

ROUGH REPORT

# VARIABLE VALVE TIMING

Submitted by,

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**ABSTRACT**

Until recently, an automobile manufacturer used one or more camshafts (plus some pushrods, lifters and rocker arms) to open and close an engine's valves. The camshaft/camshafts was turned by a timing chain that connected to the crankshaft. As engine rpm's rose and fell, the crankshaft and camshaft would turn faster or slower to keep valve timing relatively close to what was needed for engine operation. Unfortunately, the dynamics of airflow through a combustion chamber change radically between 2,000 rpm and 6,000 rpm. Despite the manufacturer's best efforts, there was just no way to maximize valve timing for high and low rpm with a simple crankshaft-driven valve train. Instead, engineers had to develop a "compromise" system that would allow an engine to start and run when pulling out of the driveway but also allow for strong acceleration and highway cruising at 70+ mph. Obviously, they were successful. However, because of the "compromise" nature of standard valve train systems, few engines were ever in their "sweet zone," which resulted in wasted fuel and reduced performance. Variable valve timing has changed all that. By coming up with a way to alter valve timing between high and low rpm's, Honda, Toyota and BMW and many more manufacturer's can now tune valve operation for optimum performance and efficiency throughout the entire rev range.

## **INTRODUCTION**

Engine breathing is analogous to the breathing of any living organism. At rest, the lungs take in the necessary amount of air for normal function. When running, the lungs and heart work faster to supply more oxygen to the system. Engines can't do that because their breathing apparatus (comprised intake manifolds, intake runners, valves, valve lift and throttle bores) is fixed.

There was a time when engines had to be big to be powerful. There was a time when engines could either be tuned for low-rpm torque or high-rpm power, but not both. There was a time when a specific output of 100 hp per liter was the stuff of racecar fantasies. Today these limitations are all but gone. Getting 100 hp for each liter of displacement is now possible on cars that have to get good gas mileage, emit clean air, act civilized enough for your grandmother to drive them and sell for under \$20,000

Remember that an engine is basically a glorified air pump and, as such, the most effective way to increase horsepower and/or efficiency is to increase an engine's ability to process air. There are a number of ways to do this that range from altering the exhaust system to upgrading the fuel system to installing a less-restrictive air filter. Since an engine's valves play a major role in how air gets in and out of the combustion chamber, it makes sense to focus on them when looking to increase horsepower and efficiency. This is exactly what Honda, Toyota and BMW and quite a number of other manufacturer's have done in recent years.

Popet values are used in gasoline and diesel engines to control the inlet and exhaust of air passing through the engine. When the intake values open, air is drawn into the engine cylinder. After the fuel has been burnt, the exhaust valves then open to let it leave. In conventional engines, the popet valves open and close at a constant speed. Their timings do not depend on how fast the engine is running. At high engine speeds [e.g. when overtaking a slower vehicle], this starts to become a problem. Large amounts of air are required by the engine at higher speeds. However, the intake valves may close before all the air has been given a chance to flow in. On the other hand, if the valves were calibrated to remain open for longer periods of time, problems start to occur at the lower engine speeds. In these situations, unburnt fuel may exit from the engine since the valves are still open. This leads to lower

engine performance and increased emissions. By using advanced systems to alter the opening and closing of engine valves, they have created more powerful and clean burning engines that require less fuel and are relatively small in displacement.

