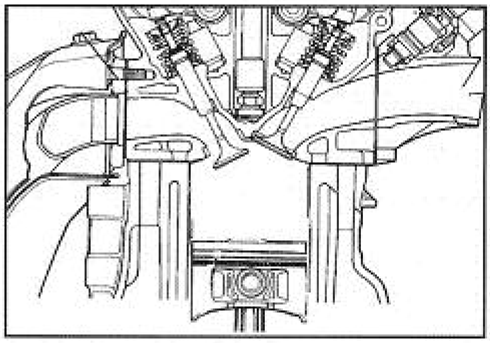


Figure 5-2. ***Why waste the heat of the expanding gas? Why not use its energy to help evacuate the cylinder? That's what engine tuners are up to when they get the cam to open the exhaust valve while the piston is still on the power stroke. Near BDC, the exhaust valve pops open and the expanding gases punch into the low pressure of the exhaust system.***

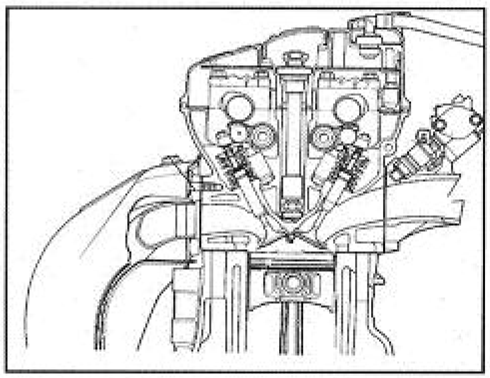


Figure 5-5. ***The point at which the intake valve closes influences how much intake charge the cylinder captures as well as the dynamic compression ratio of the engine. Closing the intake valve too late causes a loss of some intake charge because it's forced back into the intake manifold. For high-RPM power, you must have a cam that closes the intake later in the cycle because you need the duration.***

the exhaust mass is a gas, it's compressible, so it behaves sort of like a spring. During the power stroke, the gas is expanding and forcing the piston down the bore, generating power. It's under high pressure. One of the things engine tuners have discovered is that if you open the exhaust valve near the bottom of the power stroke, you can use some of that energy to push the exhaust gases out of the cylinder. (Opening the exhaust valve while the gases are still burning gives internal combustion engines their characteristic exhaust sound.) Then, the piston comes up the bore and forces most of the rest of the spent gas from the cylinder.

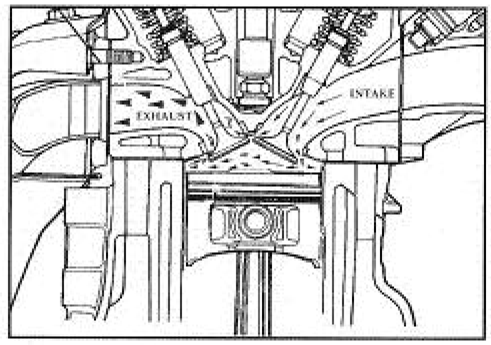


Figure 5-3. ***Just as the exhaust valve opens on the power stroke, so does the intake open on the exhaust stroke. At high RPM, a certain amount of overlap helps improve the quality of the intake charge by using the exiting exhaust pulse's low pressure to draw intake air through the combustion chamber. At low RPM, too much overlap results in low intake pressure and intake charge contamination because the high-pressure exhaust gases bleed into the low-pressure intake. This results in a lopey idle and loss of low-end power.***

The exhaust stroke by itself can't get all the spent gas out of the cylinder because the piston doesn't completely fill the combustion chamber at the top. Ashes don't burn and that's basically what's left after the power stroke. Removing them so the next charge is as uncontaminated as possible helps make power. Engine tuners use the same strategy on at this end of the four-stroke cycle as they do on the exhaust cycle. That is, they open the intake valve before the piston reaches TDC and before the exhaust valve closes.

Engine tuners also discovered that they could use the inertia of the escaping exhaust gases to pull in a little extra fresh charge air and use that to push out the residual exhaust gas—a process called "scavenging" the combustion chamber of spent gases. It's a pretty cool trick that is totally dependent on proper timing of the opening of the intake valve and the closing of the exhaust valve.

Overlap is a critical area of four-stroke engine tuning. The intake valve is opening and the exhaust valve is closing as the piston is rushing toward it, so you have to be aware of the potential for valve-to-piston conflict. Of utmost importance though, is how the phasing of the valve events at overlap influence the performance of your engine—mainly in shifting peak power to a different RPM range.

If the intake is opened too soon, you get too much exhaust gas pulsing into the intake tract. This is called intake reversion. Let's face it, the intake manifold has much lower pressure than the cylinder at this point. You always get some exhaust gas if you have overlap, but too much hurts engine performance. If too much exhaust gas gets into the intake, it contaminates the intake charge. Yet, because of the scavenging effect, most of the contaminated intake air is drawn through the cylinder and out the exhaust, as it should be. If you have too much scavenging, though, a lot of the intake charge-air will rush through the cylinder and out the exhaust, leaving you with a lean cylinder. With a turbo and its backpressure, you have to minimize the potential for exhaust gas reversion. With too much overlap on a turbocharged engine, the exhaust can flood the intake system. Too much overlap on a supercharger and you can waste lots of fuel by blowing it straight through your engine. Alas, tuning is always a balancing act.

The efficiency of the scavenging effect rises with engine RPM, which is reasonable. The gases have a higher velocity, and therefore, less pressure and more inertial energy to do the work of pulling the intake air through the cylinder. It's also influenced by the efficiency of the exhaust port and related manifolding, such as headers, exhaust tube diameter, and muffler. If the exhaust system is highly efficient, you don't need to open the exhaust valve as soon as you would if the exhaust was slightly restricted.

It's interesting to note that intake contamination isn't usually a problem at high RPM because the tendency for exhaust gas to pulse back into the intake is most pronounced at low RPM. This is why long duration cams with lots of overlap idle so poorly. The exhaust stroke is, in addition to recycling spent mixture, pumping pressure into the manifold, so it messes up the vacuum signal to the carburetor, if so equipped, and sends a confusing manifold absolute pressure (MAP) reading to the computer. It's not until you speed up the charge air velocity at higher RPM that the engine starts to make good smooth power.

Valvetrain Dynamics

For the cam to produce power, the valvetrain must follow the lobe "signal" of the cam. The more precisely the valves do so, the more power you can make and the more reliable your engine will be.

To set a standard for judging f current valvetrain technology, imagine what characteristics the ideal valvetrain should have. If it were possible, the ideal valvetrain would instantly open and close the valve at precisely the right moment. Further, these valve-timing events could be varied during engine operation to optimize power throughout the entire RPM range. In addition, there would be no valve head to inhibit charge flow through the port into the cylinder. Moreover, all this would occur without any friction whatsoever.

Unfortunately, the current state of valvetrain technology cannot achieve such performance. (VTEC gets us closer, iVTEC closer still.) What we're stuck with is a mechanical compromise built from materials that have mass, which is accelerated, and therefore has inertia that must be managed. (For a valve system to instantly open and close and not self-destruct, it would have to be composed of material without mass. That jus' ain't gonna happen in this dimension.)

The valvetrain is a mechanical leverage system that converts the rotating eccentric of the cam lobe into a straight-line reciprocating motion at the valve. Between these components on the Honda engine, there is space, called lash, which is needed to compensate for the expansion of the metals of the valvetrain components and the engine as it heats up.

The job of the camshaft, in addition to its lift and duration duties, is twofold. First, it must open the valve as quickly as possible (accelerate), but not so fast as to cause the valvetrain components to lose contact with the cam (valve float) after full lift is reached. Second, it must close the valve as quickly as possible, again with out valve float or slamming the valves on the seat so hard that they break. This is a delicate balancing act, and these requirements are what, literally, shapes the lobes of the cam.

