KELFORD CAMS
POWER UNLEASHED

HOW TO DEGREE YOUR CAMS

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motoiq

An engine works best when the right things happen at the right time. Say your spark fires before your pistons are in their right spots - you might embarrass yourself on the dyno. You might even end up with a scenic view of your bottom end. The relationship between an engine's crank and its cams is no different. The rise and fall of its pistons has to sync with the opening and closing of its valves, which happen to be controlled by its cams. This is even more important to pay attention to once aftermarket cams, adjustable cam gears or other mismatched components - each with their own tolerances - are introduced as well as once an engine's block or cylinder head have been resurfaced. Small tolerance changes or amounts of material removed will change the distance between the cams and the crank, which will alter their relationship with one another and affect cam timing. Even a new timing belt, timing chain, or tensioner can affect cam timing. All of this should be enough to make you want to degree your cams.

Cam degreeing - or "zeroing in" cam timing -is a good way to make sure that your cams are performing the way they ought to and that your piston-to-valve clearances are what you think they are. It's also a good way to make sure that your valves open and close at precisely the right time. The process positions a cam's centerline - in crankshaft degrees-exactly where the cam manufacturer says it should be. It's a process that should be done whenever aftermarket cams are swapped into place or any time the distance between the valves and pistons has changed - like when using a thicker or thinner headgasket or when a head's been milled - before firing it up. The consequences of not doing so are piston-to-valve contact or, at best, lost power.

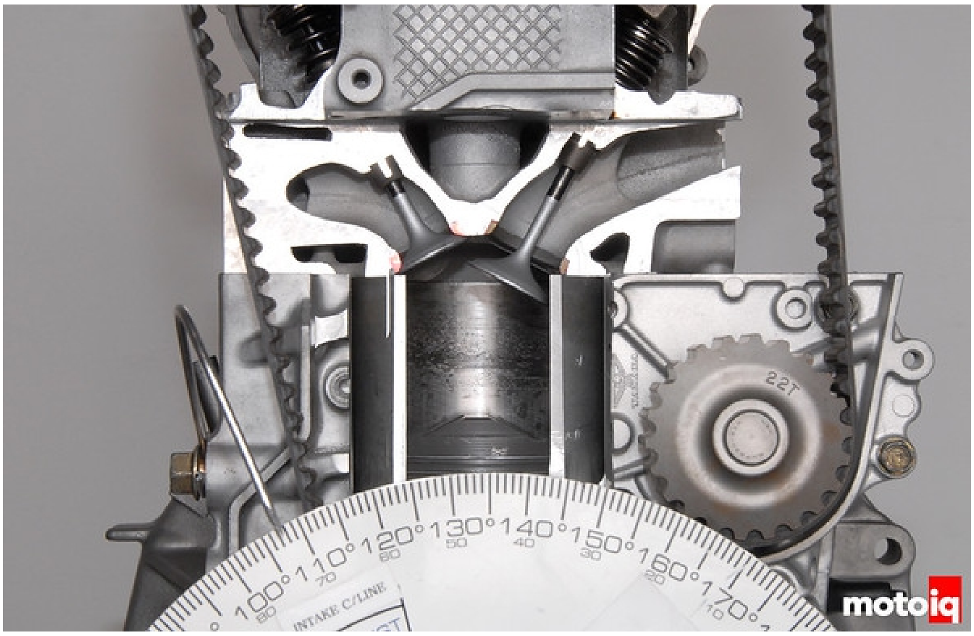
You'll need adjustable cam gears to do all of this as well as a degree wheel, a dial indicator, and some basic hand tools. But don't think that cam degreeing has anything to do with dialing in your adjustable cam gears to some magical, predetermined setting. Your cam gear manufacturer has no idea how many times your block's been surfaced, how much your head's been milled, or whose cams you've got. Neither does the kid on the innerwebs whose got "the same setup" and assures you that a couple of degrees of advance on your intake cam is exactly what you need. To be sure, cam degreeing is more than simply the twist of a couple of adjustable cam gears based off of where the cam gear maker says "0" is. Cam degreeing ensures that the cams are in their correct position. For your engine. Nobody else's. The guesswork's eliminated.

Cam degreeing is more than a twist of a couple of adjustable cam gears based off of where the cam gear maker says "0" is. The process ensures that a cam's centerline is in its correct position for your particular engine. If you've got aftermarket cams, cam degreeing is essential for optimum performance.

