fasttech

ON CAM

This month Stu reveals the lowdown on what to look out for when uprating your cams to make the most of your engine's performance.

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The valve size will greatly affect the choice of cam for your engine

Cam lobes differ in width and height for different applications

ONE of the jobs I did at Motorsport Developments this week had me advising a chap about how to progress further with his engine.

One of the many things I told him was that he was now in a position to benefit from a set of camshafts. I explained the cams would enable us to run a little less boost and make a little more power whilst expanding his rev range a few hundred rpm too.

It was around this point in the conversation that he asked me, "What exactly is a camshaft?", not to mention, "What is it for?", and, "How do the different types make the car faster and in what way?".

So, I figured it was time I wrote a full and in-depth article on cams, how they work and what they can do, but be warned, it's a very complex subject so you may need to read it a few times to let it all sink in. OK? Good. Let's — as always — go back to basics.

VALVES

A four-stroke petrol engine works on the suck, squeeze, bang, blow theory (see the last issue if you don't understand that part), and all of these different modes of operation are both differentiated between and controlled by, the inlet and exhaust valves.

Most engines in use today have four valves per cylinder — two inlets and two exhausts — but there are exceptions to this rule.

The four-stroke engine operates as follows: on the induction stroke (suck), our inlet valves (or valve) are open and the exhaust valves are shut, the piston is travelling downwards at speed, creating a depression at the inlet valves, thus drawing in the awaiting mixture or air and fuel at a great speed.

The valves then close, trapping the fuel and air mixture inside the now-sealed cylinder just as the piston has past the bottom of its stroke. The piston, that is now travelling upwards towards the cylinder head again, starts to compress the mixture of fuel and air that it previously induced (squeeze).

Once the mixture is compressed as hard as it can be and then ignited by the spark from the spark plug (bang), the piston is forced downwards by the expanding and burning fuel mix and the power stroke is thus developed which turns the crankshaft for us.

All the valves still stay firmly closed so that all the energy from the burning and rapidly expanding mixture is acting to propel the piston down the bore. Once it reaches the bottom and starts its journey back upwards, another set of valves opens. This time it is our

Valve springs play a critical part in the valve operation exhaust valves, and all the waste gas from combustion is pushed out of the cylinder and into the awaiting exhaust pipe (blow), thus completing the four-stroke engine's cycle and we begin again back at the start. This, of course, all happens very, very fast.

VALVE OPERATION

Why did I tell you all this? Well, I have explained all this so that you understand the importance of the inlet and exhaust valves. Great I hear you say, but what about the camshafts? This feature isn't supposed to be about valves... Ah, but when we are talking about the inlet and exhaust valves and their timing, we are indeed also talking about camshafts, as that is their only role in our engine — they are there to operate the valves for us.

They operate in a very simple manner: each camshaft has enough lobes on it (another name for a lobe is a cam, hence the name, camshaft) to operate the number of valves it controls and these lobes push against the valves to open them as the camshaft rotates.

Springs on the valves return them to their closed position when the lobe heads away from the valve. It is these lobes and their designed shape that control not only the actual timing of the valves, but also the amount the valve is lifted off its seat as well as the amount of time they are actually held open for.

All these things, of course, determine just how much fuel and air mixture gets into the cylinder, how much exhaust gas leaves the cylinder, and how well the combustion chamber is sealed during the compression and ignition of that mixture, not to mention where peak torque and power will be produced... So, as you may now appreciate, the camshafts really are incredibly important and can make or break an engine's performance.

UNDER PRESSURE

In an ideal world, the intake valves would open and the mixture would flow in until the point was reached where the pressure inside the cylinder was equal to the pressure in the intake system. The valves would then all close perfectly and remain that way during compression and ignition, and when all energy has finally been released from the burning mixture the exhaust valves would open and let all the exhaust gasses out of the cylinder. A perfect four-stroke cycle would have been performed.

Unfortunately, this is far from the way things happen in the real world due to various compromises that have to be made to suit the fact our engine operates at multiple speeds and under constantly varying loads. All the compromises that the designers have to make to our valve train timing and operation are put into action by careful camshaft design.