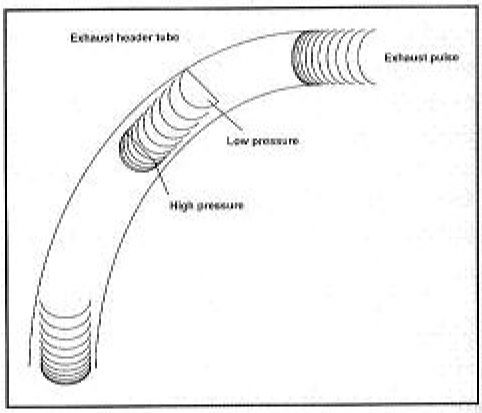


Figure 5-6. ***Looking at this map of the cam lobe sections, compare the theoretical ideal cam profile with a profile that would work in the real world. Notice the difference in ramp angles in relation to crankshaft degrees of rotation. The steeper angles accelerate and decelerate the valves more quickly. Theoretically, a square wave would represent the ideal instant response, but in the real world, that kind of cam profile would quickly turn the valve and the cam into heat and a few chemical by-products.***

Figure 5-6 shows a map of the cam lobe sections. Compare the cam profiles of these theoretical cams and notice the difference in ramp angles in relation to crankshaft degrees of rotation. The steeper angles accelerate and decelerate the valves more quickly. A square wave represents the ideal instant response.

These angles, or rates of lift, are determined by several interdependent limiting factors: First is the desired valve lift and duration. To achieve maximum head-port flow rates, the cam must move the valve head away from the seat. Duration is related to lift, in that more and quicker lift means more duration, since it takes time to lift the valve higher. Doing so means the port is flowing at max volume and velocity for a longer period, and therefore, fills the cylinder in less time. Time limits become critical as engine RPM increases and it is a limiting factor in power output.

To move the valve off the seat to max lift and set it back down, the valvetrain must be accelerated and decelerated. That means the cam designer has to deal with inertia. The quicker the valve is accelerated, the more inertia it has. Inertia is that quality of mass that, according to Newton's second law of motion, tends to stay in motion or at rest unless acted on by an outside force.

The cam profile, then, must overcome the valvetrain's resistance to being accelerated, its resistance to slowing down and changing directions at the top of the lobe and to accelerating back down toward the seat and to finally coming to rest upon the seat. In addition, taking up the lash, or the space between the valvetrain components, has to be accomplished without destroying the components.

Referring to figure 5-6, you can see how this is accomplished. Notice that the entrance to the acceleration ramp of the cam has a shallow slope, which produces a slow acceleration rate. This slowly takes up the lash and cushions the valvetrain before it is accelerated to the top of the lobe. If this area of the cam weren't shaped as it is, the cam would slam the valvetrain as if it were a sledgehammer. The shock of such an acceleration profile would soon destroy some component of the valvetrain.

Once the lash is taken up, the flank of the cam is designed to achieve maximum acceleration for a given RPM limit. The limit to the rate of acceleration, or ramp angle, is defined by the resilience of the valvetrain components while withstanding the forces of acceleration and the tension, or the pressure of the spring. As engine RPM increases, the valve is opened more quickly and consequently more force is generated.

The next limit is the inertia of the valvetrain as it reaches maximum acceleration rates. Notice in figure 5-6 that the curves near the top of the cam once again become shallow. This accomplishes two things. First, it extends the amount of time at maximum lift, which extends the amount of time that the open valve allows the cylinder to be filled. Second, it slows the valve, reducing the magnitude of inertia until the spring tension won't allow it to "ski-jump" off the top of the cam lobe, which is commonly known as valve float. Valve float is what destroys your valvetrain. (See figure 5-7 for a description of the function of the shape of the cam lobe.)

Actually, the valvetrain doesn't jump off the top of the cam. Instead, the valve is accelerated to such an extent that the valve spring can't resist its motion. The valve goes slightly farther than the rocker arm (on SOHC engines), or the cam (on DOHC engines), pushes it. This once again opens space between the components (lash), but instead of a slow take-up of the slack, the components slam back together with explosive force, and this is when parts break.

A related observation to the cause of valve float: The weight of the valve and keepers tends to be the most influential factor in determining the acceleration rate at which a valve floats. The lighter the valves and spring retainers, the higher the RPM capability of the valvetrain before it reaches the point of valve float. On Honda engines, this effect is amplified because the valve is moving farther, by virtue of the rocker arm ratio, and therefore it moves faster than the rest of the valvetrain. This is also one of the reasons that four-valve per cylinder engines rev much higher than 2-valve per cylinder engines. With two intake and two exhaust valves, you've reduced the mass that each cam lobe and valve spring has to control.

At this point, the spring pressure comes into play. The spring pressure, which is rated in in-lbs, that exists with either the valve open or closed, helps determine how quickly the top of the cam lobe can decelerate the valvetrain. Valve springs have been a weak link in the valvetrain chain because they are subject to fatigue. The higher the valve lift, the more fatigue becomes a problem. As the spring compresses, friction causes the springs to heat and the metal changes and loses some of its resilience, or spring rate. When the spring rate is reduced, the cam lobe becomes too aggressive, compared to the spring rate, and the valves will float at a lower RPM. That's why all racers who use exotic cam lifts are constantly changing valve springs. Cam manufacturers have been diligently researching this problem, and several are offering springs made from new alloys that have a longer service life.

Spring pressures, in addition to cam lobe profile, affect the design of the rocker arms. So far, no one is running a cam profile that requires a redesign of the Honda rocker arm for street use.

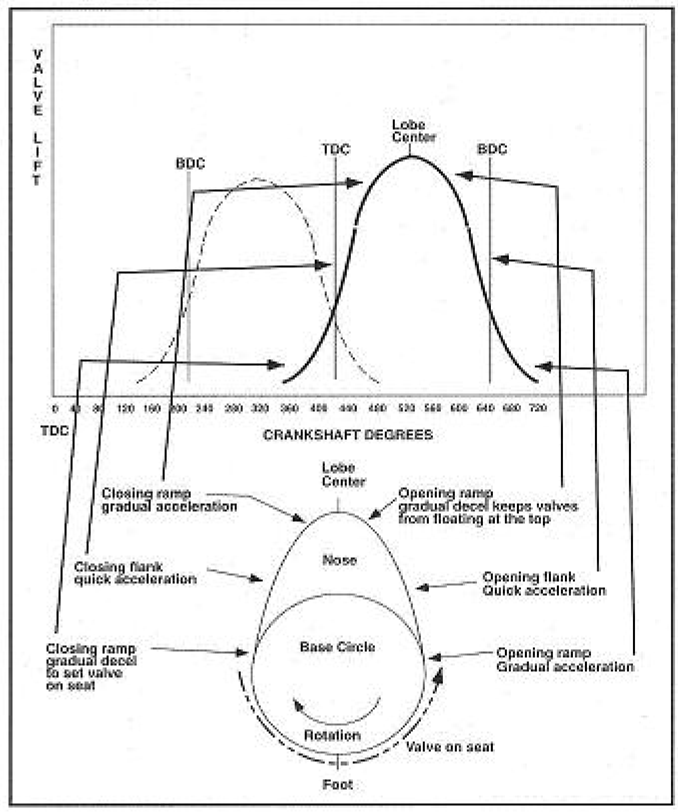


Figure 5-7. *The lobe is ground to achieve specific rates and magnitudes of valve lift. The limits of these rates are imposed by the inertia of the valvetrain components.*

However, the concept is useful. When a higher spring pressure is used, more force is required to open the valve. These components must be strong enough to physically overcome the spring pressure and not break. At the same time, they have to be as light as possible to reduce inertia. In reality, the components between the cam and the valve flex. The higher the spring pressure and the more rapid the acceleration curves, the more pronounced the flexing tends to be. In fact, if the spring pressures are high enough, the cam actually bends slightly, enough to cause a loss of lift and duration at the valve. When the rocker arm, or even the rocker mount, bends slightly, the valve doesn't follow the cam lobe profile.