Before degreeing cams, though, you've got to understand some cam fundamentals to help better see why all of this needs to be done. A good grasp on the four-stroke process won't hurt either. Page 3

THE FOUR-STROKE PROCESS

The four-stroke cycle gets its name from its four piston stages: intake, compression, power, and exhaust. For every 720 degrees that the crank spins, each of the engine's pistons travels up and down twice. Meanwhile, the valves, carefully controlled by the cams, introduce air and fuel into the cylinders and let exhaust gases out. In the real world, the precise beginning and end of each cycle is pretty foggy because of cam profiles and all sorts of complicated physical and chemical constraints. Instead of 180-degree increments, an engine's valves typically remain open far longer in order to introduce enough air and release enough gas. Proper valve timing is critical to how well the four-stroke process works, and proper valve timing begins with cam degreeing.



Degreeing cams can be pretty confusing if you don't have a grasp of the four-stroke engine cycle. Proper valve timing is critical to how well the four-stroke process works, and proper valve timing begins with cam degreeing.

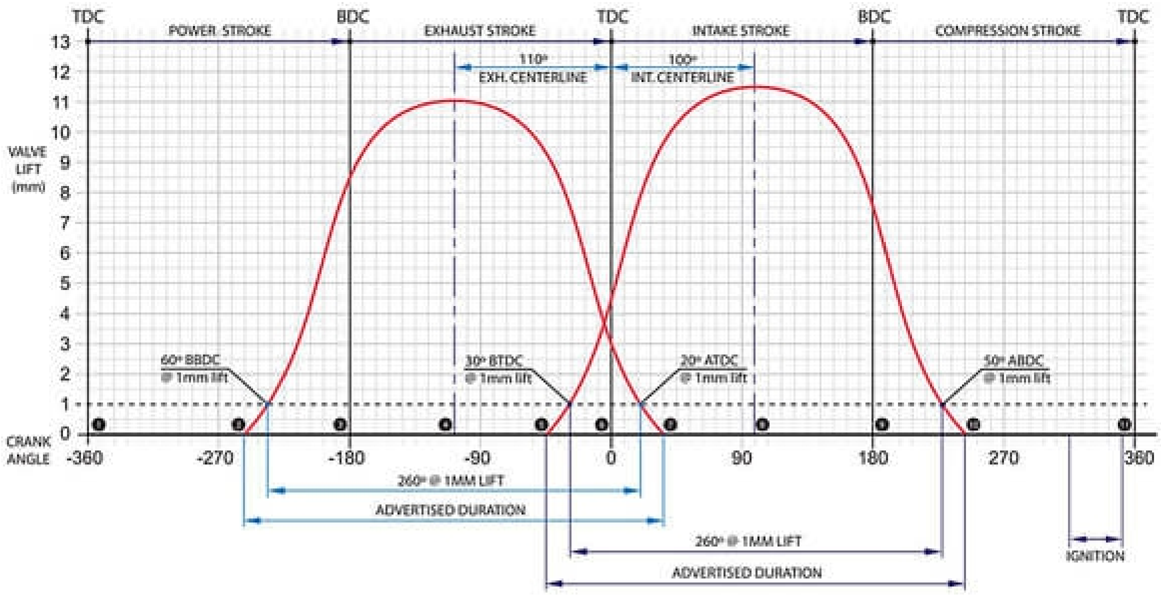
CAMSHAFTS

They look simple, but cams are some of the most complex parts of an engine. In simple terms, cams are long, cylindrical-shaped shafts containing several irregular-shaped lobes that convert rotary motion into reciprocating motion. They're driven by a belt or a chain, which links directly to the crank by a pulley. When spun (rotary motion), their lobes impart their eccentric shapes onto their corresponding rocker arm pads. Rocker arms actuate the cylinder head's valves (reciprocating motion) in an orchestrated fashion, relative to engine speed, and synchronize with the engine's piston movement at precisely the right time. Although, an engine's valvetrain is made up of all sorts of components, only the cams determine when the valves open, for how long, and when they'll close. As a result, an engine's cams dictate its power curve and at what point in the RPM range the engine will produce maximum horsepower and torque. If a cam isn't degreed, and therefore not positioned exactly where it needs to be, it'll never perform the way it should.

Cams may seem complicated, but their job is quite simple: to convert rotary motion into reciprocating motion. When spun (rotary motion), a cam's lobes impart their irregular, eccentric shapes onto their corresponding rocker arm pads, which actuate the cylinder head's valves (reciprocating motion). All of this has to synchronize with the engine's piston movement at precisely the right time, which makes cam degreeing even more important

CENTERLINE

A cam's centerline is the fixed point on its lobe that occurs exactly halfway between when the valve opens and when it closes. Locating a cam's centerline isn't as easy as it sounds, though, since peak lift doesn't last for just a single degree of crank rotation. All you've got to do is look at the shape of a cam lobe to see how difficult pinpointing its centerline can be. Cam degreeing is all about locating a cam's centerline and positioning it so that it occurs—in crankshaft degrees—exactly where the cam manufacturer says it should. If you've ever played with adjustable cam gears, then you've essentially done something similar, albeit somewhat arbitrary.



