Camshafts 101

The Inside Scoop on Camshaft Selection

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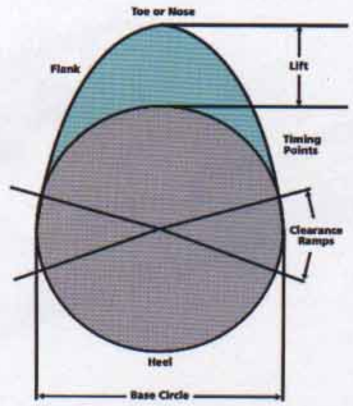
GENERALLY SPEAKING, LARGER DURATION CAMS WILL MAKE MORE TOP END HORSEPOWER AND LESS BOTTOM END POWER. THE LONGER YOU HOLD THE VALVES OPEN, THE MORE TIME THERE IS FOR THE AIR TO EITHER GO INTO OR OUT OF THE CYLINDER.

Jealous because your friend has a 300 degree stage V cam and yours is only a measly 280 duration stage II? Want a big cam for that crazy loopy idle and awesome top end pull? All these questions and misconceptions will be addressed. Turn off your stereo, give your girlfriend your credit card and tell her to go shopping; lock your door and tell everyone you need some alone time... Camshafts 101 is in session.

Camshafts are probably one of the most misunderstood components in building a high performance engine, yet they can adversely affect your peak horsepower and the engine's powerband. I know I've said this before, but 95 percent of us will be much happier and faster with an engine that produces a big fat powerband compared to a high RPM peaky horsepower engine. Having said this, let's have a close look at the bumpstick. The lobes or 'eccentrics' on the cam either act directly on the valve or have a follower that actuates the valve. The purpose of the camshaft lobe is to translate rotational motion into linear motion. This linear motion is the opening and closing of the valves. To correlate how a camshaft lobe opens a valve, closes a valve, and effects airflow through an engine, we need to know the basics of the Otto four-cycle engine.

Intake, the piston travels downward sucking in air and fuel through the open intake valves into the cylinder. **Compression**; the pistons travels upward compressing the air-fuel mixture (intake and exhaust valves are closed). **Combustion/ Power**; the air/fuel mixture is ignited causing a pressure spike pushing the piston down and turning our crank (intake and exhaust valves are closed). **Exhaust**; the piston travels upward expelling the exhaust gases through the open exhaust valves. This process takes two full revolutions of the crank and repeats itself. Notice, also, that during the four cycles (two crankshaft revolutions) the intake or exhaust valve only opens once, hence the reason the camshafts spins at half the speed of the crankshaft. From the above description it would seem that the valves instantly open and close at the top and bottom of the each cycle. This type of motion is impossible and that's why camshaft lobes have smooth rounded contours, otherwise they would be squares with sharp 90 degree transitions. The valves don't open and close at the exact top (top

Camshaft Lobe
The lobe of the camshaft is comprised of several components that work in unison but all have different functions.



dead center - TDC) and exact bottom (bottom dead center - BDC) either. We'll discuss this a little later. Knowing the basics of how the valves and piston rotation cycles control air into and out of the engine, we may now take a closer look at the camshaft and valve timing events.

There are four basic parts to the camshaft lobe: the heel, opening/closing ramps, opening/closing flanks, and the toe. Let's correlate the valve motion with the components of the camshaft lobe. Starting at the heel is where the valve remains closed & stationery (dwell). As the lobe spins, the opening ramp takes out the 'slack' and clearance in the valvetrain and starts to open the valve. The opening flank is where the highest velocity occurs plus where the valve is opening and on its way to full lift. Upon reaching the toe of the lobe, the valve slows down near full lift. On the closing flank the valve is returning to its closed position. The closing ramp slowly rests the valve back on its seat and prevents bouncing and excessive valve/seat wear. The basic parameters of a lobe design is how much the valves are opening (valve lift) and how long they are staying open (duration). When the engine is on its exhaust cycle and the piston is reaching the top, there is a period where the exhaust valve is still open and the intake valve starts to open. This third parameter is called overlap and is determined by the Lobe Separation Angle (LSA), which references the location of the intake cam lobe to the exhaust cam lobe. These three variables of a camshaft are what determine power output, emissions and drivability of an engine.

Camshaft duration and valve timing events (when valves open and close) are the most important variable in making horsepower. Duration is measured in crankshaft degrees and specifies how long the valve stays open. Unfortunately there is no adopted standard to compare cam durations! When the valve first starts to move off the seat or when it comes down back on the seat there is little linear valve motion and lift compared to the rotational motion of the cam. That's why if we measure duration the instant the cam comes off the valve seat and then comes back down on the seat we can get a high number like 310 degrees of duration. If we measure duration starting at .050" of valve lift, we'll see that duration now has been reduced to maybe only 270 crank degrees. So if we measure duration starting at different valve lifts we'll get different duration numbers. American cam manufacturers usually use .050" (some use .020"), and Japanese cam specs give duration at 1mm, which is .039" of lift. The same cam we used in the example above might be advertised by a Japanese company as having 285 degrees of duration.

So when your friend tells you his cam is a 290-degree duration cam, ask him at what valve lift, and when he gives you that blank stare, proceed to educate him.

