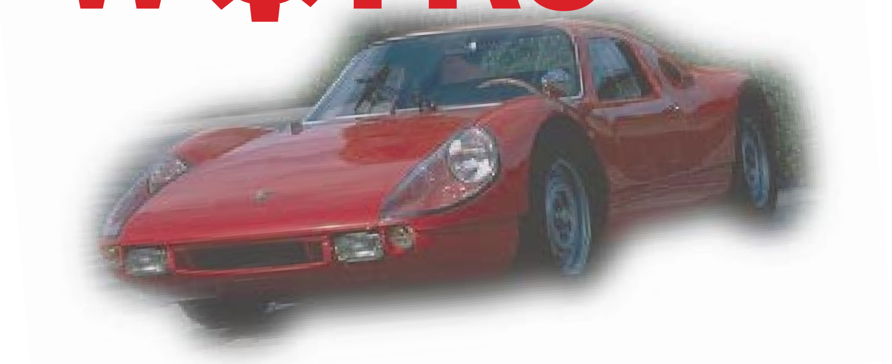


SOFTWARE-BASED CONTROL MAY REPLACE MECHANICAL CAMS THAT CONTROL INTERNAL COMBUSTION-ENGINE VALVES, BUT POTENTIAL ROADBLOCKS REMAIN.

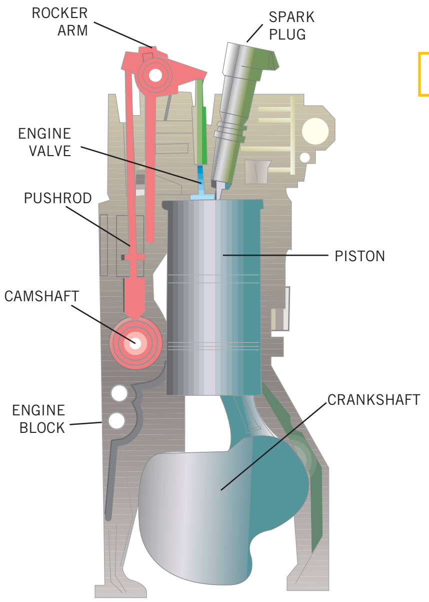
Electronics may be poised to displace engine cams

By Bill Schweber, Executive Editor

WHETHER YOU DRIVE A PLAIN, old car or a fancy, top-of-the-line model, as long as your vehicle has an internal combustion engine, it has cams that drive engine valves and their timing. Under the control of cams, which are connected to the engine crankshaft, the valves allow the ignitable gas-plus-air mixture into the cylinders and the exhaust out of the cylinders at precise moments. This timing is critical to the four-stroke combustion process that is common to automobile and truck gasoline and diesel engines.

The crankshaft, cam, and valve combination, or the valve train, is a whirring, interlocked set of mechanical pieces that uses either pushrods and springs or an overhead cam and direct engagement to control the valve motion via rocker arms (**Figure 1**). (Note that there is an electronic counterpoint to the engine-timing subsystem: The system-clock generator and associated clock-distribution circuitry are used in processor-based boards, such as motherboards.) The cam-based system is complex but reliable as a result of years of refinement and hundreds of millions of units in operation in the field (see **sidebar** "Cams set the pace for valves"). Although the system is relatively inflexible, it is especially reliable when flexibility in operation and timing are not a priority. In addition, it is entirely composed of visible mechanical parts, so you can diagnose and repair problems.

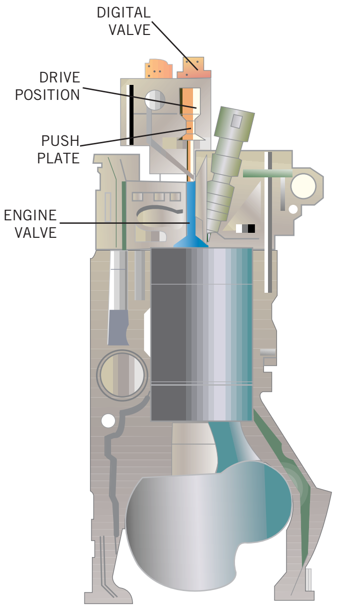
Figure 1



Most standard internal combustion engines use an arrangement of cams, pushrods, and rocker arms to control valve timing and motion profile.