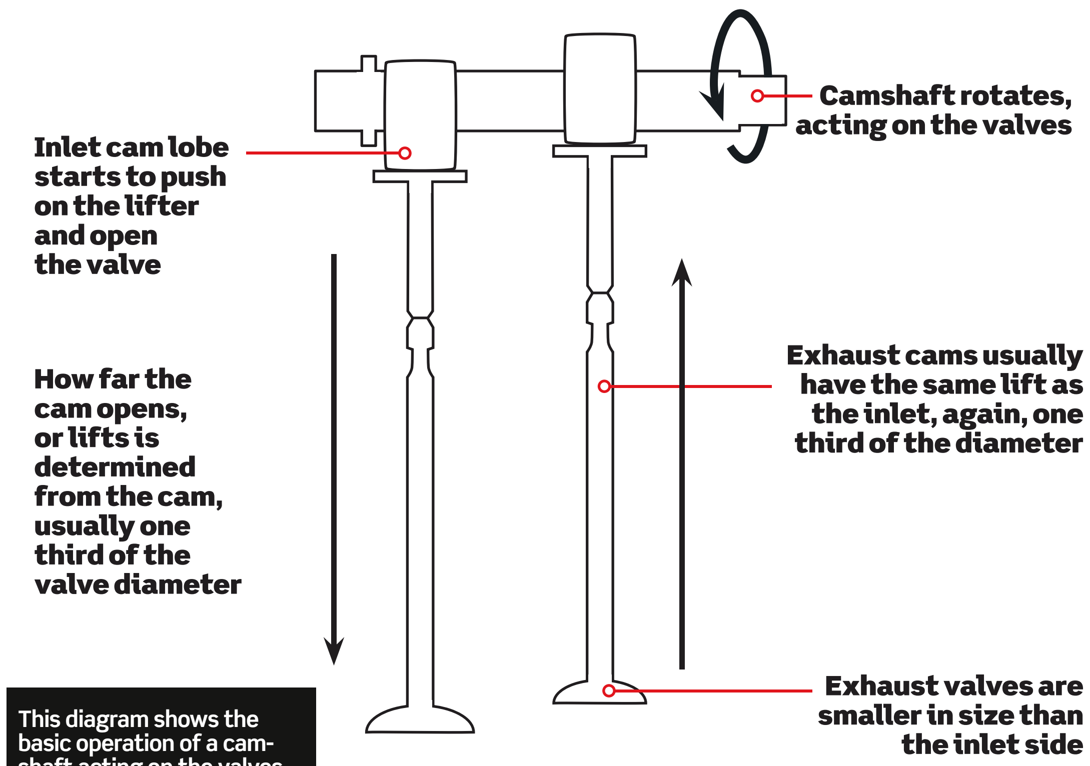
Double valve springs are used on high power motors

GROUND CONTROL

So how do the camshafts work? In a nutshell, the camshaft is literally a shaft made of metal with various cams ground upon it. How many cams are ground upon it depends on how many valves that particular camshaft will operate, so in a single overhead cam engine with eight valves, this shaft will have eight cams ground into it. Another more popular term for the cams is a lobe, so from here on in we will call them cam lobes.

The camshafts are connected to the crankshaft, normally by a toothed belt or chain and geared in such a way that for every two revolutions of the crankshaft we get only one revolution of the camshaft. This allows our engine to produce its four independent strokes or cycles.

Directly underneath the camshaft lobes are found the items that press down on the valves... These will normally be either rockers, in a single overhead camshaft design, or cam followers in a double overhead camshaft design. Incidentally, the followers can be either solid or hydraulic in operation too, but that's not really of any relevance at this point.



This diagram shows the basic operation of a camshaft acting on the valves

WORK IN PROGRESS

Now, to look at how things work in the real world, let's start our engine and run it at a really slow speed — around 1000 rpm (a figure close to the idling speed of most engines and a nice easy number to work with).

As previously mentioned, in an ideal and theoretical world, we would be able to open the inlet valve right at the top of our intake stroke and then close it again right at the bottom before the piston changed direction and tried to push our new mixture backwards out of the inlet valve.

After the power stroke had been produced we would have the exhaust valve open right at the bottom of the stroke and stay open until we reached the top and had pushed out maximum exhaust gas before we opened the inlet again to restart the cycle — and at idle speed that would work reasonably well, in as much as it would probably at least idle OK. If we tried to run high revs the engine would become very inefficient...

So what changes with increased engine speed? Let us jump forward to 4000 rpm, where most turbocharged production engines will make their peak torque and see what's different there.

When we run an engine at 4000 rpm, we have to understand that our intake and exhaust valves are operating at 2000 times per minute — that's 33 times per second. Take a second to think about that figure. That truly is a staggering speed! It goes without saying that the air is obviously travelling at an equally staggering speed, otherwise our engine wouldn't work, and this is where the problems begin in camshaft timing and design.

AIR IN

As the intake valve opens, our air starts to accelerate into the awaiting cylinder due to the piston travelling down the bore and leaving a slight depression in its wake (turbocharged cars of course will be having the air forced in as opposed to drawn in by the depression).