Generally speaking, larger duration cams will make more top end horsepower and less bottom end power. The longer you hold the valves open, the more time there is for the air to either go into or out of the cylinder. The reason the power shifts in the RPM range when increasing duration is because the air is a fluid and when moving through an engine it has dynamic properties that increase cylinder filling (more air) at higher RPMs. To illustrate this principle we'll look at the intake stroke when the piston is moving down and when the intake valve is open. This valve-timing event, called intake valve closing, has the largest influence on horsepower in a naturally aspirated engine. When the piston reaches the bottom (BDC) we still want to keep the intake valve open even while the piston starts making its way back up. Air is rushing in to fill the vacuum created by the downward moving piston and this air is moving fast and with momentum. If we closed the intake valve at the very bottom of the piston stroke, we'd lose any extra air that was still coming in as a result of that momentum. Of course if the air is not moving very fast, for example at low engine RPMs, it has little momentum and we wouldn't want to keep the intake valve open because the upward moving piston might stop the flow of incoming air and actually start pushing it back out the intake valve. This is why longer duration cams that keep the intake valve open longer suffer low RPM horsepower and torque loss in exchange for high RPM power.

The second most important valve-timing event in a naturally aspirated engine is the opening of the exhaust valve. As the combustion process takes place, both the intake valve and exhaust valve are closed and the piston is being pushed downward by tremendous pressure. Even though it might seem that the best time to open the exhaust valve would be after the piston reaches the bottom of the combustion stroke, there is more power to be made by opening the valve earlier. Most of the combustion energy is used up well before the piston reaches the bottom of its stroke so the exhaust valve can be opened as early as 60-70 crank degrees before the piston reaches the very bottom (BDC). Opening the

exhaust valve this early gives the exhaust more time (duration) to go out the exhaust valve and also reduces the amount of power the piston consumes pushing exhaust gases out of the exhaust valve (pumping losses).

The last two valve timing events are intake valve opening and exhaust valve closing. These two timing events take place as the piston is reaching the top of its exhaust stroke and into the beginning of the intake stroke. Again common sense tells us to close the exhaust valve as the piston reaches the top of its exhaust stroke and then open the intake valve as the piston begins the downward motion of its intake stroke. If we wanted a glass smooth idle and good low RPM torque then this would be the answer, but for increased mid range and high RPM power we need some overlap. Overlap is measured in crank degrees and is defined by how many degrees both the exhaust and intake valve are open at the same time. Typically as the piston is approaching the top of its exhaust stroke the intake valve will start to open while the exhaust valve is still open. And then the exhaust valve will close a little bit after the piston crosses TDC and goes into the intake cycle. Generally more overlap helps high RPM power at the sacrifice of idle quality and low RPM torque. More overlap increases power at higher RPMs because the fast moving exhaust gases help to draw in the intake charge as the intake valve opens and gets the fresh intake charge moving into the cylinder as the piston goes into the intake cycle. Idle quality and low RPM power suffers because at these conditions airspeed is too low for the scavenging effect and some of the exhaust gas can make its way back up the intake valve and wind up hurting airflow through the engine.

Valve lift is important, as power increases with more lift, but there is a limit. A port will only flow only so much air no matter what the valve lift is. Opening a valve much beyond that lift limit won't increase horsepower and will only cause unnecessary wear on valve guides and valvetrain wear/noises.

SELECTING A CAMSHAFT

Let's say we built ourselves two 2.0L DOHC 4-cylinder engines; one for drag racing and one for the road course/street. The drag motor will spend most of its time in the 6,500-9,500rpm range while the street/track motor will see a much broader 3,500-7,500rpm range. The drag motor will have a short runner intake manifold, extensively ported head, higher compression, and an open exhaust. All these modifications raise the volumetric efficiency (how much air the engine can flow) and shift it higher in the RPM range. Since we're not concerned with idle or low RPM power, we can choose a more aggressive cam that favors higher RPM power. A cam like this would have high valve lift and long duration on the intake and exhaust side, for example, 11.5mm of total valve lift and 285 degrees of duration at an advertised 1mm of valve lift. This type of cam will typically have a lot of overlap and this can be found or calculated from a cam card supplied by the cam manufacturer.

An important thing to consider is that as we run higher static compression, we need to close the intake valve later to reduce effective compression. This is a little complicated to explain but let's just say that the dynamic compression, or the compression a real running engine sees, changes with RPM and with cam timing events! You never want to run a high compression piston with a short duration early intake valve closing cam as there will be a tendency for detonation and less power output at higher RPMs. A cam with too much duration and overlap would rob our drag engine of power across a majority of the powerband and maybe only increase horsepower slightly at 9,500rpm. In this instant either the engine has to be reworked to allow it to flow more air at the higher RPMs or to pick a less aggressive cam. Without extensive dyno or track testing, always choose the more conservative cam as this will likely make you faster at the track. Our street/track motor will have lower compression pistons, longer runner intake manifold, mild porting, and some sort of exhaust system. All these components lower the peak VE and shift it lower in the RPM range. With the correct cam this engine will make less power than the drag engine but will have more torque and a much wider powerband. This cam application will have shorter durations, lower lift (for increased valvetrain life), and less overlap.

With modern DOHC engines we have the flexibility of using adjustable cam gears and fine-tuning the power according to our needed powerband. As a general rule of thumb, retarding both cams will give us more high RPM power, and advancing the cams will increase lower RPM power and torque. Retarding the cams closes the intake valve later giving us more cylinder filling at high revs when the intake airspeed is high. Advancing the cams closes the intake valve earlier giving us a higher dynamic compression at lower engine speeds and increases torque. Adjusting the intake cam independently to the exhaust cam will change the overlap period and ultimately change the power curve. As a final note on cam selection, turbocharged engines prefer milder cams than naturally aspirated engines. Take small steps with turbo cams and be very careful with aggressive cams as they can make a turbo car almost un-driveable.

All this information might seem overwhelming and complex, and that's because it is! Cam timing is a difficult concept and to accurately compare cams we must use a dynamometer or advanced engine simulation software to get reliable results. If neither of these tools are available, the best advice I can give is to research what camshafts reputable sources are running for your application. From there, use your newfound knowledge to compare similar cams and tailor them to your needs. This process might take a few cam swaps and trips to the dyno or track, but in the end you'll have a car that is faster and more driveable.