It's amazing how much some valvetrain designs flex at high RPM. Because of this flex, some of the lift and duration of the cam is lost. Obviously, the better engineered and matched the valvetrain components are, the closer they will follow the lobe profile, which causes the engine to produce more power. This subtle but critically important point is why you should always use the combinations that the cam manufacturers recommend. Unless you really know what you're doing and have experience to prove it, mixing components can rob you of power and reliability.

Valves usually bounce when they set back on the valve seats. The amount of bounce is directly associated with the lobe profile and how it ramps back on the base circle. This deceleration curve is designed differently for intake and exhaust valves. The intake can hit the seat harder than the exhaust valve, because it is cooler. The hot exhaust valve is softer and must be decelerated more before it is allowed to hit the valve seat.

While we have barely exposed the subtle complexity of valvetrain dynamics, the main point of this discussion is that the valvetrain is a system. All the parts must work in relation to the others to balance the forces required to operate the valves. Because it is a system, your component choice is critical. We all know that to finish first, first you must finish. If you make the correct choices with your valvetrain, you'll improve your chances of finishing and finishing first.

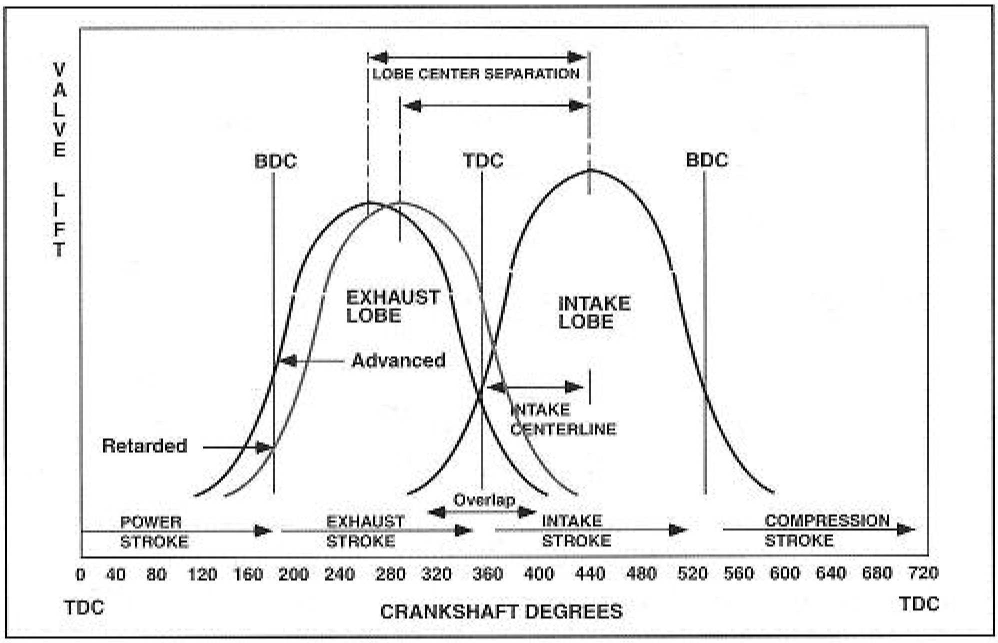


Figure 5-8. ***Retarding the exhaust cam opens the exhaust valve later in the power stroke, closes it later in the intake stroke, and increases overlap, all else being the same. Advancing it does the opposite. Retarding the opening of the exhaust valve increases the length of the power stroke and, provided the piston is still moving, can enhance torque.***

How Cam Timing Events Influence Performance

Timing Exhaust Valve Opening

The exhaust valve opens somewhere near BDC on the power stroke to use the pressure inside the cylinder to help evacuate it. Again, we talked about this in the Cam Basics section. The tricky part is at what point during the crank rotation and power stroke to open it. Open it too soon, and you lose cylinder pressure and possibly horsepower; too late, and you run out of time to remove the used gases from the cylinder and that'll cost you horsepower. It's a balancing act.

John Concialdi of Advanced Engine Management told us that most of the work of the cylinder is done in the first 90 degrees of crank rotation, so timing the exhaust valve-opening event after 90-degrees of crank rotation is a sound tuning tactic. For a low-RPM, long-stroke torque motor, open it later to keep the pressure on the piston longer. For a short-stroke, high-RPM horsepower combo, open it sooner to give you as much time as possible to evacuate the cylinder.

Retarding the exhaust cam opens the exhaust valve later in the power stroke, closes it later in the intake stroke, and increases overlap, all else being the same. Advancing it does the opposite. (See figure 5-8.)

If your exhaust system isn't very efficient, it's sometimes helpful to advance the exhaust timing for high initial cylinder pressure, which will force the exhaust pulse out of the exhaust system and give extra time for the exhaust gases to make their way out of the cylinder. This is not the case with Honda exhaust systems, which are efficient right from the factory and even more so when you install headers. In fact, if you install a header and a free-flowing exhaust system, it may pay to advance the exhaust a little, depending on the amount of overlap the cam has.

Intake Valve Opening

Advancing intake cam timing opens the intake valve sooner before TDC, thus increasing overlap. Increasing overlap usually improves high-RPM power because it uses the inertia of the exhaust pulse to pull intake air into the cylinder. At low RPM, advanced intake timing has a tendency to contaminate the intake charge air with burned gases and generate reversion turbulence from the exhaust pulse bleeding into the low-pressure intake system. This also pumps pressure into the intake, slowing the charge down and messing with the map sensor. On a carbureted combination, this turbulent pulsing intake vacuum signal really hurts the carburetor's ability to meter fuel accurately. This is especially true for multi-carb units with individual runners for each cylinder and carb. Retarding intake cam timing opens the intake valve later, decreasing the amount of overlap. This improves low-RPM torque because it limits or prevents intake charge contamination and reversion turbulence in the intake manifold. Less-charge contamination and reversion turbulence also gives you more intake vacuum and smoother idle quality. (See figure 5-9.)

Exhaust Valve Closing

Retarding exhaust cam timing delays closing the exhaust valve, which increases overlap because it narrows the lobe phasing on DOHC engines and the lobe separation angle on SOHC engines. Closing the valve later in the cycle increases overlap and increases the scavenging effect at high RPM by taking advantage of the inertia of high-velocity intake and exhaust pulses. However, if you hold the exhaust valve open too long, you'll move much of your air/fuel mix through the cylinder and right out the exhaust, causing a lean condition in the combustion chamber and possibly a detonation problem. The scavenging effect isn't really a factor at low RPM (See figures 5-9, 5-8 and 5-10.)

Intake Valve Closing

Timing the close of the intake valve influences several important factors that create horsepower. Foremost is leaving it open long enough past BDC, so that

The Influence of Rod Ratio on Valve Timing Events

We talked about the effects of rod ratio in the bottom end section. If you look at the accompanying figure, you'll see that those effects extend to timing valve events. Almost every system in an engine influences all the others. A seemingly simple thing like the length of a rod has a ripple affect throughout the engine combination.

A longer rod lets the piston dwell at TDC for more degrees of crankshaft rotation, and a savvy super tuner will adjust the timing of the valve events around TDC to take full advantage of the pressure curves of each combination. For example, a longer rod gives you more time at overlap before the piston starts down the bore than a short rod combination. Conversely, if you have a shorter rod ratio, a high-speed cam with slightly less overlap may be better.

Notice the steeper curves that appear as the piston approaches and leaves TDC. We've already talked about a short rod combination having higher piston velocity and how it can outspeed the flame front. There's more to it. The acceleration curve of the piston toward and away from BDC influences the optimum timing of the opening of the exhaust valve, as well as the closing of the intake on the compression stroke. The short rod combination waits a lot longer before shooting the piston up the bore. The point at which you close the intake affects the dynamic compression ratio of the engine, so delaying closure of the intake valve on the short rod combo doesn't result in as much of a loss of dynamic compression ratio.

