by Kevin Cameron

Cam timing is not identical with the meaning of life, but to hear people talk about it you might think it was close. Actually, cam timing is a purely technical matter, and is based upon ordinary discoverable physical phenomena. It can be understood!

The first question to be tackled is total cam duration. This choice depends upon the engine's intended use, as you can see from the language used in cam-grinders' brochures. Some decoding is in order.

The first part of the decoding has to do with reducing BIG NUMBERS to something that actually means something. We Americans like big numbers, and cam-grinders oblige by adding in the duration of their clearance ramps to make cam profiles look longer. The clearance ramp is a zone of very low lift rate, intended to take up valve clearance gently before the cam begins to seriously accelerate the valve up off its seat. On the closing side, the ramp takes care of putting the valve back on its seat at a velocity low enough that the valve will not (a) bounce a lot (they do bounce on seating) or (b) hammer the seat or cup the valve.

Since these clearance ramps involve only tiny amounts of lift, they give an exaggerated idea of what the actual flowing valve duration is. To get a better idea, look at "timing measured at 1.0-mm checking clearance" or, if you have the cam at hand, measure it yourself with that .040" or 1.0-mm clearance. At one millimeter of lift, some useful flow may take place, so this is arbitrarily chosen as a means of getting a better idea of actual cam duration. In car cam catalogs the checking clearance may be .050" because auto engine valve lifts are so large. The bottom line is, never let yourself be impressed by valve timings exaggerated by the addition of the clearance ramps. Always look for timings at .040" checking clearance.

Next you must decode the cam descriptions in the makers' literature.
"Streetable mid-range boost" generally means this cam has near-stock duration but increased lift. Such a cam will have a wide usable torque range – something that comes in handy in racing. The reason the Honda RC211V has been so successful in MotoGP racing is not trick electronics – it is because this motorcycle has torque everywhere and is easy to ride.

"All-out power for Bonneville and high-rpm drag use" means the cam has its duration extended so far that at lower revs the piston has plenty of time to pump much of what has been sucked into the cylinders back out again before the intake valves close. You should take this description to mean 'useless but interesting'. Uncounted numbers of novice engine builders have been sucked into buying these paperweights because they mistakenly think that horsepower can win races. Have a look at the Aprilia in MotoGP – impressive steam down the straights, but never in the top-10. Motorcycles spend their on-throttle time accelerating, and that means they benefit from having high torque averaged across the rpm range actually used. In other words, if you race on a track that requires use of first gear, and you have a normal 1st-to-2nd rev drop of 25%, you absolutely must have a cam that will pull across the top 25% of your rev band. If you don't, you will find yourself stuck on the exit of that 1st-gear turn with your engine making a weak, hollow sound just below its usable torque while your competitors howl or bubb off into the distance ahead of you. Believe me, you won't reel them back in down the next straight. They are gone.

The concept of seeking maximum torque as an average across the rpm range actually used is worth emphasizing again. Almost nobody does this because we are all so easily hypnotized by BIG (as opposed to useful) numbers.

"Streetable but increased higher-rpm punch". This may be the one. It's a toss-up with "Streetable mid-range boost".

You must also consider that four-valve engines require less total cam duration than do two-valve designs. This is because initial flow area is total valve perimeter multiplied times lift, and because the four-valve with its small valves can lift them faster than the two-valve can (think of valves as floppy parasols – the bigger the parasol, the more it flops). This means the four-valve develops flow area faster than a two-valve, and thus needs less total duration for the same flow. Read through the cam catalogs to get an idea of representative numbers.

Legend says that back in 1980 American Honda had cams made for its 1025-cc fours in increments of 5-degrees of duration, then tested every cam to grind their way doggedly to an optimum. By contrast, Rob Muzzy said in 1982, “Nothing new has come along in cam design for the past 25 years, so it makes sense to pick a reasonable number (total duration) and then work with it. Adapt the cheap, easy-to-change parts (exhaust pipe, intake lengths) to the expensive hard parts (cams). Not the other way around.” As I recall, Muzzy had a fair amount of success.