This cam diagram reveals the cams' relationship to the four-stroke cycle. The big red curves represent each cam's profile. As their centerlines are adjusted by the degreeing process, their curves may shift either left or right across the diagram.

LIFT

Cam lift is the maximum distance a valve opens away from its seat and is typically represented in inches or millimeters. Imagine a room full of people trying to exit through a single doorway. They can open the door wider (lift) or leave it open longer (duration). Either way, more people are gonna get through. To understand why you should care about lift, you've first got to understand the relationship the valves share with the cylinder head. Although valves are necessary for the engine's cyclical process, each valve's head (which is necessary for sealing against the valve seat) restricts airflow and must be moved as far away from its seat as practical to allow air to pass by. Increasing valve lift introduces more air and fuel into the combustion chamber and increases the rate at which exhaust gases may exit. Generally speaking, adding lift results in more power. However, the valves should also open and close as quickly as possible without causing valve float or damaged valve seats caused by excessive impact; the farther the valves open, the farther they've got to travel for each cycle. Cam degreeing doesn't affect how much lift will occur but it does determine when it happens.

DURATION

Increasing valve lift is an effective method for introducing more air into the cylinders, but holding the valves open longer (more degrees of crankshaft rotation) has a similar effect. Unlike lift, duration is measured in degrees of crankshaft rotation; it's the segment of the cycle that a particular valve is held open. You can't quantify duration in units of time, though, since at lower engine speeds the valves stay open longer than at higher engines speeds, despite equal durations. It makes sense then that adding duration holds the valves open longer - at any engine speed. Duration is fixed according to the cams but, like lift, cam degreeing determines when it begins and when it ends.

Lift and duration are independent values but do complement one another. Together they result in a cam's profile, otherwise referred to as its “rate of lift” or “ramp.” If a cam isn't degreed properly, its profile cannot fully be taken advantage of.

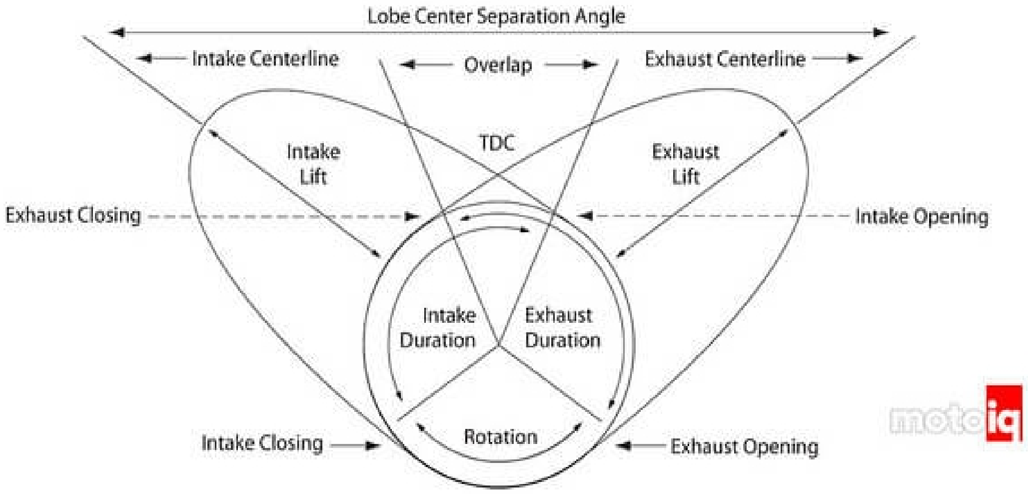
LOBE SEPARATION ANGLE

A cam's lobe separation angle is the angle measured in crankshaft degrees between its intake lobe centerline and its exhaust lobe centerline. Dual-overhead cam lobe separation angles can be manipulated with adjustable cam gears. This, combined with lift and duration values, will determine how much overlap there is. Cam degreeing not only locates the correct centerline but also allows the lobe separation angle to be realigned for optimum performance. Although trial and error on the dyno can lead to an ideal lobe separation angle, the risk of piston-to-valve contact is greater and the process can take significantly longer.