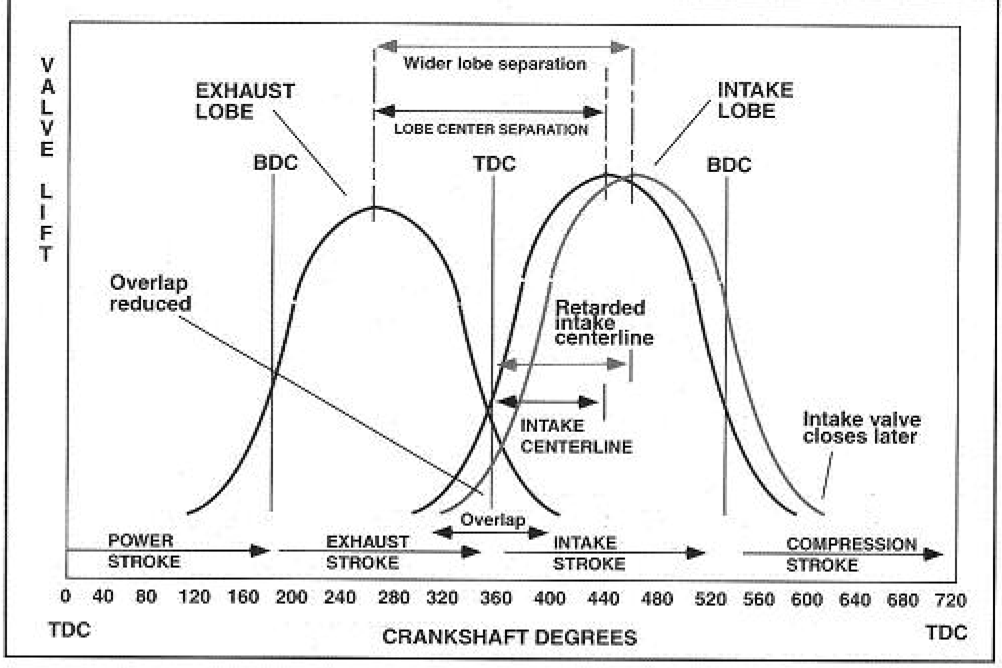


Figure 5-9. ***Retarding the intake cam increases overlap and can cause the intake charge to become contaminated with the exhaust. Opening the intake too early in the exhaust cycle means the pressure differential may push the intake charge back out the intake. This is called reversion.***

Cam Tuning Math

1. To find overlap duration:

(Lobe Phase or Lobe Separation Angle * 2) – Duration = Overlap Duration

2. To find lobe center:

Duration/2 = lobe center

3. To find Split Overlap Duration Lobe Center Timing:

A. Divide cam duration by 2 to find lobe center value
B. Divide Overlap duration by to find each cam's portion of overlap duration
C. Subtract B from A to find "split overlap duration" lobe center timing

while the piston dwells at the bottom, it gives the cylinder time to fill. Remember, the intake charge has inertia now that it is moving, and it continues to fill the cylinder even though the piston is starting up the bore on the compression stroke. Of course, you can't leave it open too long or the piston forces the charge back into the intake. This scenario is much like opening it too soon during the exhaust stroke, with the same consequences.

The number of crankshaft degrees you can retard the closing of the intake valve depends on the RPM of the engine. As RPM rises, so does the velocity and inertia of the charge. At high RPM, you can leave it open longer. The inertia of the moving air column packs more charge into the cylinder before it is forced out the intake by the piston rushing up the bore. The reverse is also true. At low RPM, you have to close it sooner or you'll get reversion.

Timing the close of the intake valve also affects the dynamic compression ratio of the engine. If you close it sooner in the compression stroke, you begin the actual compression stroke sooner, and therefore, you'll see higher pressure at TDC on the compression stroke. Close it later, and the actual compression stroke begins later to form less pressure at TDC.

Basically, you increase high-RPM horsepower by delaying the closing of the intake valve; you increase low-RPM torque by closing it sooner.

The Effects of Cam Duration

We already talked about duration in the cam basics section, but a quick review won't hurt. Cam duration is simply how long, in crankshaft degrees, the cam keeps the valve open. Duration influences the other valve timing events. Obviously, if you keep the valve open longer, the closing point is delayed and vice versa. It also influences the critical overlap zone—if the valve stays open longer, the valve usually has to open sooner, which leads to more overlap. Overlap is the combined effect of duration and the lobe center separation on single cam engines and the effect of cam phasing on dual-cam motors. Longer-duration cams are good at producing high- RPM power because they hold the valve open longer (as well as lifting it higher), allowing more time at high RPM to fill the cylinder. Since long duration usually increases overlap, at low RPM the intake charge tends to get contaminated with "used" mixture and raise the pressure of the intake. These two conditions are not conducive to making low-end power. Fortunately, these effects go away at high RPM operation to let the engine scream—if the combination's right. (See the cam basics section for more info.)

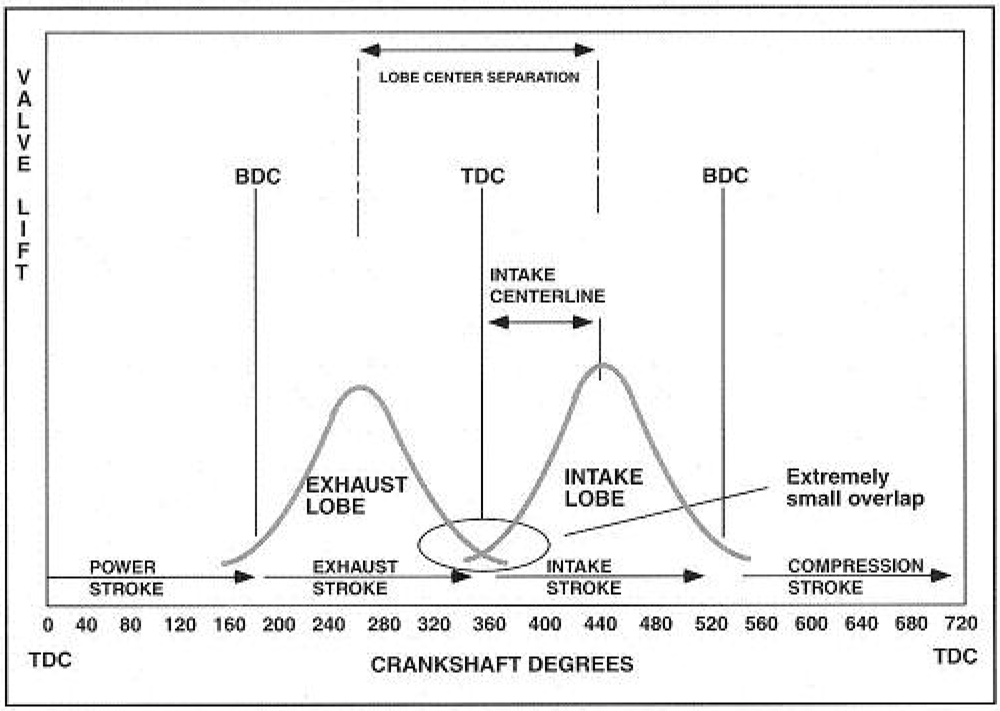


Figure 5-10. ***Valve timing events are keyed to the direction of crankshaft rotation. Advanced timing means the valve event occurs sooner in crankshaft degrees relative to its direction of rotation. For example: advance the exhaust cam and retard the intake cam and you reduce the overlap and change the valve timing relative to the cylinder pressure cycles.***

Lobe Phasing/Lobe Separation Angle

Lobe phasing, or lobe separation, describes the timing differential of the intake and the exhaust cam lobes. It is measured in degrees between the lobe centerlines of the intake and exhaust cam lobes. A wider lobe phase reduces overlap for a given cam duration, and therefore tends to produce low-RPM torque. A closer lobe phase increases overlap, and so increases high-RPM

