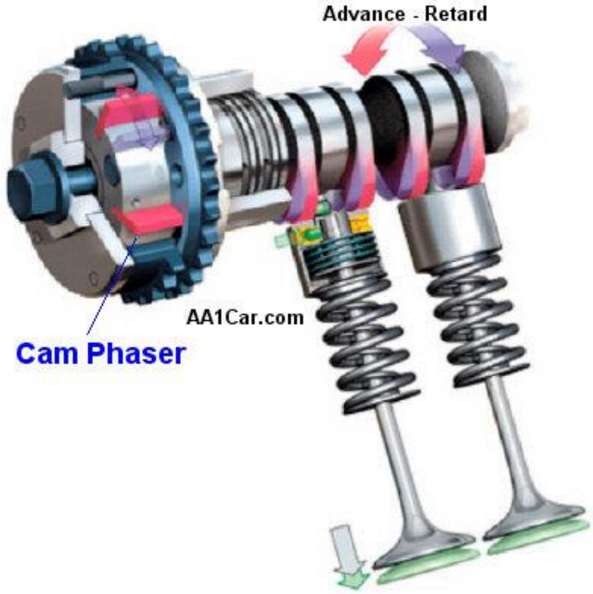


Variable Valve Timing

by Larry Carley copyright 2019 AA1Car.com

Variable Valve Timing (VVT) is a technology that's used on many late model engines to improve fuel economy, idle smoothness, emissions and performance. Variable valve timing allows valve timing to change with engine RPM, unlike standard fixed cam drives that never change.Valve timing determines when the intake and exhaust valves open, how long they remain open, and when they close. In turn, this affects intake and exhaust flow, intake manifold vacuum, running compression, volumetric efficiency, throttle response, and how much horsepower and torque the engine develops at any given RPM.

Traditionally, valve timing has always been fixed. Once set by the alignment of the timing marks on the camshaft and crankshaft drive sprockets or gears, valve timing does not change -- unless a timing chain stretches, or a belt jumps a notch or breaks. The problem with fixed timing is that always ends up being a compromise.

Valve timing settings that produce the best idle, intake vacuum and low RPM torque are not the same settings that produce the best mid-range power or high speed power. Advancing valve timing improves idle quality and low

RPM torque while retarding valve timing improves high end power. Ideally, valve timing should change with engine speed and load like ignition timing does. But with a standard cam drive (belt, chain or gears), that is not possible. Consequently, valve timing is usually set to favor everyday drivability (low to mid-range torque).

Valve timing can be advanced or retarded a few degrees either way by offsetting the drive gear on the camshaft with an offset pin, offset keyway or timing gear with offset mounting holes. Performance engine builders often "tune" valve timing this way to shift an engine's power band up or down the RPM scale.

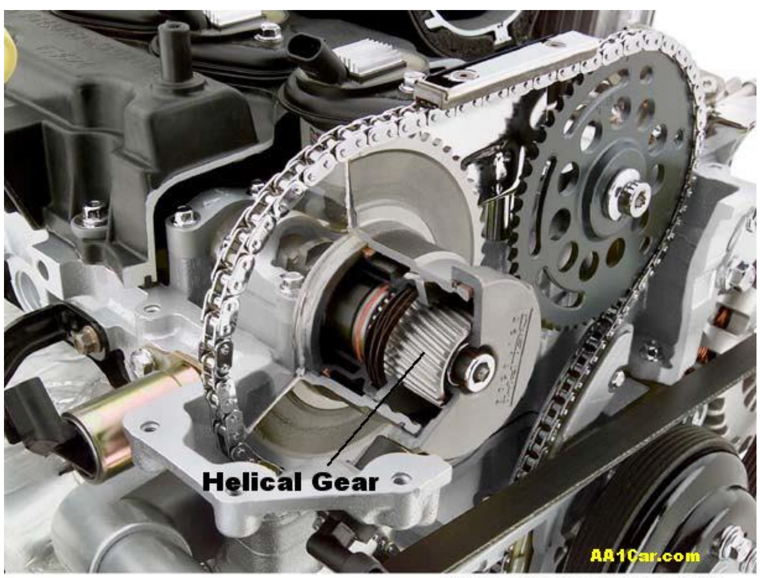
Many aftermarket camshafts are ground with 4 degrees of built-in timing advance for better low to midrange torque. If such a cam is going into a high revving performance engine, retarding the cam 4 to 8 degrees can improve top end performance but at the cost of less low end torque.

