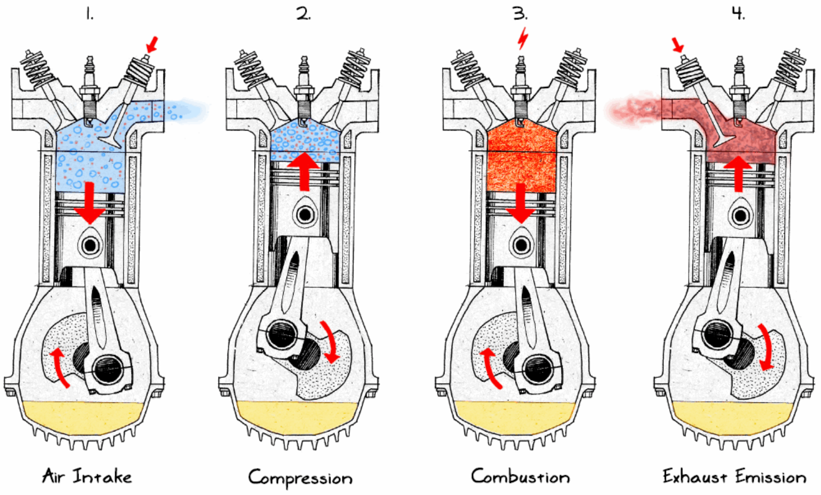
TECHNICAL FOCUS:

THE HISTORY AND FUTURE OF VALVE TIMING

Many forecast that the four-stroke engine wouldn't survive into the twenty-first century. That it's still going strong is owed to many technologies, not least its successful use of variable valve timing. By *Karl Ludvigsen*
Illustrations by *Barry Borchardt*



The four-stroke engine cycle is perfect. Whether you credit its creation to Alphonse Beau de Rochas, who wrote about it, or to Nicolaus Otto, who demonstrated it, you have to admire its elegance. First the piston goes downward to suck in a fresh charge on the intake stroke; next a stroke upward compresses the fuel-air mixture, followed by a spark that ignites the mixture to push the piston down to do work, ending with a stroke upward to push out the burned gases. Then it starts all over again.

Of course, it's not quite that simple. There's the tricky business of getting the gases in and out of the cylinders.

Having tried piston, sleeve, and rotary valves, we've pretty much settled on poppet valves as the most versatile and practical way to do this. We like cam lobes, too, as the best way to control their opening and closing, working through an intermediary like a pivoted finger or cup-type tappet to avoid side forces on the valve stems.

Do we just open and shut the valves at the tops and bottoms of the intake and exhaust strokes? No, we're more clever than that. When we're sucking in the fresh fuel-air mixture, for example, we don't close the inlet valves when the piston reaches the bottom of its stroke. We leave them open as long as suction remains in the cylinder to draw in the charge. This could be as much as 60 degrees of crank rotation after the piston reaches the bottom of its travel.

Nor, oddly enough, do we leave the exhaust valve shut until the bottom of the power stroke. We open it 50 or 60 degrees before the bottom when we think the remaining gas pressure is similar to that in the exhaust manifold. This would seem to waste useful energy, but it's the best way to avoid excessive back pressure that can hurt performance. It also explains why there's enough energy left in the exhaust to spin a turbocharger.

The trickiest part is when we're ending the exhaust stroke and starting to inhale a new charge with the piston at the top of its travel, known as "top dead center." We don't close the exhaust valve until 15 to 20 degrees of crank movement after top dead center. We want to be sure that pressure in the cylinder is as low as possible before we begin inhaling fresh gas.

Then we open the inlet valve 10 to 20 degrees before top dead center to take advantage of momentum and resonance in the inlet passages to begin the process of filling the cylinder with a fresh mixture. So between the early inlet opening and late exhaust closing at top dead center, we have 30 or 40 degrees of crank rotation when both valves are open. This is "overlap," celebrated in hot-rod annals for racy "high-overlap" camshafts. In fact, high-revving engines built for power can tolerate as much as 80 degrees of overlap.

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From these basics of cam design you can see that the watchword in valve timing for every engine is "compromise." What works at low speed may be wrong at high revs. High-overlap timing that produces power at high speed will be weak on low-speed torque and cause that lumpy idle that hot rodders love. Low-overlap helps slow-running smoothness and torque at the expense of power and efficiency. Thus cam profiles and timing are tailored to the best compromise for each engine—or have been until now.