Next you have to decide how to time the cams you plan to use. Because there are many cam durations, it is best to use the cam lobe center as a means of thinking about this.

We determine piston top dead center by setting the piston at X mm BTDC (by use of a long-reach dial gage or piston stop), noting the number on the degree wheel, then setting the piston at X mm ATDC, and noting the number. TDC is exactly half-way between the two numbers.

Rotate the crank to put the piston at this TDC, reset the degree wheel to indicate zero at that point, and we are ready to find cam lobe center (assuming the cam is installed and roughly timed, with a dial gage set up to measure valve lift).

Cam lobe center angle is really just “cam TDC”, and is found just as we found piston TDC. Set the valve at Y mm (say, 4-mm) of lift on the opening side and note the number on the degree wheel, then set the same valve at Y mm of lift on the closing side and note the number. The lobe center of that cam lobe is the timing midway between the two numbers. Remember that trying to back up to the timing on an engine with chain-driven cams may give a false reading by pulling chain slack over to the tension side. When in doubt, rotate forwards only.

Why use this “mid-way between two points of equal lift” method? Why not just feel around for peak cam lift with the dial gage? We don’t because the lift hardly varies over several degrees on both sides of peak, making it hard to decide where the center of the lobe truly is.

There are lots of ways to screw up in making these measurements but by being methodical, not too desperate, and even ready to laugh at yourself, you can get through it. I once had to measure intake and exhaust lobe centers on four protested bikes at Suzuki Cup, while ten or twelve factory team mechanics looked on (Muzzy had made the protest). I didn’t die and neither will you. Once you have been through it, you become the expert. No pain, no gain.

The useful lobe centers are typically between 99 and 112 degrees, but if you discover a trend of improvement, you must follow it wherever it leads. Notice an interesting thing here; the con-rod is at right-angles to the crank arm at about 76 degrees ATDC, so this is the point of maximum piston velocity. Yet the usable intake lobe center positions (which are also the point of maximum valve lift) don’t occur until 20-30 degrees after this? Why? The reason is that intake flow takes time to accelerate. The piston whips down on its intake stroke, pulling a deep vacuum in the cylinder, and the airflow uses the rest of the intake valve duration to catch up and fill the cylinder. In effect, the cam is phased later than the piston movement to allow for this delay. If air had no mass, it would need no time to accelerate, and so it could follow piston motion exactly. Reality is not like that!

Now, you might think (as I did) that cam timing would be a process of so locating the intake closing timing that the inrush of intake air had just stopped against the pressure generated by the piston, beginning to rise on its compression stroke. That would be ideal, but in fact that’s not the main determinant of optimum intake closing. The first reason is that the engine operates over a range of rpm, so that lovely balance point of intake inrush and rising piston is just one point on a wide band of rpm. The second reason is that this engine has exhaust pipe wave action.

Incidentally, you should note that intake porting has an influence here. If you give your engine huge ports it slows the intake velocity down so there is less “free supercharge” available after BDC as intake kinetic energy uses itself up. This is why strong-pulling engines these days usually have surprisingly small but very streamlined ports.

Back to the subject at hand – here's the real deal. Bang, the exhaust valve opens and a steep pressure front rushes out and down the pipe. At some point, the header pipe ends in an expansion of some kind – either into a larger collector pipe or megaphone or the atmosphere. As the pressure pulse expands into that larger diameter, it expands in all directions – including back up the exhaust pipe whence it came. That reflected wave of expansion can do useful work if it arrives back at the engine in the right time frame.