VALVE OVERLAP

The point at which both the intake and exhaust valves are opened simultaneously is known as overlap. Overlap generally occurs for a short period of time - when the intake valves are opening, the exhaust valves are closing, and that cylinder's piston is at TDC. Overlap might seem counterintuitive but the process helps draw exhaust gases out of the combustion chamber more efficiently. Also known as “scavenging,” the process can potentially increase horsepower by allowing for a more efficient cylinder fill by evacuating unusable gases more quickly. Too much overlap isn't always a good thing, though, and can draw the intake charge right into the exhaust, wasting both air and fuel.

Cam degreeing directly affects valve overlap and timing. Depending on which way the cam is adjusted during the degreeing process, overlap can increase or decrease as cam timing advances or retards. The important thing to remember is that, once degreed properly, valve overlap and timing are where the cam manufacturer says they should be. Small adjustments can then be made with the help of a dyno but, chances are, that might not be necessary.



The anatomy of the camshaft. This diagram reveals some of the fundamentals that you should understand before attempting to degree cams.

TOP DEAD CENTER

The piston reaches the top of its bore at TDC (top dead center). Although TDC is indeed a specific point, it's tricky to pinpoint since the piston can dwell at the top of its bore for several degrees. Dwell is simply a byproduct of the relationship between the crank and its rods. Other important reference points when degreeing cams include BTDC (before top dead center) and ATDC (after top dead center).

BOTTOM DEAD CENTER

The piston reaches the bottom of its bore at BDC (bottom dead center). Like TDC, BDC is also a specific point but can be just as difficult to locate because of piston dwell. Other important reference points when degreeing cams include BBDC (before bottom dead center) and ABDC (after bottom dead center).

Familiarize yourself with each these locations on the degree wheel before getting started.

Before moving on to the degreeing process, let's take a look at the intake cam we'll be using, which has a duration of 264 degrees. This particular cam begins to open its valves at 41 degrees BTDC, peaks at 98 degrees ATDC, and fully closes at 75 degrees ABDC. We won't need to concern ourselves with the cam's lift value in order to degree it.

WHAT YOU'LL NEED

1. You can't degree cams without a degree wheel. A degree wheel will reveal all sorts of information relating to valve timing events. Larger wheels typically yield more accurate results.

2. You'll also need a dial indicator with some sort of base that'll attach firmly to the cylinder head. If your dial indicator's got a magnetic base, bolt a scrap piece of steel to the cam caps and place it there.

3. Some sort of pointer, like a coat hanger or a stick of welding rod, along with a piston stop will also be necessary.

4. Your cam manufacturer should've provided you with a cam card. It's got all sorts of important information on it that you'll need to degree your cams.

5. Gather whatever hand tools you'll need to access your valvetrain, adjust your valves, and rotate your crank.

This simplified degree wheel doesn't have any more marks or information on it than necessary and is small enough to fit onto the edge of the crank with the engine still in the car. Numerically, this wheel is suitable for clockwise- or counter-clockwise-spinning engines.

Lets Start Doing It

There's more than one way to degree cams but the centerline method is the most common. There are even multiple ways to perform the centerline method. However, the following procedure is arguably the most common.

As explained, a cam may reach peak lift for several degrees of crankshaft rotation. Therefore, finding a cam's peak lift won't necessarily reveal its centerline. In order to find its centerline, you'll need to locate the exact midpoint between when a particular valve opens and when it closes. For dual-overhead cam engines, the procedure must be followed twice — once for the intake and once for the exhaust. Typically, measurements are taken on the number one cylinder's valves.

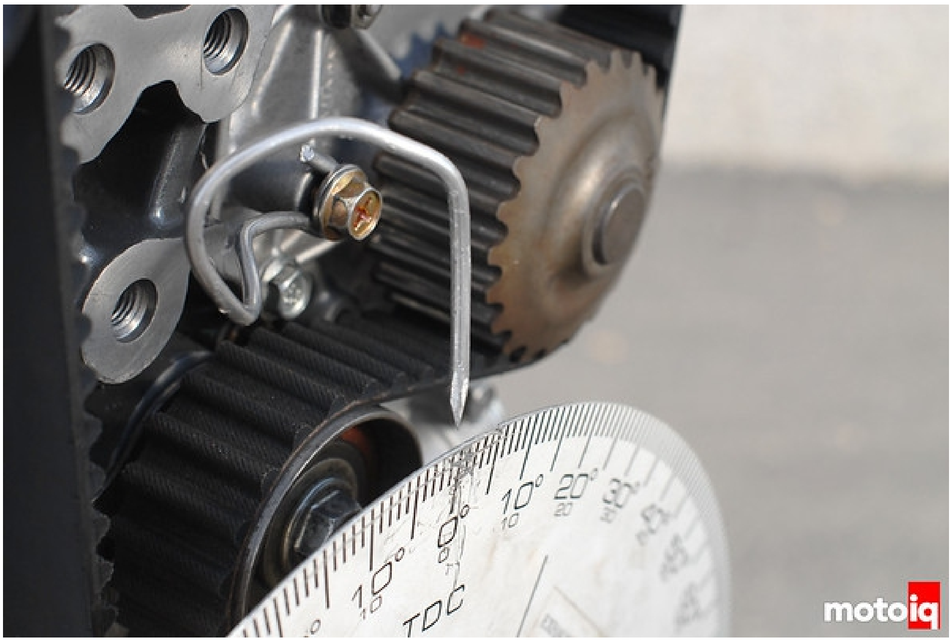
Step 1:

Begin by positioning the number one piston at TDC using the engine's and crank pulley's marks and fasten the degree wheel in front of the crank pulley with its TDC mark pointing up. Remove any covers or other accessories to allow the wheel to sit flat. All of this is easiest with the engine on a stand but can also be done anywhere so long as you can fit the degree wheel into place and still read it.

Most degree wheels are designed for clockwise-spinning engines. This degree wheel was relabeled to make cam degreeing counter-clockwise-spinning Honda engines a bit less painful.

Step 2:

Find a short piece of welding rod or a metal coat hanger, bend it into a “J” shape, and sharpen its long end to a point. Slide a bolt through its bent end and fasten it to the engine near the degree wheel. Bend the rod so that its sharpened end points toward the degree wheel's TDC mark.



A piece of aluminum welding rod bent and fastened to the block makes for a good reference pointer.

Step 3:

When degreeing cams, never rely on the engine's pulley, block, or timing belt/chain cover marks to pinpoint TDC. Variables like block height, inconsistent keyways, and piston dwell often make such methods inaccurate by as much as five degrees. Instead, use the piston-stop method to determine precisely when the piston's reached its absolute highest point as well as the middle of its dwell. Begin by rotating the crank approximately 15 degrees in its normal operating direction so that its number one piston is just past the approximate TDC location you found earlier. Thread a piston-stop into its spark plug hole until it touches the number one piston. If you don't have a piston stop, you can use a customized spark plug or fabricate your own piston stop out of anything rigid that threads into the spark plug hole and touches the piston just past TDC.

You can buy a fancy piston stop or make one out of an old spark plug and some spare hardware. Just about anything that'll thread into the spark plug hole and prevent the piston from reaching TDC will work.

Step 4:

Continue to rotate the crank in its normal direction of rotation until the piston contacts the piston stop and record the degree wheel value corresponding with the pointer. Rotate the engine in the opposite direction until the piston contacts the piston-stop again and record that value. If both figures are the same, you've lucked out and have already located TDC. Usually, though, those two numbers will be different. True TDC lies halfway between them. For example, say that you've first recorded 26 degrees BTDC and then 22 degrees ATDC. Add the two numbers together, divide the result by two, and you get 24. Next, reposition the pointer halfway between the two, which in this case is exactly 24 degrees apart from each previously recorded value. Be sure that the pointer is dead-on and don't disturb it. The math should appear as follows:

First Reading (26° BTDC) + Second Reading (22° ATDC) = 48°

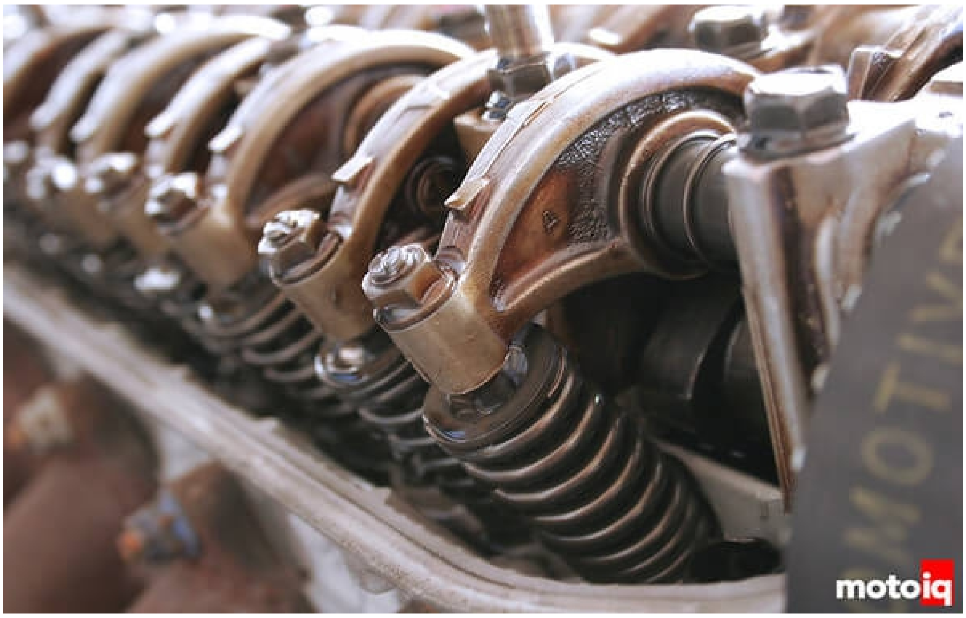
48° / 2 = 24°

Step 5:

Remove the piston stop and rotate the crank so that the pointer lines up with the degree wheel's TDC mark. You've now accurately located TDC and, chances are, it's not where your timing cover and crank pulley say it should be. If you're not sure that you did this step correctly or your wire or crank get bumped out of position, start over. The cam degreeing process is only as accurate as its initial TDC location.

Step 6:

In order to degree cams, you'll need to verify that the centerline of both the intake and the exhaust (intake only if SOHC) are where the cam manufacturer says they should be. Locate the intake lobe you'll be measuring and close its valve lash completely. Make sure that the valve is closed by confirming that the rocker pad is positioned on the cam's base circle, not its lobe. If you're degreeing an engine with variable valve timing like we are, be sure to measure from the appropriate lobe and activate variable valve timing if necessary.

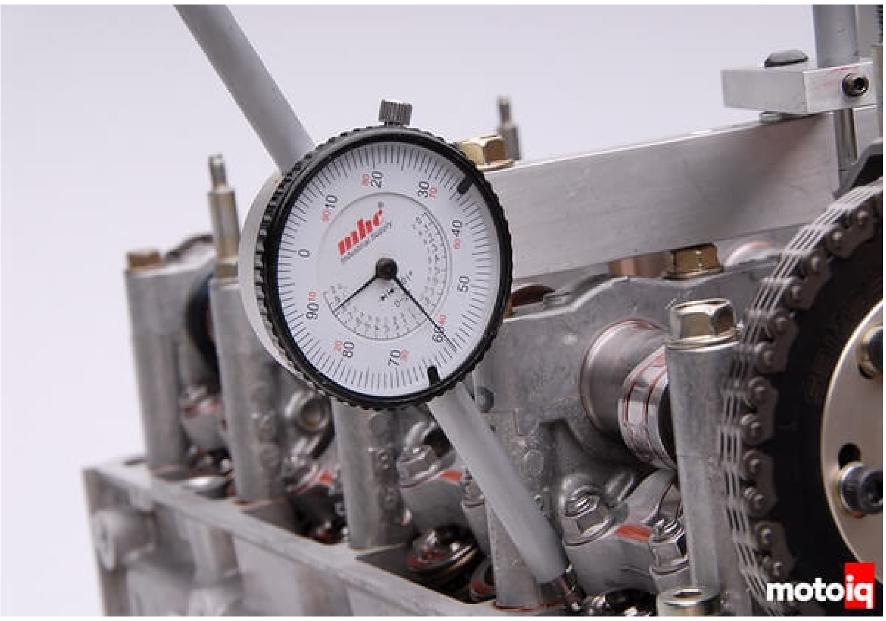


When degreeing cams, it's important to close the valve lash completely and take all measurements from the top of the retainer, not the rocker arm.

Step 7:

Fabricate some sort of base to securely mount the dial indicator to the cylinder head and place it near the number one cylinder's intake valves. Position the dial indicator's tip on top of one of the number one piston's intake valve retainers. Don't position its tip on the rocker arm otherwise the results will be distorted. In order to reduce geometrical errors, be sure that the dial indicator's needle remains parallel to the valve.

A fancy cam degreeing setup like this will allow you to verify TDC and check both intake and exhaust centerlines in one shot. A single dial indicator will yield the same results but will take a few minutes longer. (This particular setup also includes a dial indicator for locating TDC.)



It's important that the dial indicator's needle remains parallel to the valve. This is the only way to achieve an accurate reading.

Step 8:

Now is a good time to make sure that the dial indicator's needle is set up to display the appropriate amount of travel. If it isn't, be sure to add an extension or adjust it as necessary. In other words: be sure that the dial indicator doesn't max out before the valve has either fully opened or closed. Set the dial indicator so that it reads "0" and rotate the engine until its valve reaches full lift. Verify that the indicator still has additional travel.