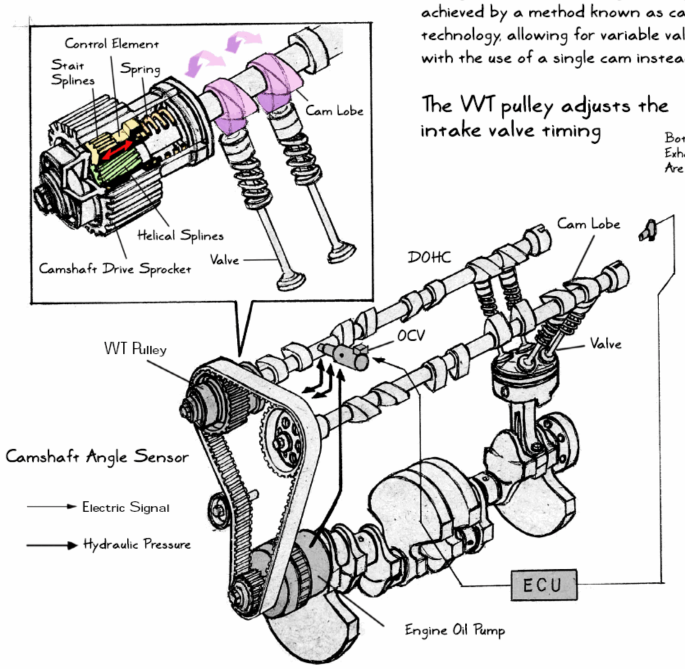
Engineers, who hate compromise, have long been trying to figure out how to change the valve timing of a running engine. Interest accelerated dramatically when emissions had to be reduced. In 1970 GM started exploring "Variable Cam Timing As an Emission Control Tool." Its researchers reported tests that showed how the overlap period could be exploited by valve-timing adjustment to dilute the incoming charge with exhaust gases deliberately as a means of keeping flame-front temperature below the 2500°F that causes a spike in NO_x emissions.

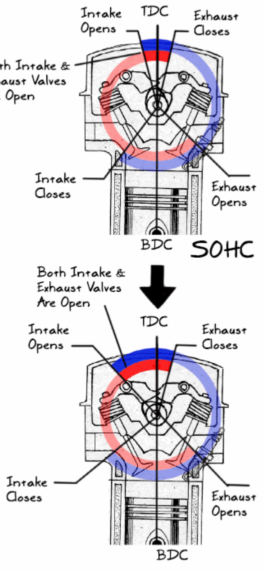
External recirculation of exhaust gas (EGR) became a well-known technique for NO_x reduction in the 1970s, but if it could be achieved internally it would be much less cumbersome. More overlap makes this possible, some exhaust gases actually entering the inlet tracts to be regurgitated into the cylinders with their fresh charge. But this wrecks the idle and low-speed running, deteriorating the engine's ability to fire up its catalysts with high exhaust temperatures during the crucial start-up period.

Enter, stage left, variable valve timing.

First to use it in production was Italy's Alfa Romeo. Alfa was a good candidate because it has produced twin-cam engines since time immemorial. Having separate camshafts for the inlet and exhaust valves made it easy to vary the timing of one, the other, or both. Alfa's Giampaolo Garcea invented a device that fitted inside the drive sprocket of the inlet camshaft. It joined sprocket to cam by helical splines along which a member slid to change the timing. At high engine speeds, it could advance the inlet timing by 32

Shown Below Right: A diagram of intake valve timing at its different stages of adjustment, achieved by a method known as cam-in-cam technology, allowing for variable valve technology with the use of a single cam instead of two.





degrees to give 48 degrees of overlap instead of the default value of 16.

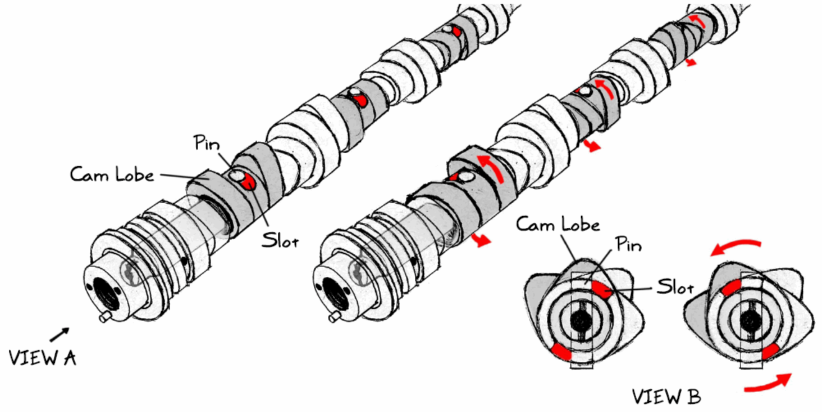
Alfa Romeo's system, which switched between two inlet-valve timings, was first used on U.S.-market Spiders with fuel injection. In 1984, Alfa rolled it out for other models in Europe, timed more for fuel economy than emissions. In the latter application, its success depended on its operation by Bosch's then-new Motronic engine control. Since then, successful valve-timing variability has depended almost completely on triggering by modern electronic engine-control systems.

