Variable Valve Timing - The Next Phase
Variable Valve Timing For Performance Applications
By Marlan Davis

Once upon a time, picking a cam for a given engine combo was all about compromise: improve top-end power at the expense of low-end torque, run well at wide-open throttle but sacrifice idle stability and part-throttle cruise driveability, trade off performance for gas mileage, run hard or run clean. Thanks to OEM-developed variable valve timing (VVT), it doesn't have to be that way anymore.

VVT is a generic term for various concepts that allow changing the advance, overlap, and even (in the case of some import overhead-cam engines) the duration and lift of a four-stroke internal-combustion engine's intake and exhaust valves while the engine is operating. This technology has been under development for more than a century (a variation was tried out on some early steam engines), but it is only within the last 20 years or so with the advent of sophisticated electronic sensors and engine management systems that it has become practical and effective.

Why VVT?
The initial impetus to put VVT systems into production cars was the ever-increasing pressure to meet environmental goals and fuel efficiency standards while still maintaining reasonable performance. With today's VVT systems, engines are so efficient at reducing emissions that the notorious separate EGR valve has become virtually extinct; VVT provides sufficient passive EGR charge dilution that considerable fuel economy, idle, and emissions benefits are achieved without the need to resort to clumsy add-on devices. Although not originally its main intent, as applied to performance, VVT allows running a relatively radical cam that still maintains a stable idle and low-speed driveability. VVT can be coupled with another new technology, active fuel management, which allows selective deactivation of multiple cylinders under cruise when full power isn't required. Combined, these technologies should permit the survival of large-displacement V-8 engines for the foreseeable future.

Changing The Cam Cycle
The most common VVT implementation is advancing and retarding the intake and exhaust valves' opening and closing points. Advancing the cam means moving the lobe centerlines to produce earlier valve timing events during the engine's cycle; retarding a cam is the opposite. On engines with the intake and exhaust cam lobes ground on the same billet, a VVT mechanism advances or retards the entire cam (intake and exhaust) equally. Although the lobe centerlines change in relation to top dead center, the lobe-separation angle (LSA, the distance between the intake and exhaust lobe centerlines) remains the same. LSA changes are only possible if the intake and exhaust lobes are ground independently (not on a common billet). Until recently, this required a DOHC (dual overhead cam) setup.

Generally, you'd want to advance a cam for more bottom end, higher vacuum, and better idle characteristics. Retarding a cam aids the top end. A typical production cam optimized for an advance/retard VVT system is usually ground with reduced overlap, with VVT retard dialed in as needed to maintain or enhance the top-end power.

For those systems capable of also changing the lobe separation, a smaller lobe-separation angle increases overlap. Given the same duration, separation and overlap are inversely proportional. More overlap decreases low-rpm vacuum and response and improves the signal provided by the fast-moving exhaust to the incoming intake charge in the midrange,
often providing noticeable engine acceleration improvements. Less overlap can increase efficiency by reducing raw fuel seepage into the exhaust and improve low-end response due to less reversion of the exhaust gases into the intake port. In terms of emissions, you obviously don't want raw fuel getting into the exhaust, but under certain conditions, introducing overlap at low rpm to dilute the intake charge induces passive EGR and improves mileage, albeit at the expense of low-end torque. It's a fine balancing act.

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Hydraulically actuated cam phasing is the preferred method for variably advancing or retarding a cam. An electronically controlled hydraulic valve (sometimes referred to as an oil control valve or OCV) directs engine oil into a camshaft phaser assembly that replaces the timing chain's upper sprocket. Inside the phaser cavity is a rotor that rotates within a stator as needed to advance or retard the cam. An additional advance/retard calibration table or map that relates cam lobe and crank position to engine speed is added to the computer (ECU or electronic control unit).

**Things To Watch Out For**

One potential VVT problem is that the ECU assumes the use of a mild cam, permitting a fairly large latitude of advance and retard. This can cause piston/valve interference issues when installing an aftermarket cam with more duration, overlap, and lift. Workarounds include refloashing the factory computer to tighten up the allowable range of cam movement, adding a mechanical phase-limiting device, and/or installing custom pistons with deeper valve notches.

Valvespring configuration is also critical on VVT engines. Hydraulically actuated phasers are susceptible to over-aggressive valvespring seat pressures, which may overwhelm the oil pressure-generated hydraulic forces needed to correctly actuate the phaser mechanism. With the factory computer, this generates a fault code and puts the cam into full retard. Special valvesprings are therefore required that can support a hotter cam without overwhelming the VVT system. Bearing this in mind, let's take a closer look at VVT technology as it’s applied on typical domestic engines used by hot rodders.

**GM LS Engines**

GM started using VVT on some LS-style small-blocks in 2007. The L76 6.0L aluminum block, LY6 6.0L iron-block, L92 6.2L Cadillac Escalade, and the new L99 6.2L Camaro are among those LS engines with VVT, with more applications to follow. The L99 is also available as a crate engine from GM Performance Parts (PN 12611022).