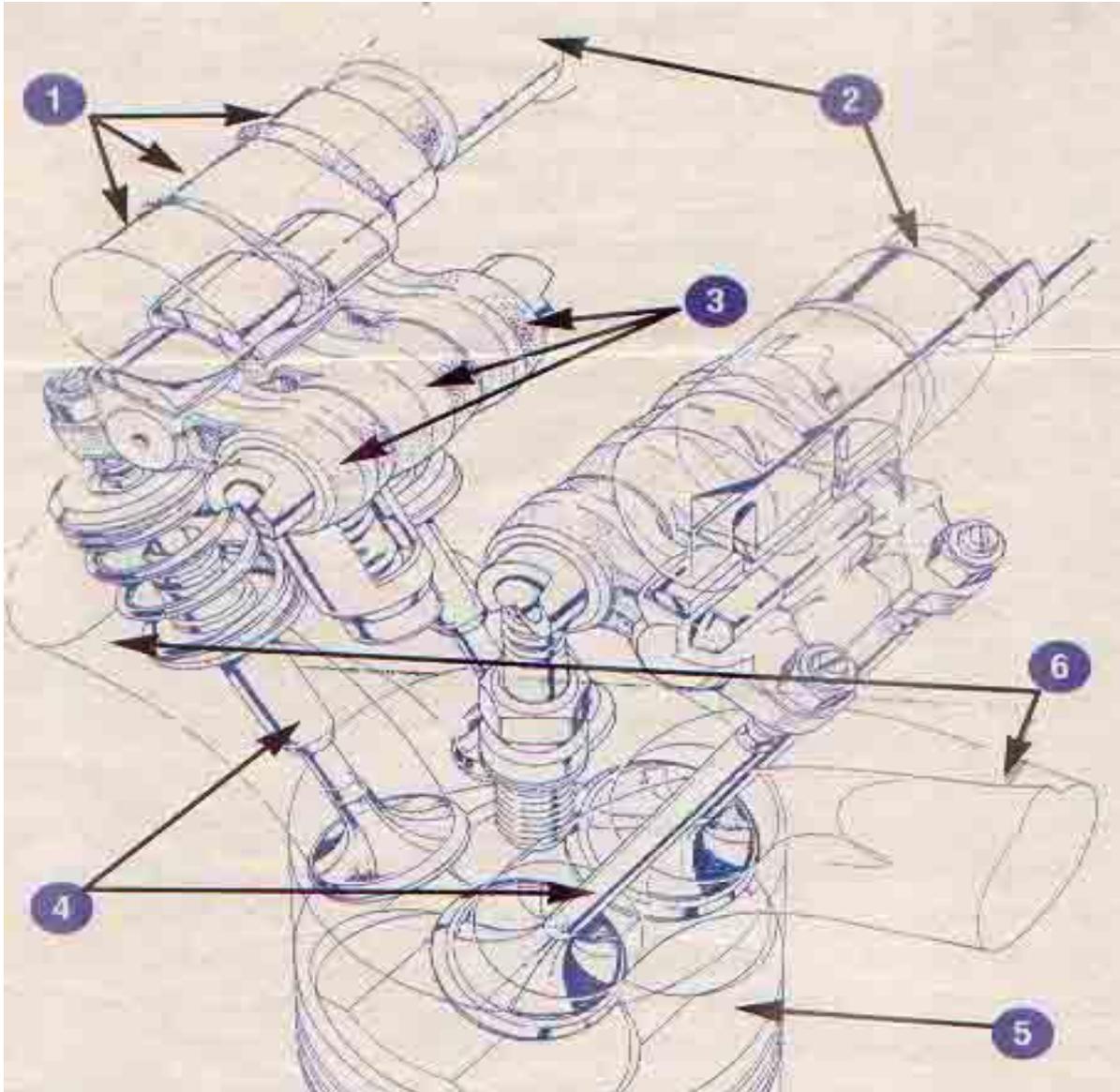
## **DEVELOPMENT OF VVT TECHNOLOGY**

Honda broke the ice when the NSX debuted in 1991 as the first production car with a variable valve timing system. Honda's VTEC (which sort of stands for Variable valve Timing and lift Electronic Control) system, which has basically remained unchanged since then, is still one of the most effective systems for making ultra high specific output. Ferrari has a really neat way of doing this. The camshafts on some Ferrari engines are cut with a three-dimensional profile that varies along the length of the cam lobe. At one end of the cam lobe is the least aggressive cam profile, and at the other end is the most aggressive. The shape of the cam smoothly blends these two profiles together. A mechanism can slide the whole camshaft laterally so that the valve engages different parts of the cam. The shaft still spins just like a regular camshaft, but by gradually sliding the camshaft laterally as the engine speed and load increase, the valve timing can be optimized.

## **TYPES OF VVT**

### **Honda VTEC**

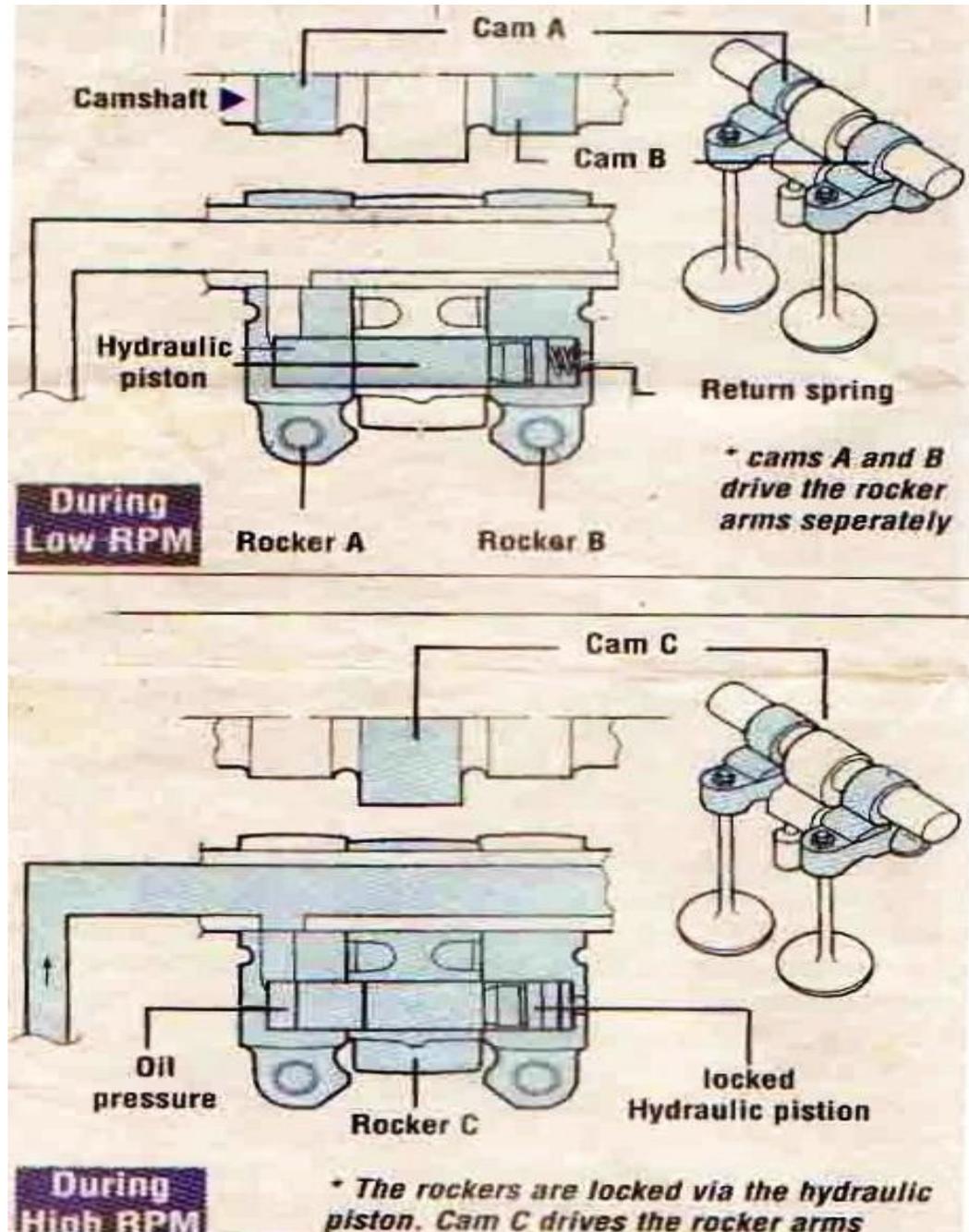
The concept is incredibly simple. So simple, in fact, that you have to wonder why nobody thought of it earlier. Basically each pair of valves has three cam lobes, two that operate the valves at low-rpm, and a third that takes over at high rpm. During low-rpm operation, the two rocker arms riding the low-rpm lobes push directly on the top of the valves. In most cases, the cam profiles of the two intake valves will be slightly different, promoting swirl in the combustion chamber for better drivability. At high rpm (usually 4500 rpm to 6500 rpm range, depending on the engine) the ECU sends a signal to an oil control valve that allows oil pressure to flow into the low-rpm rocker arms. A third, high rpm rocker arm sits between the two low-rpm arms and follows a much more aggressive lobe.