Then more applications surfaced, all on twin-cam engines. Nissan fitted its NVCS system to the 300ZX in 1987 and in 1989 Honda introduced its first VTEC, which provided switching between two different cam-lobe profiles. Later it supplemented this with camshaft-position variation. On its twin-cam six, BMW began using its VANOS system in 1992. A hydraulic vane-type device, it was fitted to the inlet camshaft. Double VANOS followed in 1998, fitted to both camshafts and allowing fully variable valve-timing adjustment instead of step changes. Porsche first exploited a chain between twin camshafts to get timing variability, later adopting its own version of a cam-lobe-switching system.

All of these were and are used on twin-cam engines, taking advantage of that layout's ease of controlling inlet and exhaust events separately. But many engines still have single overhead cams, with inlet and exhaust lobes on the same shaft. Plentiful, too, are good old pushrod engines, inline and V, with the same arrangement. How are we to change the phasing patterns and timing of cam lobes on one and the same shaft?

The easy way, of course, is to get a partial benefit by varying the rotational position of the complete camshaft. There's no change in overlap, because inlet and exhaust lobes are fixed in their relative positions. However, shifting the relationship of the whole cam to the crankshaft can bring some advantages in altered inlet-valve timing. In 2005 GM was the first to do this in a new version of its 3.9-liter V-6 as used in Chevrolet, Pontiac, Saturn, and Buick models, claiming benefits to emissions and fuel economy.

This was easy enough to do. The well-established technology of a hydraulic phase adjuster on the driven end of the camshaft was all that was needed. This was child's play compared to the real challenge, which was to vary the relative positions of inlet and exhaust lobes on a single camshaft.



Well aware of the benefits of EGR through overlap, in 1973 GM's researchers built an experimental camshaft for a Chevy V-8 that was capable of doing just that. It used an inner shaft concentric with an outer shaft that carried the exhaust cam lobes. Helical splines shifted the position of the intake lobes, mounted in two sets of four on the inner shaft. It worked after a fashion, but was hard to make and needed materials that were judged too costly.

Other inventors had a go, including Alvon Elrod and Tim Nelson at South Carolina's Clemson University. They started work in 1984 on a system they patented in 1988 and publicized in 1991. Again, concentric shafts were used, in their case with actuation of timing changes by electric motors. Although several automakers evaluated Clemson's system, none picked it up.

In Britain, at R&D company Mechadyne International, variable valve-timing system specialist Dr.

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Tim Lancefield was puzzling over the problem. He was convinced that enough pushrod engines were still being made around the world to justify the cost and effort needed to come up with a solution.

During the 1990s Lancefield and his colleagues turned to the concentric-shaft approach. Their hollow outer shaft carries the exhaust-cam lobes. In it are slots for pins that anchor the inlet lobes, on the exterior of the camshaft, to the inner shaft. The slots are no longer than necessary to allow the amount of relative movement needed between the inlet and exhaust event timings.

With conventional manufacturing techniques, making such a camshaft would have been a nightmare. In the meantime, however, new methods came to the rescue. Camshafts began to be fabricated from steel parts that were assembled, cam lobes onto hollow shafts, giving lightness and higher precision at affordable cost. Mechadyne adopted this method to make its camshaft, starting at one end with the assembly of its lobes and ending at the other. With the addition of a phase adjuster at the drive end, its variable-valve-timing camshaft for pushrod engines was complete. What it called the "SCP" camshaft could adjust inlet and exhaust timing independently.

In the late 1990s Mechadyne started looking for customers in the obvious place: Detroit. At Chrysler, historically open to new ideas, it found interest in the Viper design group. The Viper's big V-10 engine wasn't short of power. Its valve timing had substantial overlap, and as a result it struggled to achieve the stability of running at idle and low speeds that was needed to meet new rules requiring on-board diagnostic (OBD) systems. Variable valve timing looked like the solution.