Variable valve timing provides a way of getting around the limitations of fixed timing. VVT allows valve timing to change in response to engine speed and load. This provides a much wider power band and better all-round performance. Valve timing can be advanced at low RPM to improve idle quality, throttle response and low speed torque, and retarded at higher engine speeds to increase peak horsepower.

HOW Varible Valve Timing Works

There are a variety of different VVT systems in use today. The most common type use a camshaft actuator or "phaser" mounted on the cam drive gear, and an oil flow control valve solenoid that routes oil pressure to the cam phaser.

Most VVT systems are not active at idle, and only come into play at higher engine speeds or when the engine is under load. The rest of the time, VVT is just along for the ride.

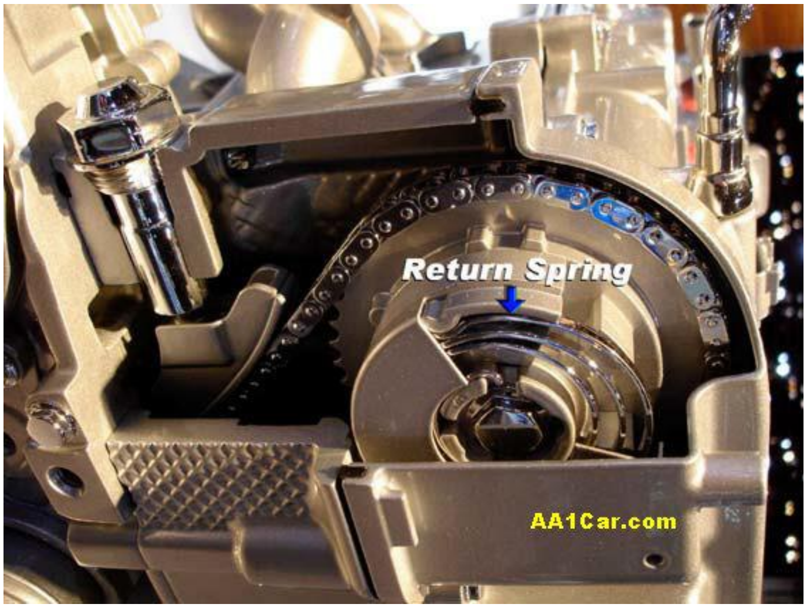


2004 Vortec 4200 I6 / Vortec 3500 I5 / Vortec 2800 I4
Variable Valve Timing

Helical gear phasers rotate the position of the camshaft when oil pressure is applied to a piston in the gear mechanism.

The first production VVT systems appeared back in 1990 on a couple of import applications (Nissan 300ZX V6 and Mercedes SL 3.0L six & 5.0L V8). These early VVT applications were on Dual Overhead Cam (DOHC) engines and only advanced the timing of the intake camshafts. The cam phasers had only two operating positions ("on" or "off") and would advance intake valve timing about 20 degrees above a certain RPM. Advancing the timing of the intake camshaft relative to the exhaust cam allowed the engines to develop more high RPM power.