GM didn't add any new internal oil passages to the block or heads. This simplifies retrofitting VVT into non-VVT LS applications. To back-fit, you would need a late-style VVT-type cam with its additional No. 2 cam-journal oil feed hole and a front nose set up for the new one-bolt retention phaser/sprocket assembly that replaced the previous three-bolt sprocket. The front cover must be swapped for the late cover that has force-motor mounting provisions. Also required is a late-model factory ECU that supports camshaft phasing, which in turn needs to work with a late-model 58-tooth reluctor wheel that presses onto the crankshaft inside the oil pan. The present need for a 58-tooth wheel makes retrofit impractical on some earlier LS motors (generally '05 and prior) that only use a 24-tooth wheel, unless the engine is down for a complete rebuild. Subject to the 58-tooth requirement, you could also use Mast Motorsports' own proprietary M-90 controller and retrofit kits that offer a stand-alone engine management and wiring system that eliminates headaches normally associated with EFI swaps.
There's also software available from HP Tuners or EFILive for reflashing the factory ECU as needed to reduce phaser range. Comp Cams offers a mechanical phase-limiting device that restricts the amount of allowable advance or retard without the need for computer reprogramming. One of these options will be needed if installing the special VVT cams available from Mast or Comp Cams.

Special VVT-compatible springs that have a low install pressure but can still support up to 0.650-inch lift are offered by Mast and Comp Cams. You should retain the GM hydraulic-roller lifter and net-lash valvetrain through 600 hp. Getting the stock VVT to work with a solid roller and adjustable valvetrain at this point is problematic.

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Besides its controller, Mast Motorsports also specializes in retrofitting complete late-model LS production and crate engines into earlier hot rods, including the VVT variants. Mast is even pushing a computer-locked EFI, VVT, oval-track crate spec engine. Mast sees VVT having a bright future in oval track racing because it can develop a broader torque peak--more low end coming off the turns, more extra power up high.

**Ford Modular V-8**

Ford calls VVT variable camshaft timing (VCT). It's available on SOHC (single overhead cam) modular engines with three-valve (3V) heads. The first use was on an '03 SOHC 3V Australian 5.4L. In 2004, Ford became the first to offer VCT in a pickup truck, introducing the system on North American F-150 5.4L 3V Triton engines. Modular 4.6L SOHC 3V engines first appeared in the redesigned '05 Mustang. There are rumors that DOHC 4V engines will receive VCT in the future.

Since the SOHC V-8 engine actually has two cams--one for the driver side and one for the passenger side--there are separate phasers, valves, and actuators that bolt to each head. To supply the extra oil needed to actuate the two phasers, VCT engines use a new, thicker oil pump that supplies 30 percent more volume than even the higher-volume pump used on DOHC 4V engines. Losses from internal oil bleed-off are reduced with the use of new, rounder (less eccentric near the parting line) main bearings. Ford says mysterious cam phaser actuation problems can be minimized by using the new factory main bearings and sticking to factory production main and rod bearing clearances.

**Ford** Racing offers a VCT hot rod cam set as well as complete VCT 3V crate engines. It also has a tool that allows the customer to download a new calibration for its 3V supercharger kits. With stock 3V heads on a normally aspirated 4.6, Ford Racing has seen up to 30 hp with its hot rod cam and long-tube headers with a properly calibrated ECU and up to 50 hp with its CNC-ported heads.

Comp Cams offers a number of VCT-compatible cams, plus a mechanical phase limiter. For serious high-performance street use, modular tuning specialist Paul's High Performance recommends pulling the stock 60- degree advance/retard range back to 20 degrees. Paul's specializes in performance parts and in-shop tuning for all Ford modular engines.

All SOHC 3V engines come stock with VVT. Retrofitting VVT onto earlier SOHC 2V engines is not really practical without installing the 3V heads, as well as the late ECU, front drives, oil
pump, front cover (which has cam position-sensor mounting provisions), and intake manifold. However, for existing 3V engines, Ford Racing has an installation kit (PN M-6017-463V) for putting the motors into a muscle car that includes the wire harness, ECU, drive-by-wire pedal, and other needed parts.

**Chrysler New Hemi And V-10 Viper**

Chrysler introduced VVT on some '09 5.7L Hemis. Like the GM and Ford implementations, the single-cam pushrod engine relies on a control valve/solenoid and a phaser. However, major changes preclude retrofit into earlier new Hemis. These changes include an increased cam bore size, new cylinder block oil passages, a different front cover, and 5mm-longer valves. Comp Cams says it has some stuff in the pipeline. BG Performance can reflash the new VVT-compatible Hemi ECU.

The Viper's new 8.4L V-10 engine is in a class by itself. Up to now, pushrod engines with VVT have been limited to advancing and retarding the camshaft only. Chrysler has changed all that with the world's first implementation of the single cam-on-cam concept (illustration pg. 90). This setup allows real-time lobe-separation changes.