- |             |            |                   |
|-------------|------------|-------------------|
| 1. Cams     | 3. Rockers | 5. Cylinder       |
| 2. Camshaft | 4. Valves  | 6. Intake exhaust |

The low-rpm lobes in this case then actuate the valves through a set of rocker arms, so that the mechanical connection can be broken if desired. The third, high-rpm lobe also has its own follower, but it is in a freewheeling state, flopping around and not contributing anything. As our engine accelerates through its rev range, it passes through the power peak of the low-rpm lobes. Then, at the engine speed and throttle position programmed into the computer's memory map a signal is sent which electronically opens a spool valve, which then directs oil pressure to a mechanical sliding pin. This pin locks the rocker arms actuating the valves to

the follower on the high-rpm cam lobe. As this grind is steeper and higher than the other four cams it will supersede them. In a few milliseconds you have completely altered the valve timing and the engine's power band begins anew.

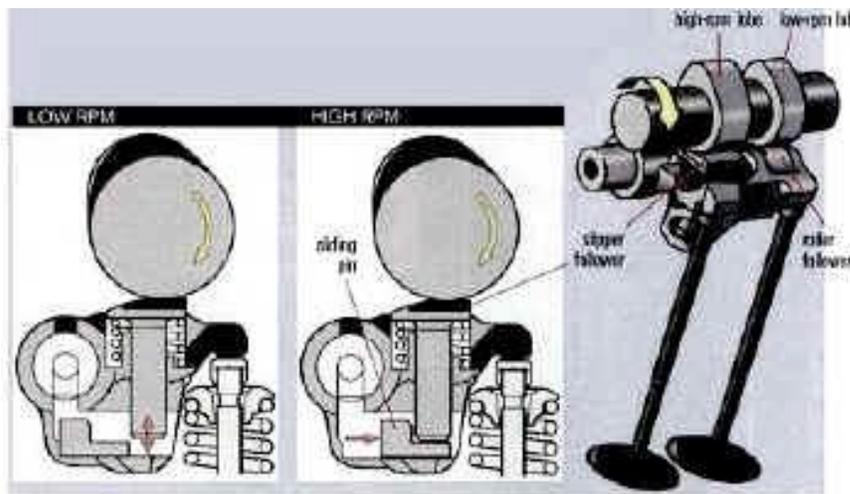


Since DOHC VTEC was costly and heavy Honda later on developed SOHC VTEC, which was lighter and cheaper than the DOHC VTEC. The SOHC VTEC controlled only the intake valves. As a VTEC driver, you can both hear and feel the change when the VTEC "kicks in" at higher rpm levels to improve performance. While this system does not offer continuously

variable valve timing, it can make the most of high rpm operation while still providing solid drivability at lower rpm levels. Honda is already working on a three-step VTEC system that will further improve performance and efficiency across the engine rpm range. The camshaft in a pushrod engine is often driven by gears or a short chain.

### Toyota VVT-i

Toyota originally introduced the VVT-i (Variable Valve Timing - intelligent) as a revolutionary design that increases engine torque and output while addressing environmental