Step 9:

Rotate the engine back to TDC in its normal operating direction, stop, and set the dial indicator so that it reads "0." Slowly rotate the crank once again in the same direction. Observe the dial indicator's reading as its respective valve begins to open. Keep rotating the crank in a smooth motion until you've reached exactly 0.050-inch of valve lift as read by the dial indicator. If you overshoot your mark while rotating the crank, continue for another full rotation until you've reached the .050-inch opening point. Record the value on the degree wheel corresponding with the pointer. This will typically occur BTDC.

Step 10:

Continue to rotate the engine in the same direction, this time stopping exactly 0.050-inch before the valve closes. Before you can find that value, though, you've first got to locate the point at which the valve fully closes. Think about it: you can't locate 0.050-inch before "X" if you don't know where "X" is. Continue to rotate the crank until the dial indicator reveals that the valve has closed. Be sure to stop as soon as the dial indicator reveals it's closed. If you overshoot your mark while rotating the crank, continue for another full rotation until you've reached the valve's precise initial closing point.

Step 11:

Once you've properly located the valve's closing point, reverse direction exactly 0.100-inch. You might be tempted to reverse the engine exactly 0.050-inch and record that value, but don't. An engine's tensioner will only synchronize its cams and crank appropriately when spinning forward, which means that any measurements taken when spinning backward will be inaccurate. Reversing its direction 0.100-inch (initial 0.050-inch + additional 0.050-inch) will give us an exact reference point and will make finding our next figure much easier. It'll also ensure accuracy since we'll once again change direction, rotating the crank 0.050-inch of valve movement, before arriving at our final reading.

Step 12:

Once you've arrived at the 0.100-inch mark, rotate the crank once again in its normal operating direction exactly 0.050-inch. As mentioned, this additional rotation in the correct direction will once again synch up the tensioner with its cams and crank. Record the value shown on the degree wheel. This will typically occur ABDC.

Note: both of these numbers—0.100-inch and 0.050-inch—are generally accepted values to use when degreeing cams. We could have just as easily used .030-inch, even .075-inch, so long as we used identical numbers after the valve opens and before it closes.

Step 13:

Take the two recorded values (open number and closed number), add them together, and add 180. The result is the cam's duration at 0.050-inch lift. Divide that figure by two. Next, subtract the opening value recorded at 0.050-inch of lift from this figure. The result is the current centerline. For example:

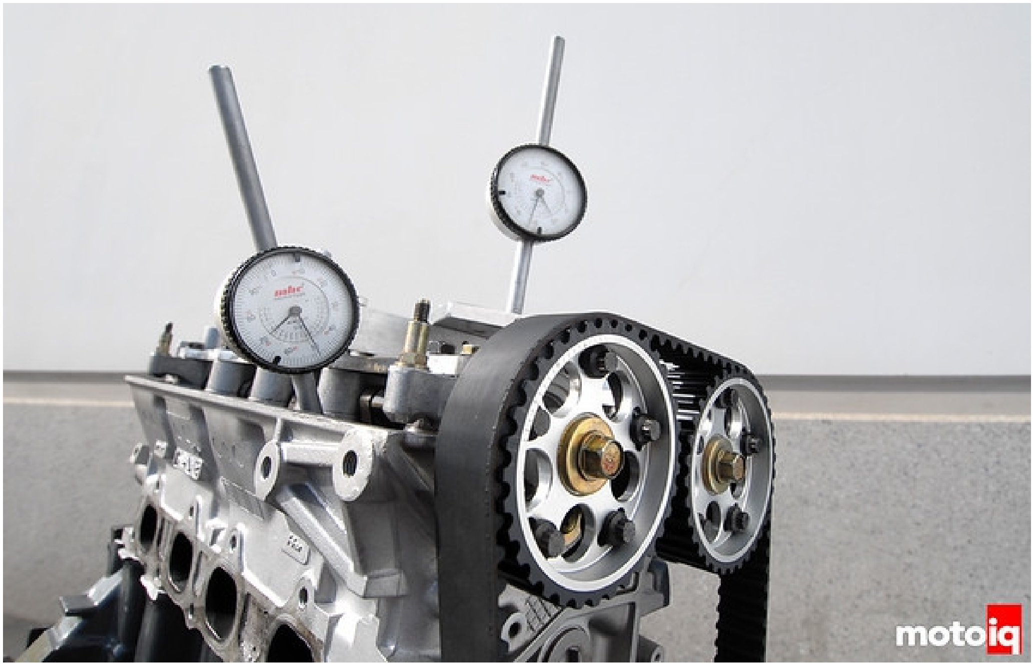
24° (open BTDC) + 52° (close ABDC) +180° (distance from TDC to BDC) = 256° (total duration at 0.050-inch lift) / 2 = 128°

128° – 24° = 104° centerline

Note: This formula applies only to engines with intake valves that open BTDC. Some engines feature low-overlap cams with intake valves that open ATDC.