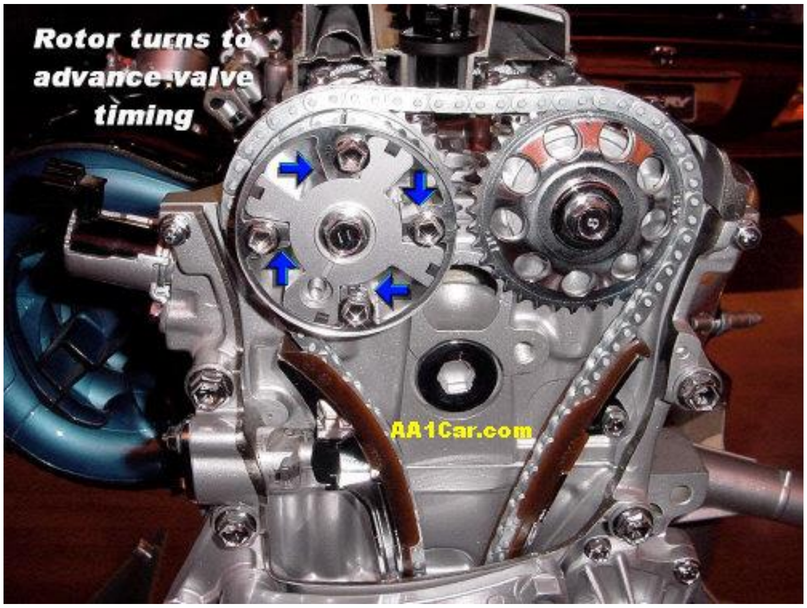
Most of the simple first-generation VVT cam phasers use a spring-loaded helical gear mechanism to change the relative position of the cam. When the PCM energizes the oil flow control valve, oil pressure is routed to a piston inside the phaser. The piston moves the helical gear which rotates the cam slightly to change valve timing. When the oil flow control valve closes, oil pressure inside the phaser is relieved and spring tension returns the cam to its original base timing position.



A circular spring in a helical gear phaser returns the cam back to its original base timing position when oil pressure is relieved.

By comparison, most VVT cam phasers on newer engines work a little differently. Instead of a helical gear and piston to change the position of the cam, many use a rotor style cam phaser with vanes or a lobed rotor inside the phaser housing.

Oil pressure is routed into the cavities on one or both sides of the rotor vanes or lobes to push the rotor one way or the other. Rotating the rotor inside the cam phaser advances or retards camshaft and valve timing.



The rotor inside this vane style cam phaser moves when oil pressure is applied to either side of the rotor vanes.

On applications where the phaser only advances or retards valve timing, there is an internal locating pin that slides into a hole to lock the phaser in position when no oil pressure is applied. When oil pressure is applied, it pushes the locating pin out of its locked position allowing the phaser to rotate.

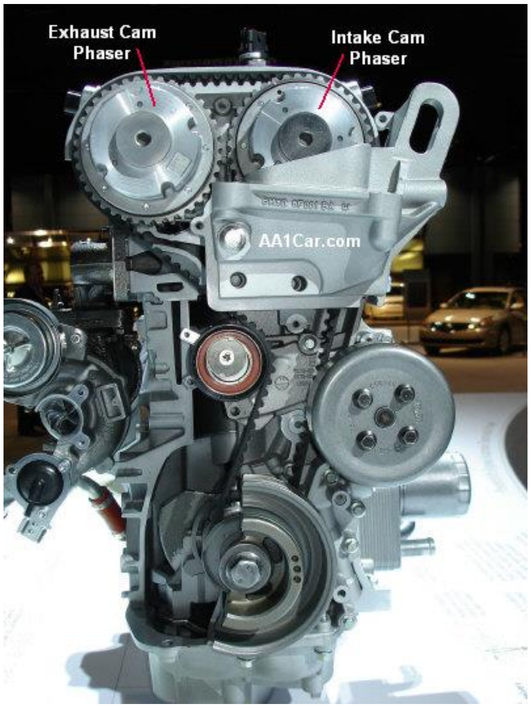
Vane style phasers react more quickly than helical gear phasers and typically change cam/valve timing up to 20 to 30 degrees in either direction. The oil flow control valve is also duty cycle controlled (pulse width modulated). This allows the PCM to make stepless or continuous incremental adjustments to valve timing instead of full advance or full retard only. This means valve timing is no longer a compromise but can be changed to match engine speed and load.