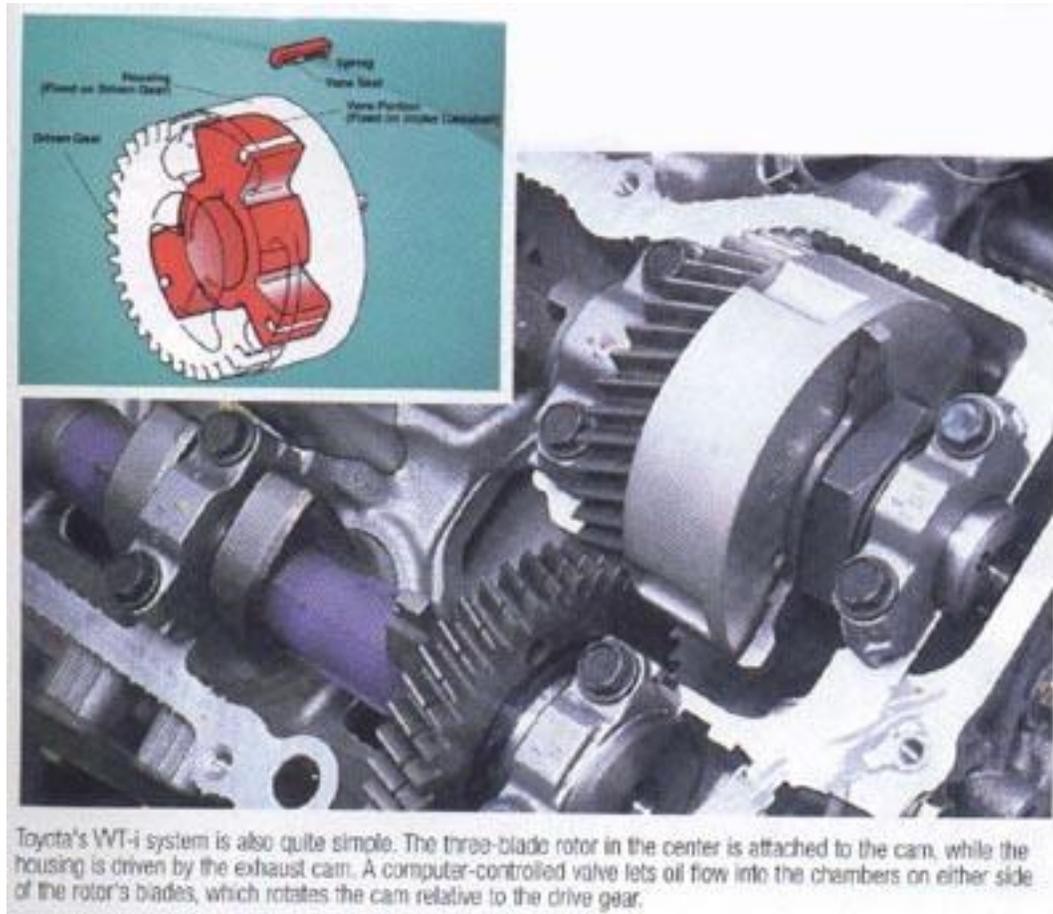


issues. By adjusting the intake valve opening timing according to the engine speed, more oxygen is supplied through the air intake valve as more fuel is injected into the combustion chamber. Power and torque is

maximized due to larger scale combustion. This optimized fuel to air ratio ensures the air-fuel mixture is combusted more thoroughly.

The VVT-i portion of the system continuously varies intake valve timing throughout the rev range by hydraulically rotating the camshaft relative to its drive gear. Note that VVT (without the "i") did not do this continuously. The VVL portion of the system incorporating two distinct cam profiles. However, the actual mechanism is quite different. Both cam lobes operate a single wide rocker arm that acts on both intake or both exhaust valves. A needle-bearing roller on the arm follows the low-rpm, short-duration, low-lift lobe, forcing both valves to open and close on that profile. The roller design and roller bearings on the rocker arm pivot help to minimize valve train friction. The high-rpm, higher-duration, longer-lift lobe rubs on a hardened steel slipper follower mounted to the rocker arm with a spring. Even though the high-rpm lobe is pushing down further than the low-rpm lobe, the spring absorbs the extra movement. At 6000rpm, the ECU sends a signal to an oil control valve at the end

of the camshaft that puts oil pressure behind a lock pin in the rocker arm, sliding the pin under the spring-loaded slipper follower, locking it to the rocker arm and forcing the arm to follow the high-rpm cam profile.



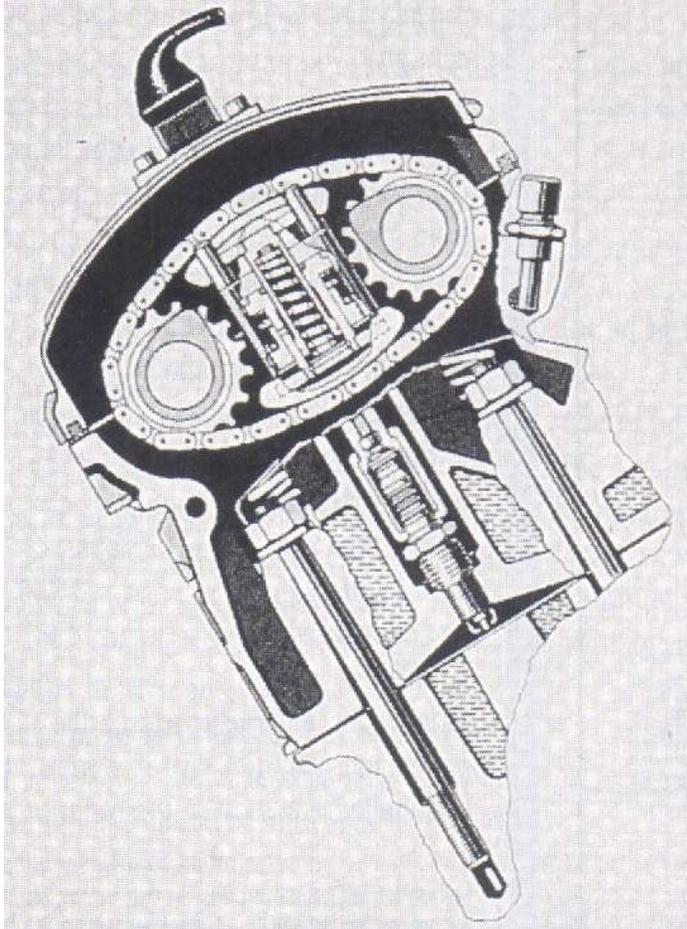
Toyota's newest version of VVT-i is also quite simple, though it may look otherwise on initial inspection. Again, the exhaust cam is driven from the crank, while the intake cam is driven off the exhaust cam. This time, the drive is via gears, and a mysterious cylinder behind the drive gear on intake cam controls cam timing. Inside this mysterious cylinder is a simple three-fluted rotor that actually drives the cam. By pumping oil into the chambers on either side of the three flutes, the hydraulic pressure can force the cam to advance or retard. This replaces the previous VVT-i system, which was basically an incomprehensible little box of gears, springs and splines.