Imagine we hit the bottom of the stroke and slammed the valve shut trapping all that air in ready for the compression stroke. It will work, but it's a waste. Why? Well, this is where the inlet lobe design gets complicated.

That very high velocity air will not simply be stopped dead by a piston changing direction as you may initially imagine. Instead, as the piston heads up the bore again it creates a ram effect whereby the high velocity air continues to ram itself into the cylinder even though the piston is heading the wrong way.

The faster the engine goes, the more this phenomena has a positive affect on cylinder filling due to the higher air speed, so we want to have this inlet valve open for longer and later at higher speeds than we do at lower speeds to get the benefit.

Remember, at low speeds the ram effect is not strong enough and you will normally find that your rising piston will literally push the mixture back out of the intake valve before its closed, thus dropping efficiency and losing power due to having less mixture in the cylinders than normal.

These are hydraulic lifters; solid, or mechanical lifters as they are known are essential for high-revving engines

This particular phenomenon is known as the ram effect and is the timing attribute that can often have the greatest impact on your engine's performance. Let's now take a closer look at the exhaust valve and its role in our engine shall we?

Cams are driven off the crankshaft — usually by a belt or chain

POWER STROKE

As the piston heads down the bore on our power stroke we could hit the bottom of the stroke and open the exhaust valve at the same time as we start back up the bore, pushing the spent gasses out.

That will work in the same way you'd expect it to, but again, it would only be efficient at low engine speeds. Why? This is where exhaust cam design gets complicated.

During our power stroke, we have a pressure from combustion above the piston forcing it downwards. Due to this pressure we must always open our exhaust valve before we get to the very bottom of the cylinder, otherwise, when the piston starts back upwards we are going to find that pressure changes from being a help to being a hindrance to our vertical movement.

Overcoming this pressure as we travel up the bore will drop our engines efficiency quite a lot for obvious reasons. The solution is relatively simple; we open the valve before we get to the bottom and thus vent the majority of the pressure out of the cylinder allowing us a fresh and easy run up the bore with minimal resistance from pressurised gas. The term used to describe this event is blow down.

As with the intake valve, high revs need this event to start sooner, and again setting this way will hurt low rpm power as we tend to waste some of the compression stroke by opening the exhaust too soon.

ENGINE SPEED

As you can now hopefully appreciate, a fixed camshaft design like this can only ever work 100 per cent efficiently at one engine speed.

Any engine speed either side of this figure will be a compromise of one form or another.

CAMSHAFT TERMINOLOGY

Let's take a look at the various different aspects of camshaft design, starting with the commonly-used terminology within the camshaft industry, and what exactly it all means.

LIFT

First of all we have lift. Everyone's heard of a high-lift cam, but what does it mean?

Lift is basically referring to how high the camshaft lifts the valve off its seat. It is as simple as that. So if, for example, your standard camshaft lifts the valve off its seat by 8 mm, it is said to have 8 mm of lift. You would expect a performance cam for the same engine to have maybe 9 or 10 mm of lift to open the valve further, thus the term high-lift cam.

If a valve is not lifted off its seat high enough it will present a restriction to the incoming fuel and air mixture, although it has to be noted there is a point of diminishing return with valve lift, and that point is normally around a quarter of the valve's actual diameter. As an example, let's say that a 40 mm inlet valve will not normally flow much more after it has been opened by 10 mm.

DURATION

Most likely, the next most common term you will hear bandied about is duration.

While lift referred to how high a valve was lifted, duration is actually the amount of degrees of crankshaft rotation that the valve is lifted off its seat, and thus open. As an example, a 285 duration cam will hold its valve open for 285 degrees of crankshaft rotation.

Interestingly, extra duration can be good for high rpm but bad for low, so beware when looking at more duration, especially if you have any low speed problems now, such as bad or lumpy idle. Extra duration gives the air fuel mix more time to get into the cylinder, and at very high speeds this is a good thing as we need all we can get, but at very low speeds, we can have problems with the valves being open at very poor times.

The duration of a cam is often used in the cam's marketed name. For example, a cam named '285' will often have 285 degrees of duration. It's worth noting, too, that more duration normally leads to more...

OVERLAP

As the engine runs through its four strokes, there is a period when both the intake and the exhaust valves are actually open at exactly the same time, and this is known as the overlap period. On virtually every engine the inlet valve will be timed to open before the piston reaches top dead centre (TDC) on its exhaust stroke. Conversely, the exhaust valve is timed to close just after the piston starts its downward run on the intake stroke.