Some of the latest VVT systems do away with hydraulics altogether. They use an electric motor inside the phaser to advance or retard valve timing. Electronic phasers can respond very quickly to changing operating conditions and do not depend on oil pressure. So as time goes on, we will likely see wider use of electronic phaser VVT systems.

Different Types of Variable Valve Timing

Different auto makers use different variable valve timing strategies for different purposes. On some older Ford and General Motors applications, for example, VVT is only used on the exhaust cam of DOHC engines to retard exhaust timing. This produces an exhaust gas recirculation effect to reduce oxides of nitrogen (NOx) emissions when the engine is under heavy load. It also allows the EGR valve to be eliminated on many engines.

On many newer DOHC engines, VVT is used on both the intake and exhaust cams. This allows the computer to vary intake and exhaust valve timing independently for even better performance, fuel economy and emissions.



Many engines have VVT cam phasers on the intake and exhaust cams to control each cam separately.

Some auto makers also combine variable valve timing with variable valve lift. This changes not only valve timing but how far (and how long) the valves open. One of the first such systems to do this was Honda's Variable Valve Timing and Lift Electronic Control System (VTEC) introduced in 1991 on the Acura NSX. The same system was later added to a wide range of Honda and Acura models. Instead of using a hydraulic cam phaser to rotate the position of the intake cam, the Honda VTEC system added an extra cam lobe and rocker arm for each pair of valves. Above a certain RPM, oil pressure was routed to the extra rocker arms. This raised the arms so they would lock against the other rocker arms and engage the 3rd "performance" lobes on the camshaft to increase valve lift and duration.

On late model BMW engines with Gasoline Direct Injection, BMW's Valvetronic system uses an electronic cam phaser to actuate a series of intermediate rocker arms when changes in valve timing and lift are desired. This allows the PCM to control engine speed and idle using valve timing and fuel injection alone, eliminating the need for a throttle. Getting rid of the throttle allows the engine to breathe freely at idle like a diesel with minimal pumping losses. The result is a 10 percent gain in fuel economy and lower emissions.

On late model Corvette LT1 pushrod engines, the standard cam drive gear has been replaced with a vane style hydraulic phaser to provide VVT. This allows the PCM to advance or retard valve timing as needed for better performance.

On newer Dodge Vipers, a special "concentric" camshaft within a camshaft is used to allow changes in valve timing, lift and duration. The concentric cam has a solid inner core and an outer tube assembly. There are two sets of lobes, one set fixed to the outer tube and a second set pinned to the inner shaft through slots in the outer tube.

The phaser on the end of the cam rotates the position of the inner shaft with respect to the outer tube to change valve timing, lift and overlap.

Variable Valve Timing Issues

As great as VVT is, it is also vulnerable to some problems. On VVT systems that use oil pressure to actuate the cam phaser, oil quality, viscosity and contamination problems can affect the operation of the phaser. If the phaser does not receive adequate oil pressure, or the oil is the wrong viscosity (too thick or too thin), or the oil is dirty, it may prevent the phaser from working properly. This, in turn, can hurt engine performance, fuel economy and emissions. Such faults will often turn on the Check Engine light and set a VVT-related fault code.

Generic OBD II Fault Codes include:

P0010....A Camshaft Position Actuator Circuit Bank 1

P0011....A Camshaft Position Timing Overadvanced or System Fault Bank 1

P0012....A Camshaft Position Timing Overretarded Bank 1

P0013....B Camshaft Position Actuator Circuit Bank 1

P0014....B Camshaft Position Timing Over-Advanced or System Fault Bank 1

P0015....B Camshaft Position Timing Over-Retarded Bank 1

P0020....A Camshaft Position Actuator Circuit Bank 2

P0021....A Camshaft Position Timing OverAdvanced or System Fault Bank 2

P0022....A Camshaft Position Timing OverRetarded Bank 2

P0023....B Camshaft Position Actuator Circuit Bank 2

P0024....B Camshaft Position Timing OverAdvanced or System Fault Bank 2

P0025....B Camshaft Position Timing Over-Retarded Bank 2

Any of these codes could be the result of a bad cam phaser, oil flow control valve or wiring fault.