The VVT-i system can change the intake cam timing over a 60 degree range, changing valve overlap from absolutely zero (for smooth idle, easy starting and better cold start performance), to severely overlapped for a natural EGR effect at medium load (eliminating

the need for an Exhaust Gas Recirculation valve), to whatever is ideal for maximum power at any point on the powerband.

### **Porsche's VARIOCAM**

Porsche's VarioCam, used first on the 968 and now used without the fanfare on all (both) of their engines is as simple as it gets. With VarioCam, the crank drives the exhaust cam, and

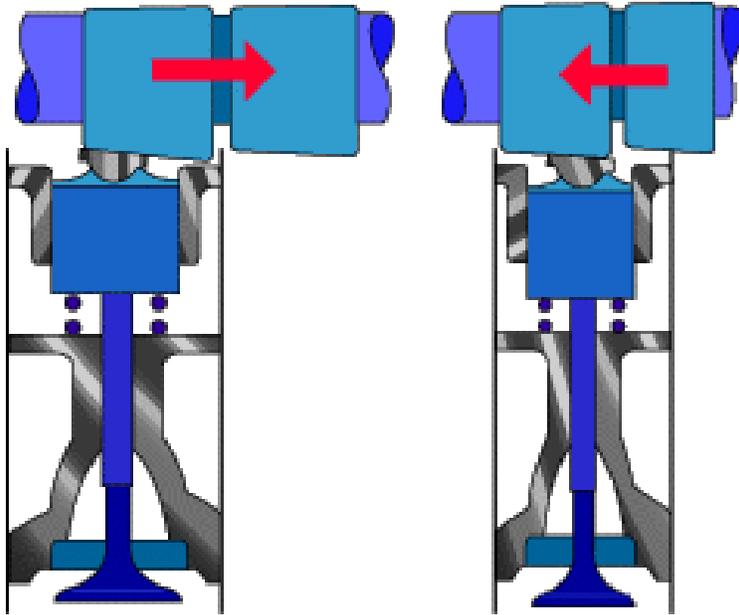


the intake cam is driven, via a short chain, by the exhaust cam. In order to advance and retard the intake cam, the chain tensioner on that short chain simply shifts up and down, moving the extra length in the chain from the tight side to the slack side. When the tight side has no extra chain (i.e. the chain is straight), the intake cam is fully advanced, as more chain is shifted to the tight side, the cam is retarded.

### **Ferrari's Cam Advance Mechanism**

Ferrari has a really neat way of doing this. The camshafts on some Ferrari engines are cut with a three-dimensional profile that varies along the length of the cam lobe. At one end of the cam lobe is the least aggressive cam profile, and at the other end is the most aggressive. The shape of the cam smoothly blends these two profiles together. A mechanism can slide the whole camshaft laterally so that the valve engages different parts of the cam. The shaft

## Variable Valve Timing



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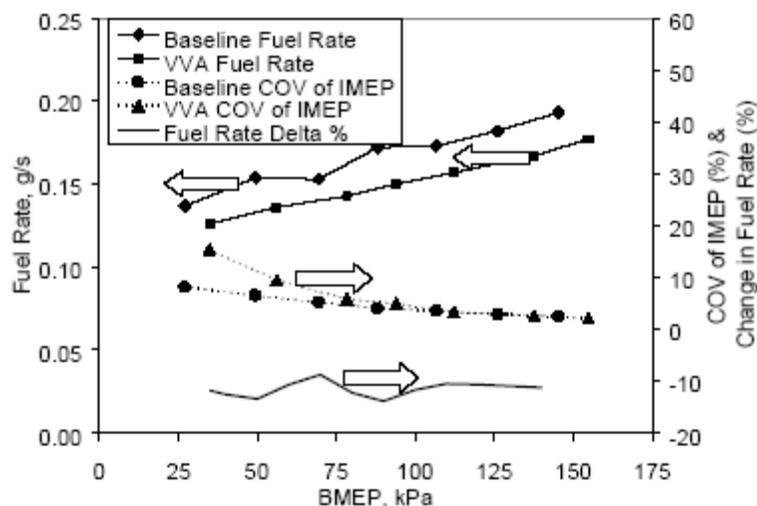
still spins just like a regular camshaft, but by gradually sliding the camshaft laterally as the engine speed and load increase, the valve timing can be optimized.