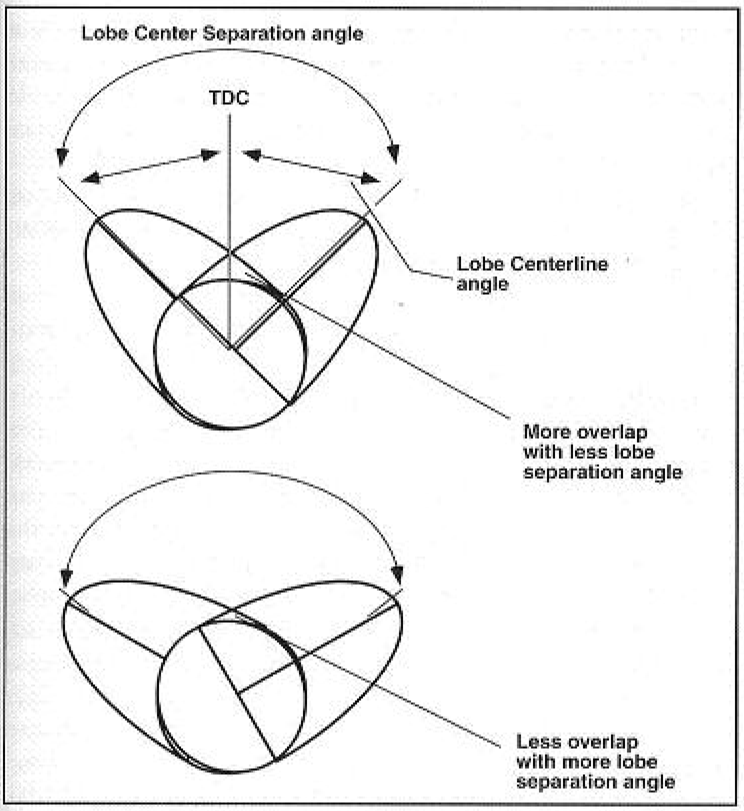


Figure 5-11. *Lobe phasing, or for the SOHC crowd, lobe separation, describes the timing differential of the intake and the exhaust cam lobes. It is measured in degrees between the lobe centerlines of the intake and exhaust cam lobes. A wider lobe phase reduces overlap for a given cam duration, and therefore tends to produce low-RPM torque. A closer lobe phase increases overlap, and so increases high-RPM horsepower.*

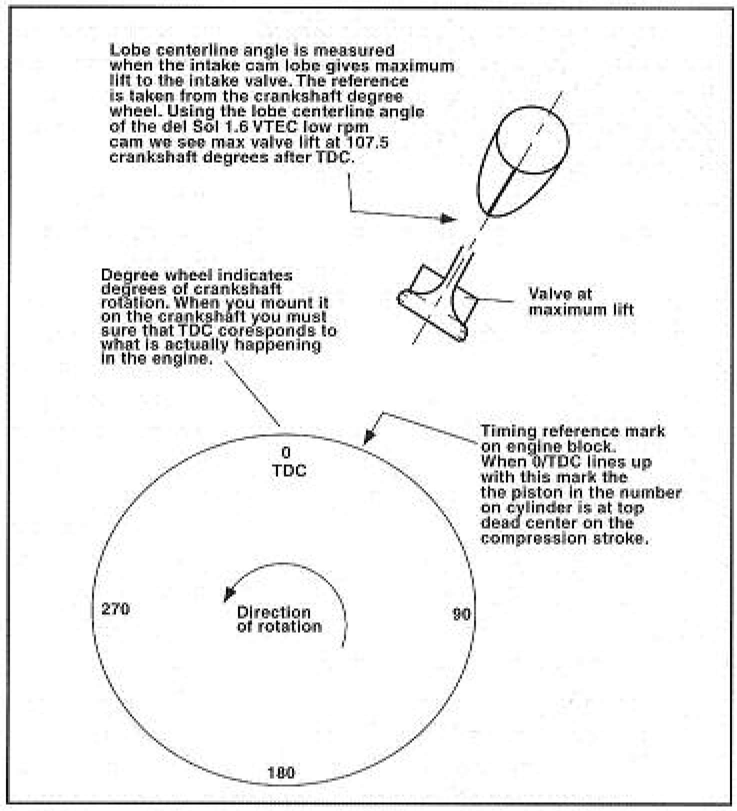


Figure 5-12. *Using a degree wheel and a dial indicator is the only why to be really sure of your cam timing. You determine the lobe centers of each cam by reading maximum valve lift on the dial indicator and reading the degrees indicated on the degree wheel attached to the crankshaft.*

horsepower. On twin cam engines, if you retard the exhaust lobe timing or advance the intake lobe timing, you're decreasing lobe phasing and increasing overlap. Single cam engines are dependent on the cam grind for lobe phasing. On single cams, this is known as lobe separation, or lobe center spread. (See figure 5-11.)

Lobe Centerline

Lobe centerline is a reference point. Essentially, it describes, in crankshaft degrees, the difference between the point of maximum lift of the intake valve and the TDC on the compression stroke. You don't want maximum valve lift at TDC, not only because of potential piston-to-valve conflict, but also because the vacuum signal from the cylinder isn't its strongest at this point. You don't have to worry about that, though. The cam manufacturer grinds the cams with a specific amount of lobe centerline angle built in. When you install the cam at the manufacturer's lobe centerline spec, you're said to have installed it "straight up." Reduce the centerline angle, and you retard the cam timing; increase it, and you advance cam timing. (See figures 5-11 and 5-12.) Lobe centerline angle is a conventional number most engine tuners are familiar with and it is a convenient starting point when you install a cam. When installing a cam, you must "degree the cam."

How To Baseline Adjustable Cam Gears

You want to "degree" your cam(s) so you know where the valve timing events occur relative to the position of the piston and crankshaft. This is of great importance, as we'll see later when fine-tuning the cam timing. To do so you'll need a degree wheel, a piston stop, and a dial indicator, as well as some means to suspend the dial indicator over the cam so you can accurately measure valve lift.

The fist step is installing the cam and adjustable timing gears correctly. Follow the instructions in the factory manual or those that came with the cam gears. Next, attach the degree wheel to the crankshaft and rig up a pointer. You can use welding rod or a wire coat hanger for this purpose. Rotate the engine so the number one piston is at TDC on the compression stroke. Both valves should be closed. By referencing the timing marks on the crank pulley, you should be able to get very close. Verify by carefully inserting a probe stick through the sparkplug hole to gauge piston position or just look into the chamber. Adjust the pointer and the timing wheel to zero or TDC.

Next, rotate the crankshaft about 20 degrees opposite its normal direction of rotation. Install the piston stop so it just touches the piston. Continue to spin the engine (opposite the engine rotation) until the piston hits the piston stop. Mark that position on the degree wheel opposite the pointer. Spin the crankshaft in the opposite direction (normal engine rotation) until the piston hits the stop. Mark this position on the degree wheel as well. Remove the piston stop. Rotate the zero point or TDC of the degree wheel (**do not rotate the crankshaft**) to the degree exactly between the two marks you just made with the piston stop installed. This is TDC.

The next step is to set the cams "straight up," that is, cam timing is neither advanced nor retarded. When you buy an aftermarket cam, the manufacturer has tested it and has ground the cam lobes to be timed in a certain way. Typically, they use the intake lobe centerline as the reference point. So, for SOHC engines you just need to align the intake lobe centerline with the number one cylinder at the degree specified on the cam card. For DOHC engines you need to do the same for the exhaust—align the cam so max valve lift occurs as specified on the cam card. On VTEC cams, you should use the low-lift cam lobes. However, if you really want to know what your engine is doing you should "degree" the high-lift lobes as well.

To do this, attach the dial indicator head so that is in the same line as the valve. If there is a slight angle between the dial indicator's measuring rod and the valve stem centerline, your lift readings will be inaccurate. With overhead cam engines, max valve lift occurs when the valve stem is farthest away from the instrument. Therefore, you need to position the dial indicator so that it retains enough travel to register max lift.