But the cam-based system has limitations. Fixing problems is not a simple operation, because you must remove, reassemble, and remeasure all of the system's parts. In addition, the system is inflexible, because the mechanical shape and dimensions of the cam's lobes, as well as the associated linkages and pieces, set the timing. However, on a positive note, this inflexibility is a testament to the system's consistency and repeatability over many years and miles. Automotive engineers can design a cam-

Figure 2



The future of valve control may be an electronically controlled hydraulic valve, which combines the flexibility of process-based control with the motive power of a pressurized fluid.

based system with some variable timing, if desired, by shifting the timing cycle slightly depending on engine rpm and other factors, but such a design is more complex and costly and relatively inflexible.

Automotive engineers have known for many years that if they could implement more control and adjust valve timing, they could boost engine output power and reduce pollutants in the engine exhaust. To take this approach, you can use a smart timing system, which involves an engine-crankshaft angle sensor for providing an input signal and a µP for executing algorithms, and then drive electronically controlled valves. This combination is easy for engineers to design as part of engine controls, especially because processors from 8-bit µCs to 32-bit units are common in vehicles. Major auto and truck makers know this, and they are testing such smart systems for their gas and diesel engines.

Three critical elements of affordable µPs, power-management ICs, and valve actuators are coming together. The goal is a flexible valve-control system that improves performance while reducing emissions. Camless control allows engine control subsystems to vary valve timing, valve lift, and compression ratio in response to engine load, temperature, fuel/air mix, and other factors. If the engine's load is light, it even allows the control module to deactivate cylinders to save fuel. Such a system can also compensate for component wear over time and engine life.

NOT AS EASY AS YOU THINK

Conceptually, it is architecturally uncomplicated to replace a mechanical valve train with a processor-based one. In practice, though, major obstacles hinder successful implementation, in addition to the long and established history of the entrenched approach. If you naively think, "What's the big deal? Just use the digital output of a processor to drive a solenoid," you lack insight into the limitations, standards, and long-term issues that automotive engineers face.

You can move a valve electronically in two ways. As one approach, you can use a solenoid, a reliable and well-understood transducer for converting an applied current into linear motion and static force. However, challenges exist if you use a solenoid under the hood. First, the current pulse you need to activate the solenoid with the force and speed required in this application is large and difficult to get from the 12V supply of the vehicle without heavy supply cables. You also need a hefty MOSFET or similar switch to handle the current, and the relatively modest digital output drive of the valve-timing processor must control the switch. Although this solenoid operates at a moderate duty cycle, its overall rate of operation is high enough that you face self-heating problems. The heat under the hood, which is especially high near the engine, aggravates these problems. For this reason, the solenoid approach must wait until vehicles switch from 12V supplies to the more efficient 42V standard that automakers have agreed to phase in over the next few years.

Solenoids alone can actuate in either direction when you reverse the power supply to them. But this is complicated to do in a single-supply, grounded environment, such as a car or truck. It is more practical to use a spring to develop the return force. The solenoid then has to open the normally closed valve by overcoming the spring's force. You can design a solenoid with a pair of springs in which the applied force overcomes the return spring force while a helper spring pushes the solenoid in the actuate direction and reduces the holding current that you need. However, these factors add complexity and cost to the design.

Finally, solenoids are on/off actuators with relatively fixed force-versus-distance characteristics. Without springs or other external forces, the solenoid's force is lowest initially as the magnetic field pulls the core slug in toward its center; the force is greatest at the center at the final resting point of the actuator travel. Consequently, a solenoid slams the valve closed fairly hard, which aggravates wear on the valve seals unless you use mechanisms, such as springs or other damping components. (Note that the mechanical cam-based valve train solves this distance/force problem by carefully shaping the profile of the cam lobes.) One approach is to build a closed-loop solenoid with a sensor that monitors the core's position and use this information to modulate the drive current. But this approach also adds complexity and cost to the design.