This does not keep the valves open longer; instead, it opens them later and closes them later. Rotating the camshaft ahead a few degrees does this. If the intake valves normally open at 10 degrees before top dead center

(TDC) and close at 190 degrees after TDC, the total duration is 200 degrees. The opening and closing times can be shifted using a mechanism that rotates the cam ahead a little as it spins. So the valve might open at 10 degrees after TDC and close at 210 degrees after TDC. Closing the valve 20 degrees later is good, but it would be better to be able to increase the duration that the intake valve is open.

## **BENEFITS OF VVT**

### **Smooth Idle**

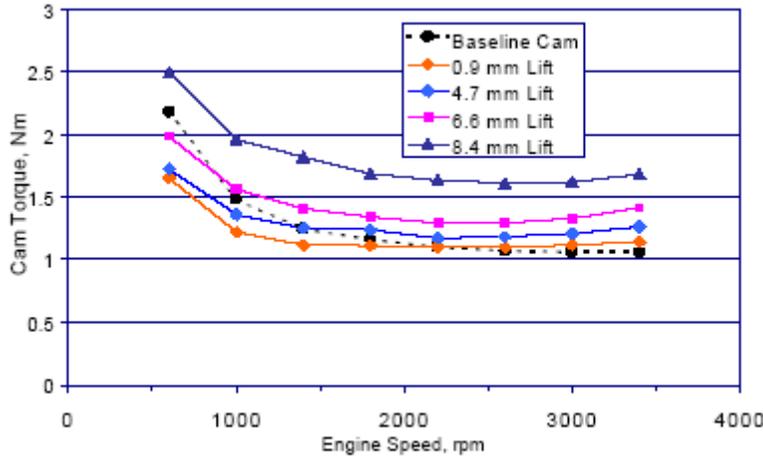


At idle rpm, retarding the camshaft eliminates valve overlap. With the intake valve opening after the exhaust valve has closed, there is no blow back of exhaust gases to the intake side.

Now, combustion is more stable because of the clean

air/fuel mixture. This allows the engine idle smoothly at a lower rpm and fuel consumption is reduced.

**Torque Improvement in Low to Medium Speed Range**

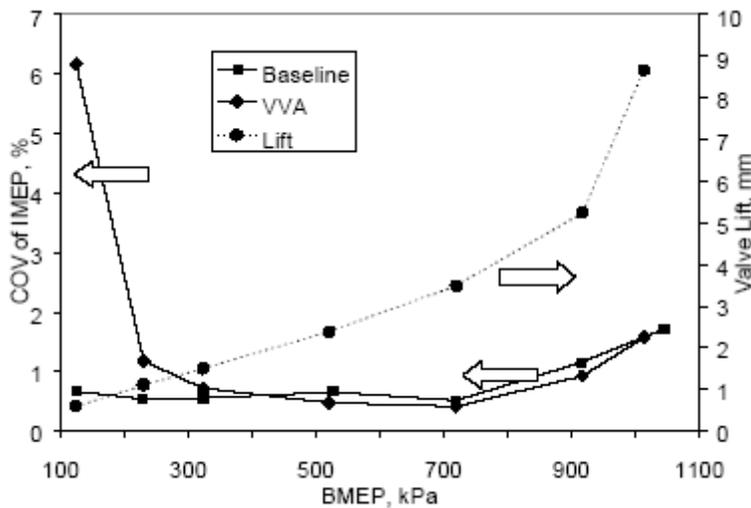


In the low to medium speed range with a heavy load, the camshaft is advanced increasing the valve overlap. This has two effects. First, the exhaust gases help pull in the intake mixture. Second, by closing the intake valve early, the

air/fuel mixture taken into the cylinder is not discharged. This improves volumetric efficiency and increases torque (and therefore horsepower) in the low and midrange rpm range. The driver notices a more powerful acceleration. Fig. 8 shows early measures of the VVT mechanism intake cam torque (friction) values. The cam torque for low lift is less than a baseline for low speed and low lift, but greater for high lifts and high speeds. Figure displays the effects of VVT upon idle speed operation.

**EGR Effect**

VVT eliminates the need for an EGR valve. As a result of increasing the valve overlap in

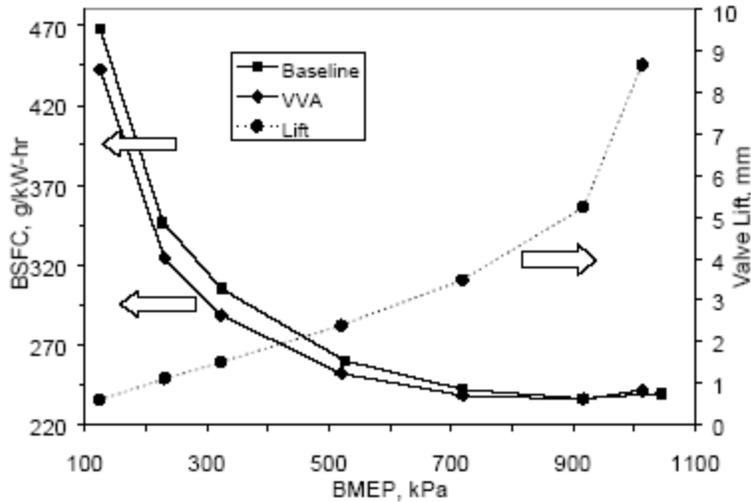


which the exhaust and intake valves are both open, the exhaust gas is able to flow to the intake side. Diluting the air/fuel mixture with exhaust gases reduces the combustion temperature and the production of NOx. Also, some of the unburned air/fuel

mixture present in the exhaust gas will be burned. Figure compares engine combustion stability (COV of IMEP) between the baseline and VVT configurations.

