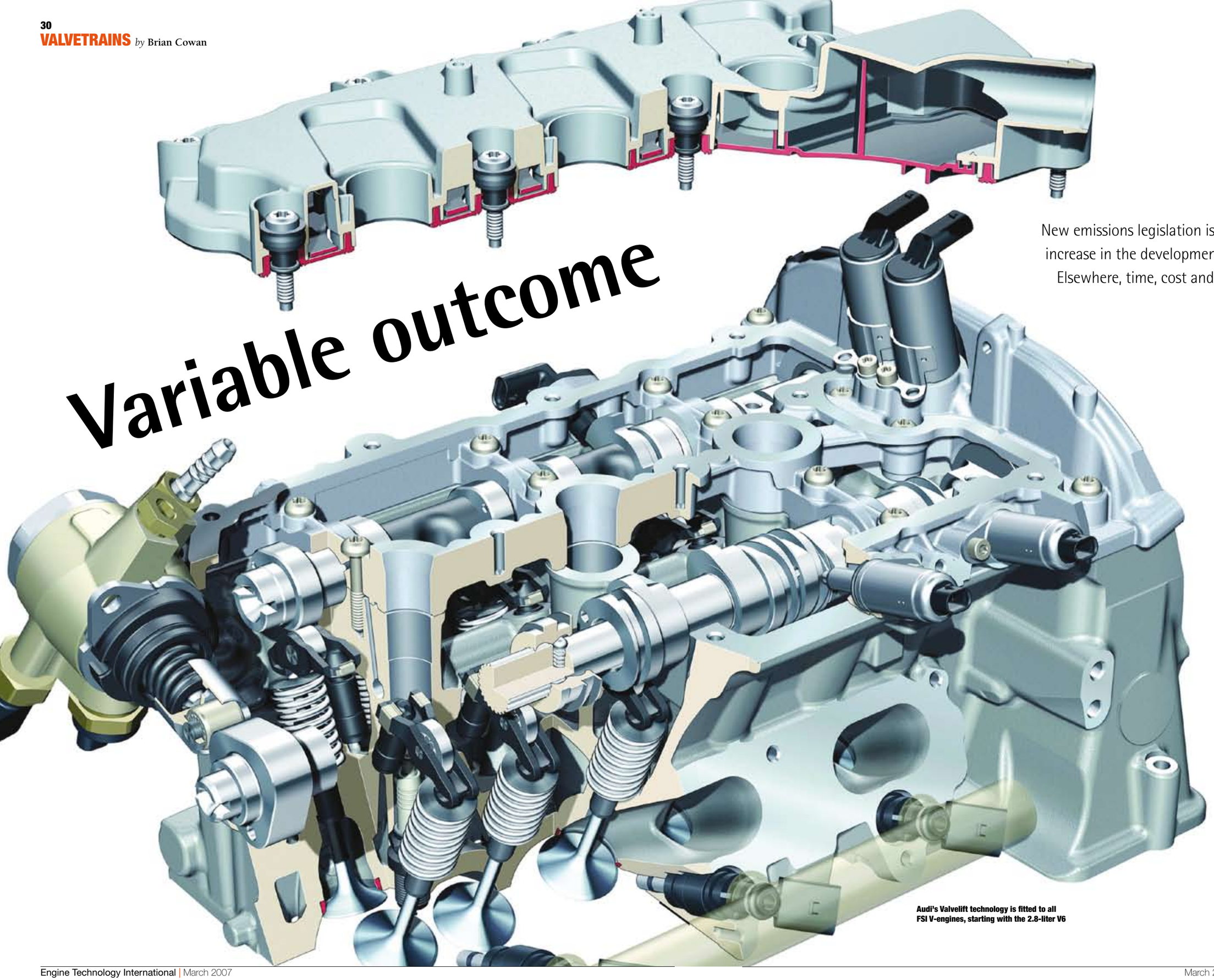
Variable outcome

New emissions legislation is one of the reasons for an increase in the development of advanced valvetrains. Elsewhere, time, cost and weight needs to be saved



Audi's Valvelift technology is fitted to all FSI V-engines, starting with the 2.8-liter V6