To verify that the cam is adjusted "straight up" you need to rotate the engine until the dial indicator changes direction. This is max lift and you should set the dial indicator face to zero. Reverse the rotation of the engine until the dial indicator reads .100-inch. Now spin the engine in the normal direction until the indicator reads .050-inch. Record the degree wheel value. Rotate the engine in the normal direction until the dial indicator reads .050-inch on the closing side of the cam lobe. Record the degree value from the degree wheel. Add the numbers together and divide the sum by two. That will be the location in crankshaft degrees of maximum valve lift.s

You want the zero degree mark on your adjustable cam gears to place the cam lobe centerlines at the degree specified by the manufacturer. You may have to adjust the cam to achieve this but doing so will pay off big when you're tuning on the dyno or need to make changes at the dragstrip. In fact, it is a very good idea to verify the accuracy of all the timing marks using the procedure detailed above. If they are off slightly you can take notes or make your own markings.

How To Find Optimum Cam Timing

I think suspension tuning and cam choice and tuning are the most difficult areas of high performance to understand. Cam tuning is weird enough but if you have a custom combination, such as a stroked motor with an altered rod ratio, even an experienced tuner gets lost. The secret to cam tuning is to understand the four strokes of your engine and how the cam, by opening and closing the intake and exhaust valves in relation to these cycles, can be tuned to your combination. If you worked with a cam manufacturer while designing your combination, they should be able to help with the timing. If not, here's an easy way to begin the tuning process, courtesy of Rob Smith of RPS Performance Products.

There are several approaches to cam tuning, but the one that Rob prefers to start with is the exhaust valve timing. The reason to start here is because opening the exhaust valve ends the power stroke. Where you choose to end the power stroke, in crankshaft degrees, has great influence on where the intake valve opens, which actually begins the intake stroke. Each of these valve timing event's optimum timing may be slightly different than what is practical because of the timing of the preceding event. However, in deciding where to compromise you should give priority to the power stroke. The power stroke should be as long as possible, so wait to open the exhaust valve as late as possible.

The smartest way to begin the cam tuning process is to split the overlap between TDC.

You have to know the duration of the cams so you can calculate the overlap. This is usually on the cam card. If not, or you bought used, you can verify the duration with the same setup you just used to degree the cam. The only difference is as you rotate the engine, you mark the degree wheel at the point the dial indictor reads .050-inch, and keep rotating the crank in the same direction until the dial indicator reads .050-inch again and mark the degree wheel. The total degree traveled is the duration. (.050-inch valve lift is the American industry standard for measuring duration. Advertised duration is the theoretical total duration beginning when the valve leaves the seat and ends when it returns.)

Next, you have to decide on the *lobe phasing* for DOHC. (For SOHC the *lobe center separation angle* is built into the cam and can't be changed.) This is fairly easy because the range of what works for four-stroke engines is well known: The following are the ranges that experience has shown works, but check with the cam manufacturer to be sure.

Naturally aspirated Street combos: 106 - 110
Naturally aspirated Race combos: 98 - 105
Turbocharged and Supercharged: 108 - 114

These are the typical degree ranges for the lobe separation angles and lobe phasing. The concept of lobe center separation angle is more suited to SOHC since it has a single cam and the lobe centers are ground by the cam manufacturer and can't be changed. FYI: 110-degree lobe separation angle is equal to 220 crankshaft degrees.

On DOHC engines, the term lobe phasing is more apt. The lobes are phased to achieve equivalent timing as the lobe center separation angle, but since the cams are separate, each one must be timed separately. So you need to think in terms of lobe center timing for both intake and exhaust cams. See figures 5-13a and b.

To illustrate this concept let's time a set of Crower cams part number 62402. The cam specs are 230-degree duration on the intake and exhaust measured at 1 mm. This means that the cam holds the valve at least 1 mm above the seat for 230 crankshaft degrees. The valve lift reference point is a convenience because it is very difficult to determine exactly when the valve is lifted off the seat. This cam grind is for a street turbo, so we'll tune to the larger lobe phasing value of 114 degrees.

To find the duration of overlap, multiply the lobe phasing value by 2 and subtract it from the duration. For example 114 x 2 = 228. 230 duration – 228 = 2 degrees overlap. That's not a lot of overlap but then a turbocharged motor doesn't necessarily require a lot of overlap.

If you wanted to move the power band to a higher RPM range, decrease the lobe phasing. We can go with the following numbers to tune to the high RPM range of turbo combos: 108-degree lobe phasing. 108 x 2 = 216 degrees. 230 – 216 = 14 degrees overlap. More overlap improves high RPM mass flow. But be careful—this much overlap on a turbo motor will run poorly at low RPM, a supercharged engine will probably just pass a lot of unburned fuel through the engine.

Either way you need to split the overlap value between TDC to determine the lobe center timing for each of the cams. Assume each cam has half the overlap, so in the example above with 14 degrees of overlap, the intake and the exhaust cam each have 7 degrees. Since the lobe center is found at mid-point of the cam's duration, we can find it by dividing the duration value by two. Therefore, 230/2 = 115 degrees. Subtracting the overlap duration from the lobe center value will give us the "split overlap" lobe center timing: 115 – 7 = 108. Therefore, the split overlap timing should be lobe centerline at 108 degrees ATDC for the intake; and 108 degrees BTDC for the exhaust. It would be the easiest, at these timing values, if you put your adjustable cam gears at zero. But if they don't line up that way just mark them so you know where to go back to if you make changes the engine doesn't like.

So where to go from here? Chances are the engine will run reasonably well at this cam timing. Nevertheless, the