### **Better Fuel Economy**

A VVT equipped engine is more efficient and provides better fuel economy from a variety



of factors. Without VVT, the engine would have to be larger and heavier to produce the same horsepower. Smaller pistons, connecting rods, and crankshaft reduce friction and mechanical losses. A lighter engine improves vehicle fuel economy.

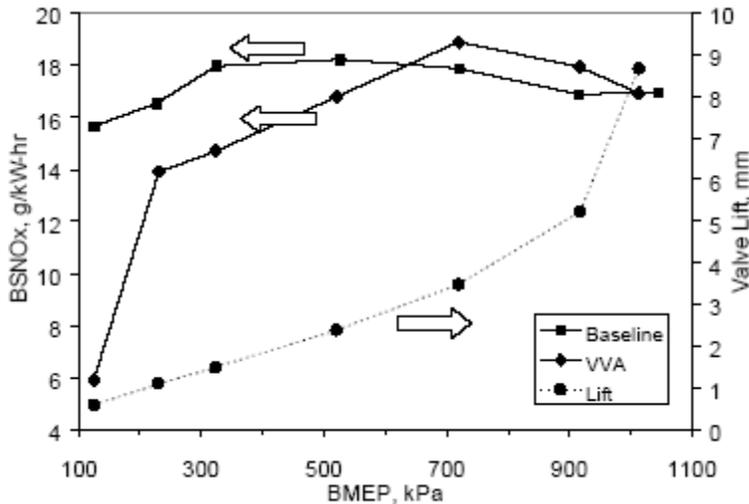
Improved fuel consumption is also realized because of the further reduction in the intake stroke resistance. In the medium-load operation range, when the valve overlap is increased, the vacuum (negative pressure) in the intake manifold is reduced. Now, it takes less energy to move the piston downward on the intake stroke. With the pumping loss reduced during the intake stroke, more energy is available to propel the vehicle.

At idle, with no valve overlap, the idle speed is lower improving fuel economy. Figure shows that at 2000 rpm, the application of the VVT mechanism to this engine (without additional engine design changes) reduces the Brake Specific Fuel Consumption (BSFC) in the low to middle load regions by 5 – 7%.

### **Improved Emission Control Performance**

In the light-medium load operation range, VVT increases the valve overlap creating an internal EGR effect. By opening the intake valve earlier in the exhaust stroke at a lower rpm allows the exhaust gases to push into the intake manifold mixing with the fresh air. The return of exhaust gas into the cylinder lowers the combustion temperature, resulting in NOx

reduction. Essentially, VVT will increase the valve overlap to obtain the same EGR effect as an engine equipped with an EGR valve. In other words, when an EGR valve on an EGR equipped engine opens is when VVT will increase the valve overlap.



Another benefit is that HCs are also reduced. Some of the unburned air/fuel mixture from the previous cycle returns to the cylinder for combustion. Finally, CO<sub>2</sub> is reduced because of the decrease in fuel consumption. Figure presents engine-out HC

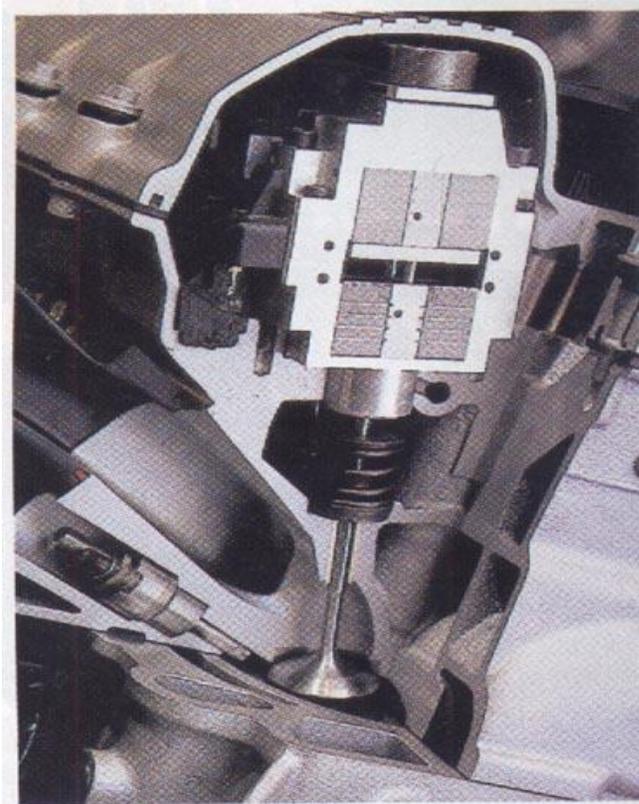
and NO<sub>x</sub> specific emissions at 2000 engine rpm.

## THE FUTURE

If all this exotic variable valve timing technology is commonplace now, what does the future hold? Currently we are limited to either adjusting overlap by moving a standard camshaft, or switching between two fixed cam profiles. There is no reason (other than cost) why both systems could not be used in parallel on one engine, but the benefits may be limited. The true future of variable valve timing is infinite adjustability of both lift and timing.

The idea of opening and closing the valves with large electrical solenoids has been bounced around for several years. Many different manufacturers from Cummins to BMW have proposed such systems, and even made running prototypes. There are a few problems with electronically operated valves, but let's look at the advantages first. Current gasoline engines control part throttle airflow via a throttle plate, essentially lowering the air pressure in the intake manifold by choking it off with a partially closed throttle plate.