In 2002 Mechadyne and the Viper crew, among them Kraig Courtney and Pete Gladysz, began working on an installation of the British firm's SCP technology. Only slight increases in camshaft-bearing diameter were needed to make room for the more complex assembly, and then, for manufacturing reasons.

Chrysler elected to vary only the timing of the exhaust valves, advancing their closing to reduce overlap at low engine speed. This alone contributed significantly to the programming that had to be added to its electronic controller, at no little cost. That controller, supplied by Continental, has processing power increased tenfold.

Germany's Mahle took on the assignment of assembling the SCP camshaft. Under license from Mechadyne, it's also promoting the new concept as its "CamInCam" technology. The result has been an 8.4-liter engine for the 2008 Viper SRT10 that can meet emissions requirements, including OBD, while producing 600 horsepower at 6100 rpm and 560 pound-feet of torque at 5000 rpm. The engine's already ample torque was another reason why inlet-valve control wasn't added to the SCP camshaft, explained Kraig Courtney, because it would only "translate to more tire smoke." The Viper makes plenty of that already.

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Does the solution to this knotty problem mean that we've gone as far as we need to in controlling poppet valves? Not if an astonishing number of researchers have their way. The sales potential offered by the auto industry is so vast that they're spending remarkable sums on the creation of the ultimate in valve control: direct electrical actuation. Valves would be individually opened and closed by hydraulic forces, under electric servo-valve control, or directly by electromagnets.

This, the so-called camless engine, holds out the promise of complete mastery of valve motion according to the engine's needs, guided by a central electronic brain. The principles of such valve actuators differ little from those described in a 1975 patent by Kenneth Longstaff and Stanley Holmes, based on the work they were doing for British Leyland. Springs are still used to help close the valves under the control of magnets in the form of solenoids. Sensors are needed as well, to give feedback to the electronic controller on what the valves are doing.

For researchers and suppliers, the creation of a cost-effective camless

engine would be a bonanza. Lotus has been working on its Active Valve Train for some years. In 2003 it licensed America's Eaton to build demonstrators and introduce its AVT to automakers. Another British firm working in the field is Ricardo. In France, Valeo is another advocate, claiming to be working with "several global automakers" on its camless concepts.

Nor is Germany's high-tech industry lagging. DaimlerChrysler's Stuttgart arm is said to be working with a concept developed by Heinz and Thomas Leiber. Their LSP Innovative Automotive Systems GmbH licensed Magneti Marelli as its supplier and development partner. Leading researcher FEV has its own system, while Bosch and AVL have another in the oven. BMW—first to develop an inlet-valve system that is also a throttle control, Valvetronic—is working on its own camless engine.

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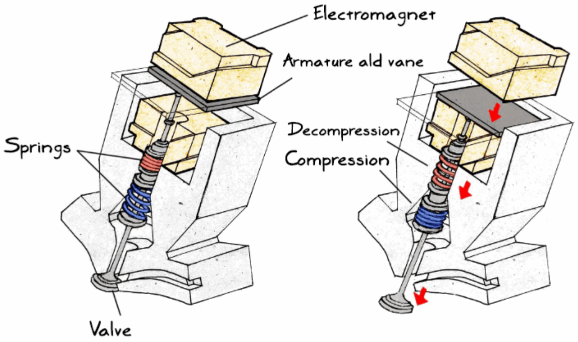
The unlimited versatility of valve timing with camless operation could be a boon to a new type of combustion that some researchers see as extremely promising. Called "Controlled Auto Ignition," it's akin to making a gasoline engine act like a diesel. With CAI, the fresh charge ignites at many points throughout the chamber, set off by the heat of compression plus retained warmth from recycled exhaust gases. No ignition spark is needed. But CAI does need substantial amounts of both internal and external EGR—just what a camless engine can provide. Early tests show a 10 percent improvement in fuel economy with CAI.



The camless campaign received a big setback a couple of years ago. For a while, we had a strong push toward forty-two-volt electrical systems for future cars. This was thought desirable for the many electrical systems that were coming, providing ample power for control-by-wire operation of steering, braking, and springing. Many developers saw the heightened voltage as essential for camless engines. Now, forty-two volts have been pushed out of view, beyond the horizon. That could improve the chances of systems that use electronics to control hydraulic valve operation.

Thus that "perfect" four-stroke cycle has needed a lot of tender loving care. Easily shrugging off the attacks of alternative engines, the indomitable Otto has shown impressive vitality. With a little help from its friends, it's alive and well in the twenty-first century. Variable valve timing is one of the techniques that is contributing in no small measure to its remarkable prosperity.