And what is that time frame? In order to accomplish anything, that expansion or suction pulse must arrive near TDC between exhaust and intake strokes, and both intake and exhaust valves must be slightly open together. This is the so-called "overlap period". If our reflected suction pulse arrives during overlap, it can enter the cylinder through the closing-but-not-yet-closed exhaust valve and get busy pumping useless exhaust residuals out of the clearance space above the piston (the lower your compression ratio is, the larger this space becomes). If there is plenty of energy in this reflected exhaust suction pulse, and if it lasts long enough and can still gain access to the cylinder (exhaust has not yet closed), it can continue out through the intake valve, causing fresh charge to begin flowing into the piston clearance space. This head start to the intake stroke is what this exercise is all about, for the extra cylinder-filling that it makes possible boosts torque over the rpm range in which the negative pipe pulse has access to the cylinder.

Now look at a cam phase diagram, with intake and exhaust opening and closing points marked on a circle. The intake begins to open somewhere shortly before TDC, and closes comfortably after BDC, while the exhaust closes shortly after TDC but opens some time before BDC. We can look at intake opening and exhaust closing points as defining a kind of "scissor" which makes overlap longer or shorter. Advancing intake lobe center and retarding exhaust causes longer overlap duration, while "scissoring" in the opposite direction closes down the overlap window.

I had the good fortune to attend a "cam rolling" session on a good dyno, using one of the old oil-cooled GSX-R1100 engines with a 4-into-1 pipe. First we set the cams to the service book lobe center angles and made a baseline run or two to see what that looked like. Then we began to "roll" the cams to various other lobe centers (using slotted cam sprockets) to see their effects. What we found was that the most important variable was the amount of overlap timing that resulted. As overlap increased, the pipe's reflected suction wave boosted torque, and we were able to get 3-5 more hp than with the stock settings.

This was not pure good news, however. If you lived in the exhaust pipe of a running engine, you would see a steady succession of waves come past, positive, negative, positive, and so on. This means that if the engine turns slowly enough, not only will the reflected negative pipe wave arrive too early to hit TDC overlap, but instead it will be a positive pressure pulse that arrives. On this test engine, this occurred at about 70% of peak-hp rpm. The result is a sharp drop in torque, as the positive pipe wave blows inert exhaust gas back into the cylinder, out through the intake valve(s) to fill the intake duct.

This means that when the piston does start down on its intake stroke, the first gas it pulls in will be more incombustible exhaust. This results in lower charge purity on the intake stroke, and a consequent drop in torque.

As this deep flat-spot usually lies just below the engine's natural torque peak, it can be quite exciting to try to climb out of this cavernous flat-spot as you accelerate off a turn. Whammo, the engine finally catches its breath and there you are, sliding onto the grass n your back, wondering what happened.

Therefore the rule is that with a simple exhaust system (single pipe or meg, or 4-into-1) every gain in torque that you "let in" by increasing overlap is matched by a correspondingly deeper hole at that 70%-of-peak-hp-rpm point. If you have a very close-ratio gearbox and don't mind using most of your concentration in engine management tasks, you may find the gains are worth the losses. Factory teams do not agree. At Daytona, where if anyone is going to want peak power this is the place, every 4-cylinder factory team puts a 4-into-2-into-1 pipe on all its bikes.

A 4-2-1 pipe lets you use a useful amount of valve overlap without creating a man-eating flat-spot at the same time. It does this by locating a second expansion at such a distance from the engine as to generate a second suction wave that neatly cancels the nasty 70% flat-spot's positive wave. An appropriately-located cross-over pipe can do much the same for a twin. Another path to the same result is Yamaha's "EXUP" valve (other companies call it something else), which at the flat-spot rpm range blocks pipe wave action by nearly closing the pipe with a gate valve.

I see that I have left you with the conclusion that finding optimum cam timing is not quite a cinch, may require some assembly/disassembly, and could be aided by (possibly expensive) time on a dyno operated by a sympathetic person. Well, tough – that's how it is. Four-strokes have center stage now so we'll just deal with the extra time they require by living longer. The alternative is just to line up the marks and admire the seatbacks of your more industrious competitors.

Posted Oct 12th, 2011 at 6:10 PM
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