## Variable Valve Timing



Electronically operated valves could replace cams in the future. This cutaway of a BMW prototype engine shows the powerful solenoid above each valve that controls its movement.

This causes significant pumping losses as the engine fights to suck air in from the manifold, and ultimately reduces the efficiency of the engine. If you limit airflow by reducing the time that the intake valve is open, though, pumping losses could be significantly reduced.

At wide open throttle (or full down pedal in the case of a throttle less engine) the valve timing could be constantly adjusted for maximum power - with no worries about one valve timing profile having to work from idle and redline like they do know.

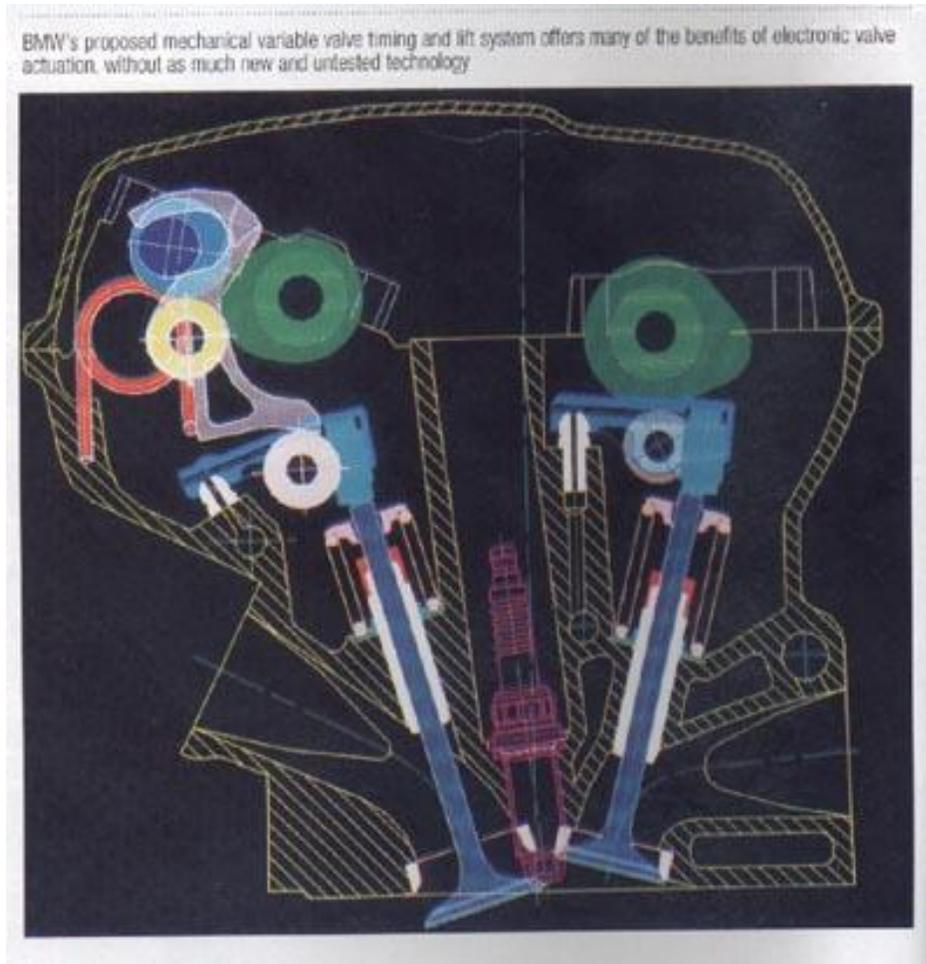
Now the downside. Eliminating all of the valve train reduces the cost

and complexity engine and reduces the internal drag, but not as much as you might think. Opening and closing the valves takes a certain amount of power, whether that power comes through a timing belt or a wire, it has to come from somewhere. In this case, the power would have to come from a huge alternator. This is not really a problem, but it is an extra cost that isn't initially obvious. More serious is the question of how to close the valves quickly but still have it land on the valve seat gently. With a cam, you just shape the lobe so it drops shut quickly and then slows down just before the seat. With a solenoid operating the valves, it takes sophisticated electronic controls

Finally, there is the matter of rpm limitations. Ideally, with strong enough solenoids, the engine would be able to spin even faster than a conventional engine, but the current solenoids have a hard time working that fast. On the flip side, though, because the valve opening speed is not engine related, mid rpm performance could be greatly improved by having the valves

slam to full open much faster than a conventional valvetrain, improving volumetric efficiency and making more power.

Finally, BMW has actually designed a mechanical system that still uses conventional cam lobes, but is still able to vary lift and timing by moving the fulcrum point of the rocker arm. The system is incredibly difficult to visualize, but it could offer most of the advantages of electrically actuated valves without delving so far into unexplored technologies.



With the current variable timing technologies, the 100 hp per liter hurdle has been cleared. Honda, in particular, has knocked the hurdle over and stomped it into the ground. With the technologies on their way, 150 hp per litre is on the horizon.

## **CONCLUSION**

So after this seminar we come to know that VVT technology is going to become prominent in road cars as this technology is going to be researched a lot and may be in few years its cost of production can be brought down to incredible levels. We already know about the benefits of such a system and there should not be anyone who dislikes this technology, since in today's eco-friendly world this technology brings a ray of hope for a cleaner and healthier environment. Already the automobile giants like Honda, Toyota, BMW, Mercedes-Benz, etc. are spending lots of money on research in this field. So VVT technology is bound to have a bright future in the automobile industry.

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