An alternative to the solenoid is the hydraulically actuated valve mechanism (**Figure 2**). In this design, pioneered by Sturman Industries (www.sturmanindustries.com), a small and fast-acting electrohydraulic actuator provides the "muscle" for valve motion under the control of an electronically controlled digital valve. (The fluid power travels via the fuel-injection system and pump.) The digital valve uses residual magnetism (the magnetic field that remains after you magnetize an object) to hold the valve open without any applied current after the current pulse moves the valve. Engineers developed this type of valve during the Apollo space program and modified it for engine control. According to Sturman, the valve offers much more pressure combined with precise position control, because the hydraulic valve is a linear transducer. The current flows through two small coils on either side of a small spool that controls fluid flow rather than through a large solenoid; as a result, the system-response time is about five times faster with the coil-based design than with the solenoid-based configuration. The processor can modulate the spool motion—and thus fluid flow and power—to yield the desired force and distance profile.

WHAT'S THE REALITY?

The camless engine is more than just a dream. Manufacturers, such as International Truck and Engine Corp (part of Navistar, www.navistar.com), plan to use it in production trucks in 2007 models. This system uses a Siemens electronics module with two Infineon 167 µPs operating at 24 MHz. A prototype camless truck successfully participated in the recent Pike's Peak International Hill Climb, which covered 12 miles of winding roads to the 14,000-ft summit, without breakdown. Renault of France is looking at using a camless system with a solenoid actuator for some diesel cars by 2002.

Of all vehicle types, big trucks, which have the most to gain in operating efficiency from the flexibility of camless engines, will probably be the first vehicle with large-scale deployment for the valves. In addition, such trucks usually have dedicated service facilities and rigorous maintenance schedules. Diesel cars and then gasoline cars will benefit next from camless engines and will probably use basic solenoid actuation with a 42V supply rail. Vendors still need to do a considerable amount of life testing and verification of the control algorithms that enhance performance. Because camless control is so flexible, it gives car and truck manufacturers many more degrees of freedom and thus countless operating modes they need to test.□

You can reach
Executive Editor Bill
Schweber at
1-617-558-4484,
fax 1-617-558-4470,
e-mail bill.schweber@cahners.com.

References

1. Higgins, Amy, "Camless engines give 'peak' performance," *Machine Design*, Oct 5, 2000, pg 72.
2. "Diesel maker to do away with camshafts," *Design News*, July 3, 2000, pg 41.
3. Murray, Charles J, "Electronic controls to replace camshafts in diesels," *Electronic Engineering Times*, April 17, 2000.
4. Birch, Stuart, "Tech Brief: Renault Research," *Automotive Engineering International Online*, March 2000.
5. Brown, Stuart F, "Closing in on the camless engine," *Fortune*, May 29, 2000.

CAMS SET THE PACE FOR VALVES

The traditional pushrod-valve train begins at the engine's crankshaft, which converts the up-and-down motion of the pistons in the cylinders into rotary motion. In addition to conveying engine power to the transmission, the crankshaft drives a camshaft through gears or a chain. The rotating camshaft's lobes push on vertical metal rods (pushrods), which serve two purposes: They carry the camshaft motion from the bottom of the engine where the camshaft is located to the top of the engine where the cylinder's valves are located. They also convert the lobe's rotation into up-and-down motion. Then, the pushrods move rocker arms. As a pushrod raises one end of a rocker arm, the other end moves down, which closes the valve associated with that rocker; as the pushrod moves down, the valve end of the rocker arm rises and opens the valve.

This system works well, but it has some limitations in high-performance engines. The mass of pushrods limits the system's responsiveness, and inevitable wear of components causes numerous points for tolerance buildup and slack. One way to overcome these drawbacks is by following an overhead-camshaft design, which is common in most high-power engines. A belt or chain from the crankshaft still drives the camshaft, but the camshaft is located on top of the engine above the cylinder heads. In this configuration, the camshaft can directly control the rocker arms, which eliminates weight and tolerance problems with the pushrods. In a dual overhead-camshaft design, one camshaft controls the inlet valves, and a second camshaft controls the exhaust valves. This design allows for precise control over each of these valves, which are keyed to the engine rotation.

Some engines vary the camshaft timing in accordance with rpm by using a mechanism to shift the camshaft timing with respect to the crankshaft. Although this procedure does improve performance, it adds complexity and allows only a fixed shift. It also lacks the flexibility, wide variability, and dynamic adjustability that camless systems provide—at least in theory.