Step 14:

To set your cam to your manufacturer's recommended centerline, note the difference between your current centerline and the manufacturer's centerline and adjust the cam appropriately. Loosen the adjustable cam gear bolts and rotate the cam in the appropriate direction to achieve the correct amount of advance or retard. For example, if you've recorded a 104-degree centerline on a cam that's supposed to have a 98-degree centerline, it's clear that there's a six-degree difference. Since an engine's cams spin at half the speed of the crank, the cam must be advanced three degrees, not six. If you've recorded a 96-degree centerline, the cam should be retarded one degree, which is equal to two degrees of crankshaft rotation.



To set your cam to your manufacturer's recommended centerline, record the difference between your current centerline and the manufacturer's centerline and adjust the cam appropriately, giving it the appropriate amount of advance or retard.

Step 15:

Tighten the adjustable cam gear bolts and repeat the process to ensure that you've achieved your cam's advertised centerline. If you haven't, start over.

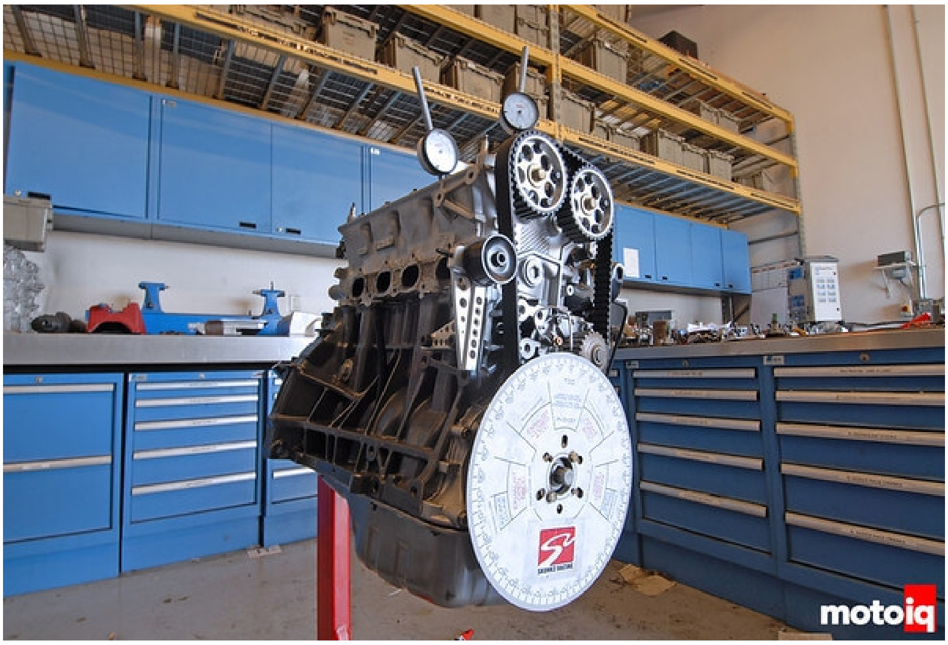
Step 16:

If you've made any sort of adjustments, be sure to re-mark your adjustable cam gears to reflect their new "0" reference points. For example, if you've retarded your intake cam two degrees, then "–2" degrees is your new "0."

Step 17:

Repeat the process for the exhaust cam using your cam card's exhaust centerline specifications. Although the math is the same, keep in mind that the exhaust valves open BBDC and close ATDC.

Note: This formula applies only to engines with exhaust valves that open BBDC. Some engines feature low-overlap cams with exhaust valves that open BTDC.



Most forced induction and high-output naturally aspirated engines will respond positively to small overlap adjustments, even after being degreed. Even so, cam degreeing allows for a sound baseline in terms of centerline position, essentially speeding up the tuning process.

Step 18:

Although degreeing ensures that your cam centerlines are in their recommended locations, that doesn't always mean that there isn't room for improvement. Most forced induction and high-output naturally aspirated engines will respond well to incremental overlap adjustments. Once degreed, and with the appropriate valve clearance information, more power can often be found with the help of a dyno.