Cam phasers can fail a variety of ways. Dirt or debris may plug up the oil holes or inlet screen that feeds the phaser, preventing oil pressure from reaching the unit. With helical gear phasers, dirt or debris may jam the gears or cause them to stick. Physical damage to the gears or excessive wear may also interfere with the normal operation of the phaser.

On phasers with helical gears and return springs, a broken spring will prevent the cam from returning to its neutral or base timing setting after it has been advanced or retarded.

A leaky hydraulic piston or leak in the phaser housing may also prevent the cam from changing position when oil pressure is applied.

On vane style phasers that have an internal locking pin, wear on the pin or its locating hole can cause noise. The pin may also shear off, preventing the phaser from locking in the neutral position. A knocking or rapping sound that is only heard at idle and primarily when the engine is hot, but goes away at higher speed, usually indicates a worn phaser that needs to be replaced.

A VVT phaser may also fail to change valve timing if the oil flow control valve that feeds it is stuck, contaminated with dirt or sludge, or is inoperative.

Variable Valve Timing Diagnosis

Before you jump to any conclusions regarding the Variable Valve Timing system if an engine is idling rough or not developing normal high speed power, you should also consider other possible causes such as a large vacuum leak (intake manifold, vacuum hoses or EGR valve), heavy carbon buildup on the intake valves (a common problem with Gasoline Direct Injection), dirty fuel injectors, low fuel pressure, ignition misfire, exhaust restrictions, loss of compression (burned/bent valves or a leaking head gasket) or a turbo problem.

One of the first things you should inspect if you suspect a VVT problem is the oil. Is the oil level low? That could cause a drop in oil pressure that might affect the operation of the VVT system. Has the oil been properly maintained? Dirty oil full of sludge is not good for VVT phasers or control valves.

When changing the oil on a VVT engine, use a high quality oil and the viscosity recommended by the vehicle manufacturer. For most late model vehicles, that would be a 5W-30 or 5W-20. Many European vehicles specify even thinner oils such as 0W-20 or 0W-40.

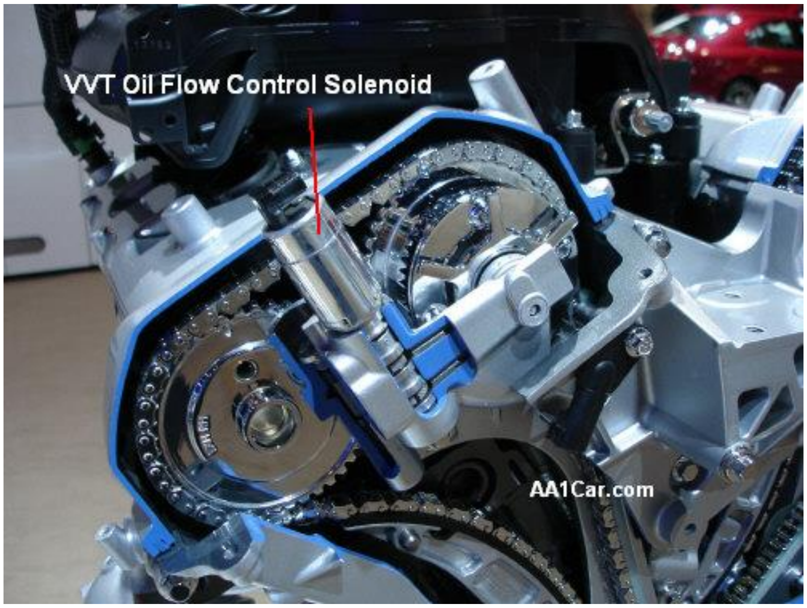
Oil pressure problems will obviously affect the operation of the VVT system. Underlying causes may include a worn oil pump in a high mileage engine, or worn main bearings or cam bearings. Use a gauge to check oil pressure if low oil pressure is suspected.