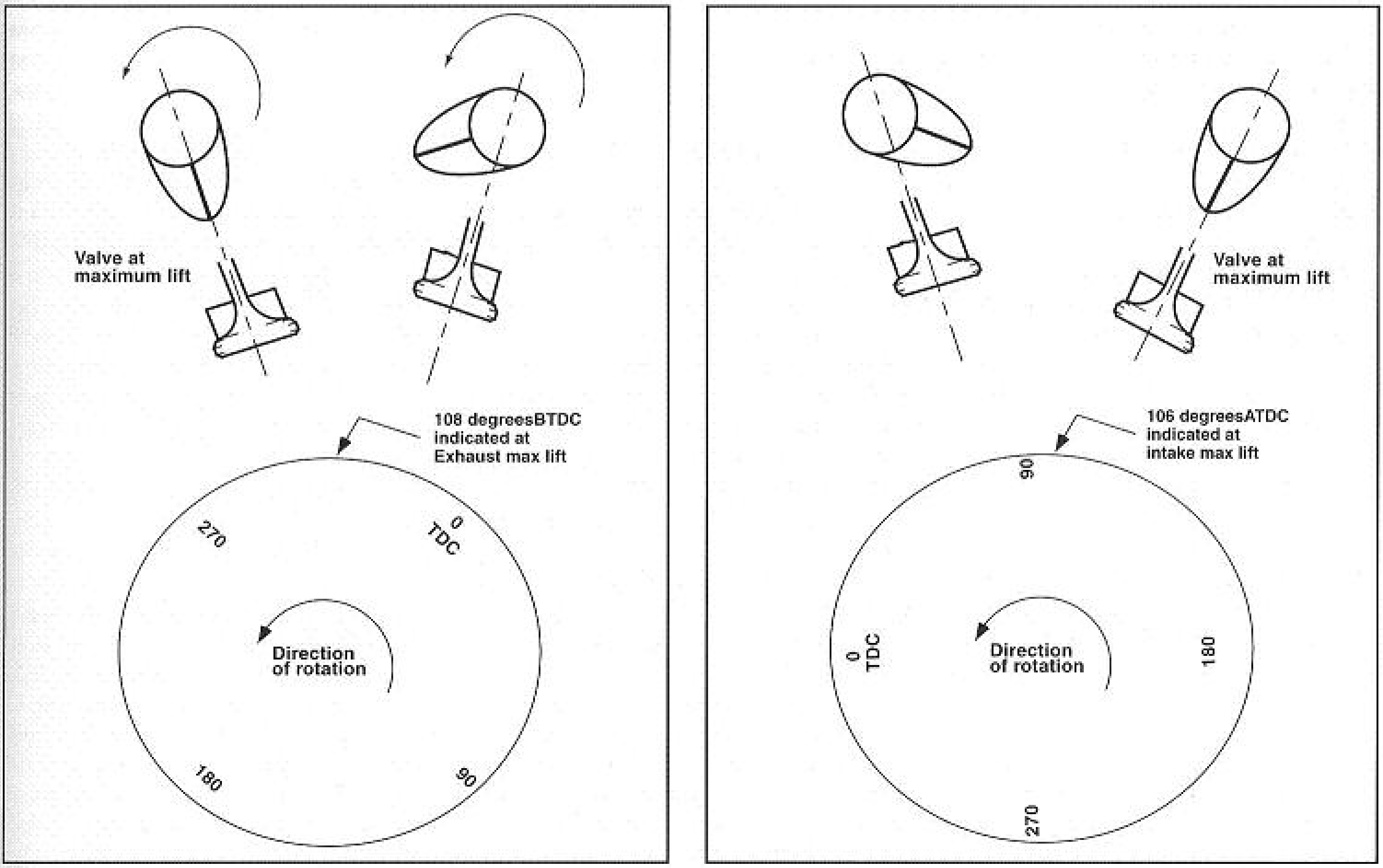
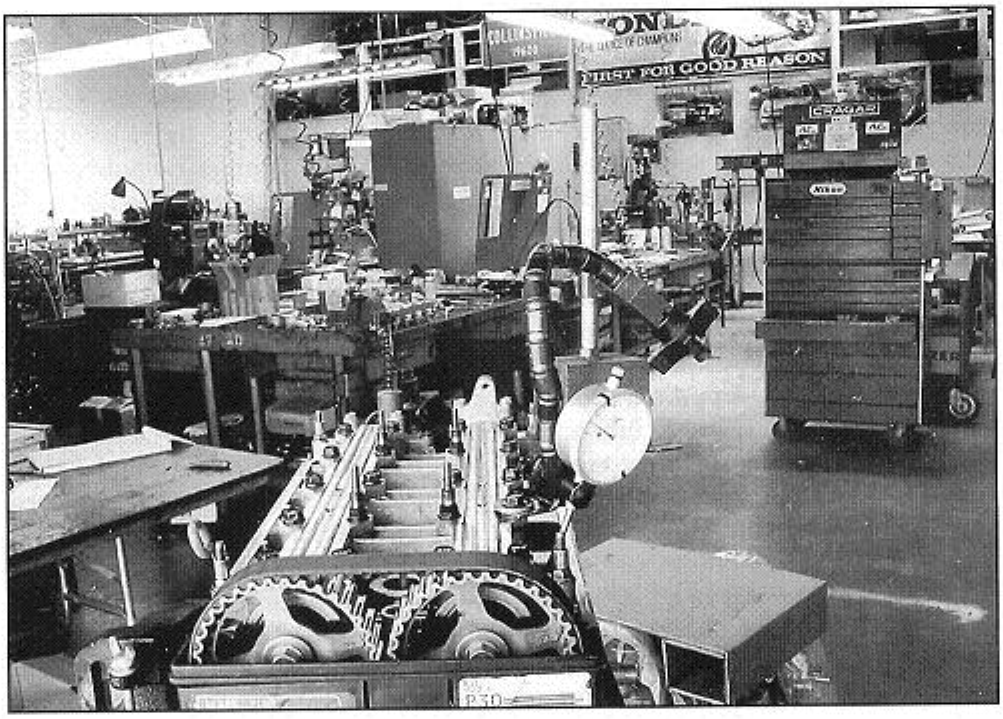


Figure 5-13a (left) and 5-13b (right): *On DOHC engine "lobe phase" is the term that describes the timing of the intake and exhaust cams. Its meaning is the same as "lobe separation angle" for SOHC or OHV cam engines. Because DOHC engines have separate exhaust and intake cams, the lobe separation angle is dependent on installation and adjustment. The valves interact between the exhaust and intake stroke, beginning with the exhaust stroke opening ending the power stroke. Most tuners use the lobe centerline at the crankshaft angle to time and adjust DOHC cam timing. The reference to lobe separation angle is useful since it is easier to visualize than lobe phase.*



Working with overhead cam engines means the max lift occurs when the valve travels farthest away from the dial indicator.

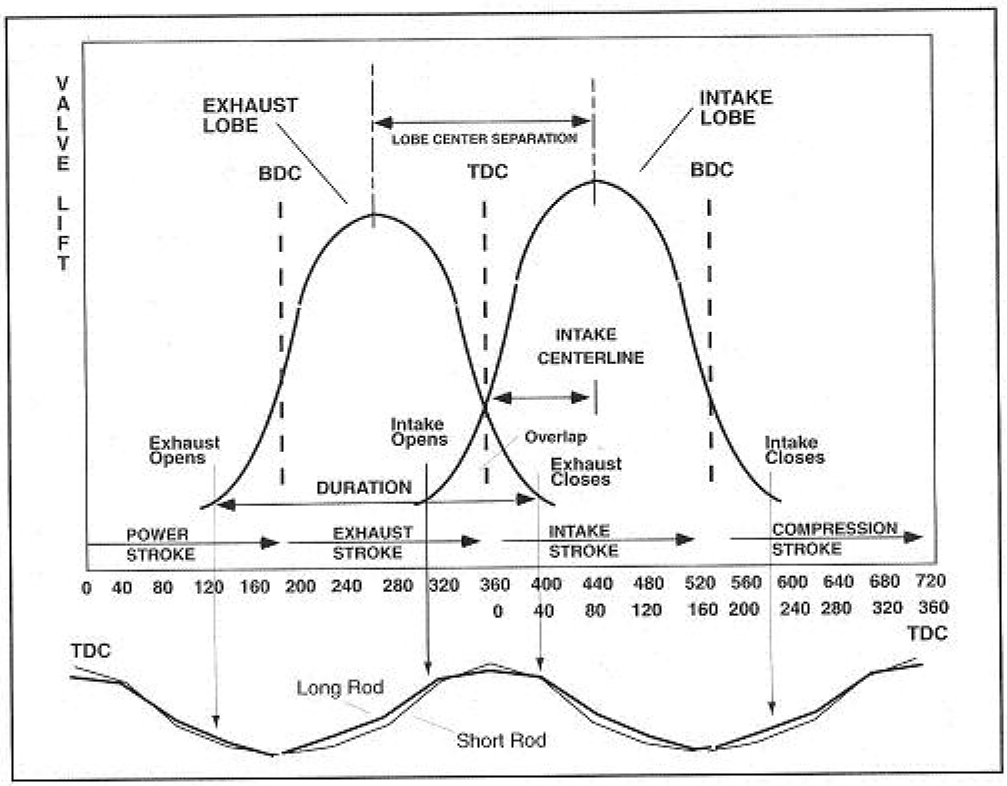


Figure 5-14: ***The tuning trick is timing the exhaust valve opening so that exhaust pressure helps evacuate the cylinder (blow down). This gives you the longest power stroke and the longest evacuation time in crankshaft degrees. This will change with a long or short rod combination. Short rod combos have a lot of piston travel between 4 and 6 o'clock; long rod combos don't move the piston as much in this range. Long rods let you open the exhaust valve earlier in the stroke without as much negative tradeoff, i.e. not using pressure and piston movement to push on the crank.***

performance enthusiast's question always is, is there more power available? Can we increase the combustion pressure of the power stroke by changing the cam timing? There may well be, but you won't know for sure unless you tune it. And instead of just twisting the cams randomly, you can determine what cam timing value to adjust if you know where the piston is in relation to cam timing.

While you have the degree wheel and the dial indicator on your engine, you can also map out the piston position curve in relation to crankshaft degrees. All you need is to rig up a measuring rod of sufficient length not to fall into the cylinder when the piston is at BDC. Use the rod to measure the piston travel per crankshaft degree. If you put it in a matrix and draw a trace, you'll see a curve. This map helps you decide on cam timing events.