Tailored for high-end power, the new cam has more lift and duration than earlier V-10 profiles. As currently implemented, Chrysler varies the exhaust lobe independently to improve idle and part-throttle combustion stability with the relatively big cam. It is possible to vary the exhaust timing up to 45 degrees, although only 36 degrees is actually used stock. Moving the intake lobe could produce more low-end torque, but the 8.4L mill already makes 560 lb-ft and 600 hp, enough for 202 mph in the Viper coupe.

Retrofitting to older V-10 engines is not practical. There are extensive changes between the current VVT V-10 and the previous-generation V-10. The cam journals are larger and there are new oil passages in the block. The entire ignition, induction, and computer systems have been changed, many rotating assembly parts have evolved, and the heads are all new and utilize direct injection.

Due to the low production volume, aftermarket support for the VVT V-10 Viper is limited. There are no aftermarket cams, although it is possible to have the stock cam reground. Contact Lyle Larson at DC Performance or Duttweiler Performance for V-10 cam regrinding, tuning, and buildup information. VVT Vipers use a unique computer, and as of April 2009, it hadn't been hacked--although BG Performance says it's working on it. Mopar Performance also offers what it calls a Stage 1 computer (PN P5007142) with modified fuel and spark tables compatible with power-adders up to 700 hp, as well as other enhancements.

Although VVT is still in its infancy as far as its potential hot rod applications are concerned, the potential of full independent VVT as used in the Viper offers up intriguing possibilities for the future of performance. Literally, advanced performance VVT offers the potential to win on Sunday and drive to work on Monday--all in the same car.

**Want To Learn More?**

EFI University (www.efi101.com) specializes in live as well as online video courses covering all phases of tuning today's high-tech EFI engines. Its latest video course, Variable Camshaft Tuning, may be purchased and viewed online in Windows WMV format. More than two hours long, the new video starts with basic cam theory, explains how cams work in general, and progresses through tuning the maze of complex systems it takes to make a variable camshaft system operate.
To show how advancing and retarding the same cam alters power curves, Mast ran a stock GM VVT L99 with 87-octane gas, unaltered fuel and spark calibration, and 1 3/4-inch primary-tube headers. Instead of letting the computer phase the cam throughout the rpm range, the ECU was locked to produce the best peak power and **torque**. This was achieved by retarding the cam 5 (red trace) and 18 (blue) degrees, respectively, from its as-ground 4 degrees advanced intake centerline. Letting the ECU continuously vary cam timing (normally the case on VVT-enabled systems, purple) develops the best peak torque and power, as well as the most area under the curve.

Ford Racing sells 4.6L 3V VVT crate motors: a 300hp stocker (M-6007-3V46) and a 350hp hot rod version (PN M-6007-A463NA, shown). The hot rod engine's VVT cam is also sold separately under PN M-6550-3V. ECU recalibration is strongly advised, although Ford says it's not mandatory. SCT Tuners is one source for Ford factory ECU recalibration software.

Ford's SOHC 3V Modular **V-8** mounts the oil control solenoids separately on the cylinder head. The connector goes through the valve cover. This is the passenger-side solenoid. There's one on the driver side, too, as there's a cam over each bank.

Comp Cams' [Ford](#) 4.6L/5.4L Modular 3V Phaser Limiter Kit (PN 5449) drops phaser movement to 20 degrees from the stock 60-degree range. By keeping cam timing in check, more aggressive profiles can be safely used without damaging piston-to-valve clearance issues. PN 5456 reduces movement from 50 to 20 degrees on GM VVT LS engines.
The Viper phaser assembly still bolts to the front of the cam and also serves as the upper timing chain sprocket. But unlike other applications, it rotates the cam within a cam.

The Viper's main oil control valve is combined with the solenoid and mounts to the top of the block. Note the oil transfer slots and passages for the phaser in the front of the block and rear of the thrust plate.

How 'bout variable lift and duration? Honda's VTEC system, first used on its classic DOHC motors, has three cam lobes and three rocker arms for each intake and exhaust valve pair. At low speeds, the rockers aligned with the two outboard cam lobes directly open and close the valves; at high rpm, the outer rockers are joined to, and directed by, the middle, high-rpm lobe and rocker arm.
The Viper's VVT uses Mechadyne's patented dual-independent concentric camshaft technology. There are actually two shafts in the cam bore, one inside the other. The hollow outer shaft incorporates the cam journals and has pressed-on exhaust lobes; a solid inner shaft drives the intake lobes.

The exhaust cams are pressed onto the outer cam tube. The intake cam lobe assemblies have pins that pass through slots in the hollow camshaft and are pressed into pinholes in the inner solid shaft. When the solid shaft is turned, the phaser can move the hollow exhaust camshaft between advance and retard positions versus the solid camshaft, within the range allowed by the slots and solid pins that go through them.