Cam Phaser Oil Flow and Control Problems

The plugged, stuck or inoperative oil flow control valve can also prevent the VVT system from functioning normally. With on-off solenoids, you can test the continuity and/or resistance of the solenoid with a DVOM for shorts or opens. You should also check the supply voltage and ground at the wiring harness to determine if the PCM command signal is getting through.

Another alternative is to energize the solenoid at idle to see if engine idle quality, RPM and intake vacuum change (they should). No change would indicate a bad solenoid or no oil flow through the control valve to the phaser.

Or, you can remove the oil flow control solenoid (Engine OFF) and apply voltage. If the solenoid does not move, the unit is defective and needs to be replaced.



If the VVT oil flow control valve is defective, sticking or plugged with debris, it may prevent oil pressure from reaching the cam phaser.

With pulse width modulated solenoids (and on-off solenoids), observe the VVT solenoid status with a scantool. It should be OFF at idle, and come ON at higher RPMs. If the valve is pulse width modulated, do the readings change with engine speed?

If your scantool is bidirectional and the software allows you to energize the oil flow control solenoid or change its duty cycle while the engine is running, that's another check you can make to see if the cam phasers are responding.

Other faults that may affect the operation of the VVT system include signal issues with the camshaft or crankshaft position sensors, a faulty MAP sensor (which senses engine load), or even a problem in the PCM itself.

Follow the manufacturers recommended diagnostic procedures if you suspect a sensor fault.

Cam Phaser Replacement

If a cam phaser is clogged with sludge or varnish deposits, you can take it apart and clean it. However, if any of the internal parts are worn or broken, you have to replace the phaser as a unit because replacement parts for rebuilding phasers are not yet available from aftermarket suppliers or from the auto makers. New cam phasers are available at most auto parts stores. Prices range from $100 to nearly $300, and do not include a timing chain or belt or a chain tensioner kit (these must be purchased separately).

Replacement procedures can vary from relatively simple to a major undertaking. Access to the cam phasers can be a challenge on engines where intake manifolds, alternators or other components have to be removed before you can pull the cam cover or valve cover to get to the phaser(s).

On many DOHC and SOHC engines, the timing chain needs to be held or locked in position when the phaser is removed so the chain doesn't slip time or come off the crankshaft sprocket. Special tools may be required to hold the chain in position.

Another issue is installing a new cam phaser correctly. The crankshaft may have to be rotated to a certain position BEFORE the phaser is replaced. It's also a good idea to mark the timing chain to the new phaser can be installed in the same position. You have to make sure the phaser itself is in the correct base timing position before it is bolted onto the cam.

Always refer to he vehicle manufacturer's disassembly and installation procedures to avoid any surprises or mistakes.

Variable Valve Timing Service Tips

On high mileage Ford 4.6L and 5.4L 3-valve V8 engines, cam phaser "knock" is a common problem. Ford TSB 06-19-8 covers this issue in detail. On some applications, the problem is not due to wear in the phasers but low oil pressure due to cam bearing wear in the cylinder heads. Fixing the problem may require replacing or remachining the heads. An alternative fix is to install a high volume oil pump to increase oil flow to the cam phasers. Another option is to "lock" the phasers at their base timing settings by installing special plugs that prevent the vanes from moving. However, this defects the benefits of VVT and requires reprogramming the PCM.

The blue plug in this photo was installed inside the cam phaser to lock it in a static position.

Always check for new or updated manufacturer Technical Service Bulletins (TSBs) when troubleshooting a VVT problem. There may be an upgraded part or PCM reflash available to fix the problem.

If a VVT engine has a phaser problem due to oil sludge and poor maintenance, flush the crankcase to remove contaminants, then change the oil and filter. That may eliminate the need to replace the phaser.

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Variable Valve Timing by Larry Carley article in 2015 Engine Builder magazine

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