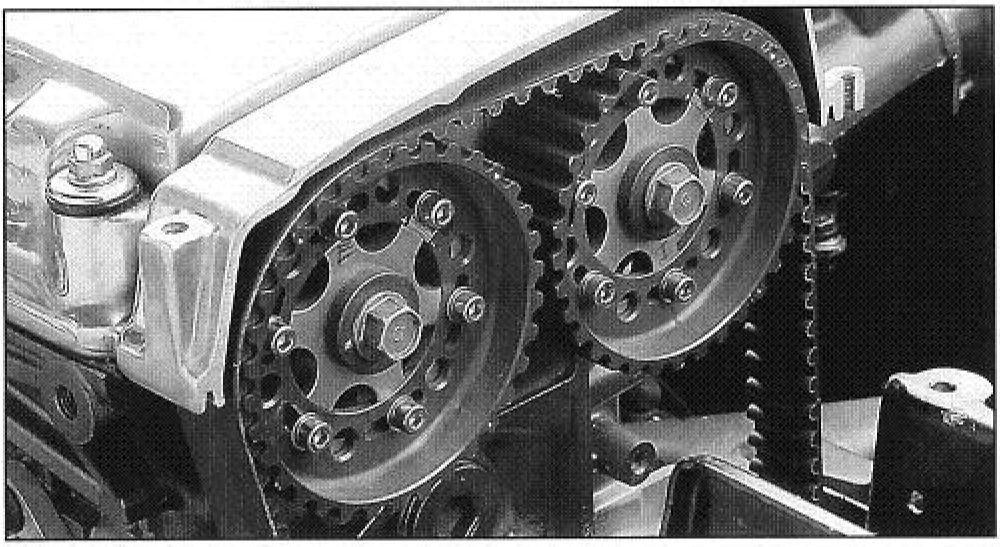
When deciding when to open the exhaust valve you want to choose the timing where the piston begins to slow, i.e. travels less distance per degree of crankshaft rotation. The exact timing will change according to camshaft design, rod ratio, and even fuel combination. However, if you know the piston travel curve relative to crank degrees you can make informed tuning choices. Figure 5-14 shows how a concept of how the piston travel curves will look for a long rod and short rod combination. We're assuming the stroke remains the same, so the rod to stroke ratio is larger with the long rod combination.

In the graphic, you can see that valve timing events occur in relation to the travel of the piston. The idea is to time the valve opening and closing events to optimize mass flow through the engine while providing the longest power stroke. When you open the valves is where the real magic happens. In general, most of the work of the power stroke occurs, to use a clock face analogy, from 1 to 5 o'clock. After that crank angle, combustion pressure is dropping rapidly and the angle of leverage is not advantageous, so why not open the exhaust valve?

One other important factor in deciding on timing the exhaust valve open event is the fuel and any power adders. Nitrous burns quickly; once the piston's half way down the bore most of the force is dissipated so you can open the exhaust valve early. In addition, nitrous generates more exhaust volume (20- to 40-percent more mass), so opening the valve early makes sense and usually more power.

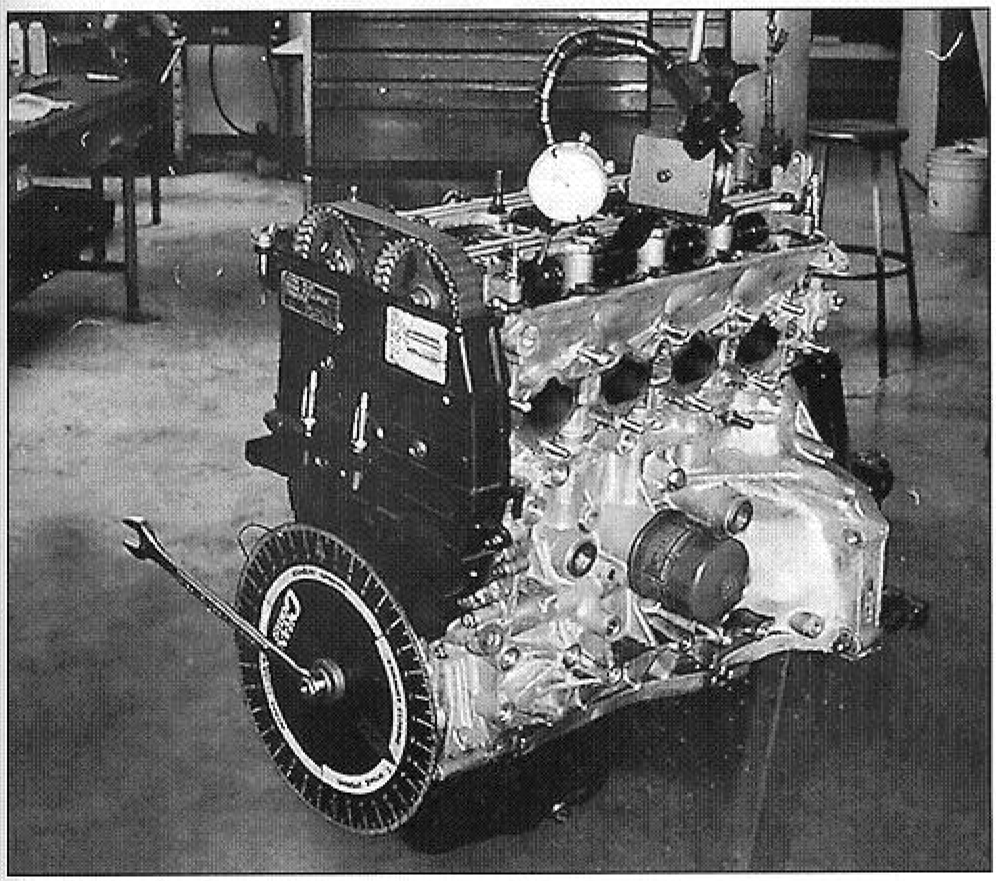
Methanol is a slow burning fuel that generates a longer power stroke, so you won't want to open the exhaust as soon as you would with nitrous. Methanol is tricky since, in addition to the slow burn, it generates a lot of mass. Therefore, you need to open the exhaust as late as you can, but when you do, open it fast and big to get as much duration as you can. When the aftermarket responds with roller cams for the Hondas, we'll be able to exploit the performance, the radical valve opening rates, and increased duration that technology provides.

The next most critical area is when the exhaust stroke blends with the intake stroke.



With adjustable timing gears on a DOHC engine, you get an almost endless range of tuning options. You can change the lobe center relationship and the timing of either intake or exhaust valve-timing events in relation to the crankshaft angle and piston travel. You can also make wrong choices and lose power or move the timing so far that the valves hit the pistons or you cause the valves to hit each other. This is a tuning area you need to approach with caution and good judgment. However, the pay off is worth the effort.

Timing of the intake/exhaust overlap events is sensitive to RPM. You want to close the back door so you don't waste fuel during scavenging; but late enough to clean the combustion chamber of residual end gas. Engine speed has a lot of influence on how this happens. Low engine speed provides lots of time for the air/fuel to get into the engine. At high RPM the valves are open such a short time, the volumetric efficiency of the engine falls to the floor along with power output. The upshot is that for a high RPM combination you want to increase the overlap, to increase the time that the cylinder can be scavenged and filled. Of course, this sacrifices low RPM power because of the effects of exhaust reversion into the intake tract. To avoid that, run less overlap timing.



Use a degree wheel and a dial indicator to determine max lift of intake valve at precise crankshaft degree. Use the stock lobe centerline angle of the del Sol 1.6 VTEC low-RPM cam with max valve lift at 107.5 crankshaft degrees ATDC. With the heads milled, max lift occurred at 110 degrees, or 3 degrees retarded.

We'll end the chapter with a recommendation for naturally aspirated engine combinations: For most naturally aspirated engines, the magic number from Dale Armstrong, Austin Coil, or Russ Collins seems to be 2 degrees advanced intake timing with split overlap. That usually works out to put the exhaust lobe center at 108 degrees and the intake at 106 degrees. With that bit of info, you should probably try that setting on your next trip to the dyno or the racetrack.