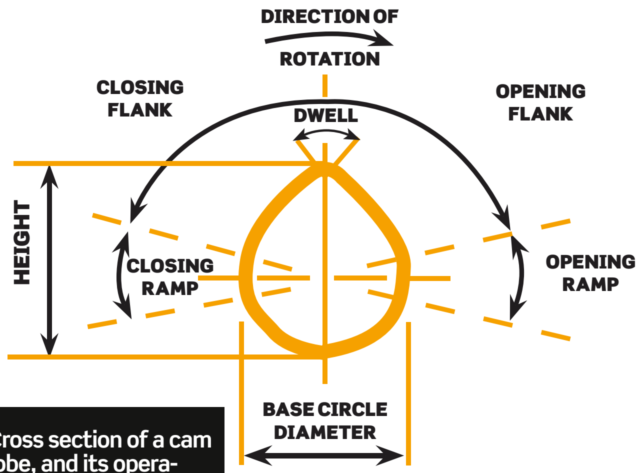
The point of having overlap is complex, but in a nutshell, the exhaust gas which is already flowing down the exhaust pipe will normally create a depression that can lead to a siphoning effect where the mixture heading into the inlet valve is drawn in at higher speed by the gases exiting the other side — a little like a slipstream effect.

It's worth noting that this very rarely happens on a turbocharged car due to the fact that a turbocharger is a large restriction in the exhaust and there is normally a pressure present at the turbine inlet. As with duration, excessive overlap normally harms the engine's low speed performance and efficiency.

RAMP

The ramp is the part of the camshaft lobe that initially contacts the cam follower/valve assembly and starts to lift it off its seat (after taking up any clearance in a non-hydraulic installation). It also has the purpose, after opening the valve, of then closing it again in, ideally, a gentle manner.

Hydraulic and solid follower ramps are different due to the fact a hydraulic follower is always in contact with the cam and thus will receive no shock from a steep ramp upon initial contact.



Cross section of a cam lobe, and its operational characteristics

FLANK

This is the area of the lobe that extends up to the nose. This part determines the acceleration of the valve whilst its length determines the lift. It is arguably the most important part of the camshaft itself.

LOBE SEPARATION ANGLE

Separation is a term not used in day-to-day camshaft chat, but it is an important figure to understand as it refers to the spacing between the intake and exhaust lobes when in a single camshaft configuration (such as a CVH).

For example, if the manufacturer quotes a separation angle of 115 degrees, that means the intake and exhaust lobes of the camshaft are spaced 115 degrees apart. Obviously, a twin-cam engine that operates inlet and exhaust valves with individual camshafts will not normally have this figure quoted in its camshaft specification.

It's also worth remembering that the actual figure quoted as a separation angle is in camshaft degrees, not crankshaft degrees as most other camshaft timing figures are quoted.

DWELL

When the valve reaches full lift at the very nose of the cam, it stops moving for a small period of time before it starts to close again. This area of non movement is known as the dwell area. This is important to ascertain when timing a cam as the true full-lift point is the midway point of this dwell area.

HEIGHT

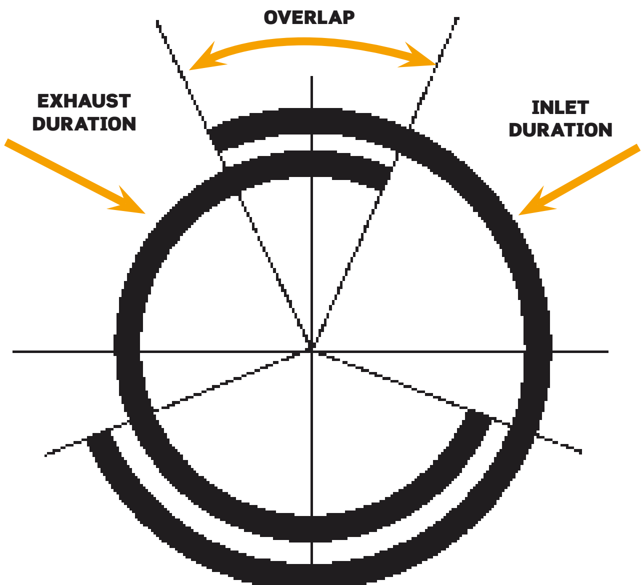
The height of the cam lobe is the measurement from the top of the ramp to the bottom of the base circle itself, measured directly through the centre of the cam lobe.

BASE CIRCLE

The base circle is calculated by measuring the overall height of the lobe from top to bottom and then subtracting the valve lift for that particular camshaft specification.

ASYMMETRICAL

This means that the lobe is not identical on both sides. Normally the opening side of the lobe is far more aggressive than the closing side. This helps to get the valve open faster, but close it more gently.



A camshaft lobe has various different modes of operation that happen in sequence as it rotates — as shown above

NEXT MONTH

Cam timing: how it affects power output, plus how to decipher those timing figures