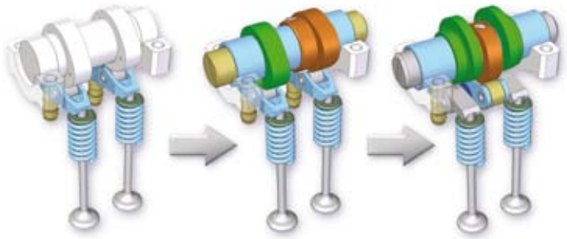
Though not quite as much of an ever-receding mirage as fuel-cell vehicles, which have been '10 years from production' for the past 15 years, advanced valve systems too have stayed tantalizingly out of reach. However, with legislation on tougher CO_2 standards looming, and with researchers closing in on the Holy Grail of HCCI, there has been a recent resurgence of interest in a field that has been relatively quiescent after a flurry of activity in the late 1990s. Full camless variable valve actuation (VVA) is still some time away, but at least three suppliers are firmly committed to developing production versions; also at an advanced stage of development are several systems that retain the camshaft but offer a high level of variability in both lift and duration. In the meantime, a clutch of ingenious phase-shifting and profile-switching designs has just entered service or are close to debut.

Schaeffler KG is confident of being at the forefront of the new wave with its UniAir system, based on the core research – carried out originally by and licensed from Fiat's CRF. UniAir is a lost motion design that uses the camshaft and engine oil to operate a high-pressure piston pump, and a fast-acting solenoid valve to control the oil volume trapped in the high-pressure area, thereby generating variable lift and timing profiles for individual valves. The valve landing velocity is adjusted using a separate hydraulic braking

piston. John Taylor, director and general manager of Schaeffler UK's automotive division, confirms that UniAir will soon reach production with an unnamed OEM. "Job one," he says, "is set for 2009".

Electro-hydraulic camless systems provider, Sturman Industries, has had a recent setback with the replacement of the HEUI (hydraulic electronic unit injector) fuel system in the company's 6.4-liter V8 diesel with a more conventional piezo-triggered common rail design. The HEUI was based around Sturman's quick-acting digital valve, which seems to have suffered from leakages in the partial-stroke mode.

The change to the V8's fuel system means that a proposed future introduction of camless operation using the same oil supply and similar stepped-piston actuators is now unlikely. Sturman, however, continues to develop its family of hydraulic valve actuation systems, including a single stage, open loop, variable lift design and a research module.



Mechadyne's VVA technology, the valve lift and duration design, carries two sets of lobes per inlet or exhaust valve set, thus operating them through a compound roller rocker as shown from left to right

While BMW's Valvetronic continues as the only true variable lift and duration design on the market, several other similar mechanically variable designs have been developed and are ready for production when engine makers consider that conditions warrant it, believes Phil Carden, from Ricardo's design analysis group. "My opinion is that the suppliers in Europe have their own designs for this sort of system, either on the shelf or in development. Nobody else has so far followed BMW, because though there are benefits to be gained with such designs they are also very expensive and don't suit everybody at the moment."

Tim Lake, from Ricardo's gasoline engineering group, concurs: "As CO_2 legislation in Europe and the US kicks in, you will start to see more and more of these applications being put into production – probably filtering from the top down. There will always be some manufacturers at the top end who will produce what you might call halo products, but the likes of camless engines are still a good way in the future in terms of mass-market applications."

In the field of advanced mechanical valve trains, one of the more intriguing has been developed by Mechadyne International. At the heart of what can become a graduated update path for an engine family is the company's SCP or concentric camshaft design, which is to reach production in the 2008 Dodge Viper. A hollow outer camshaft tube carries one set of lobes, with the second set being pinned to a solid inner camshaft. The pins project through slots cut in the surface of the hollow unit. The approach is especially suited for cam in block designs such as the Viper engine, and allows the use of phasers on each of the inlet and exhaust camshaft elements.

The motor driven electric variable valve from Denso in Japan makes use of an electric motor in the actuator mounted axially with inlet camshafts that spins faster than the shaft in order to advance the timing. Debuting in the Lexus LS460 earlier this year, Denso's system realizes better response at low engine speeds and temperature levels

In Mechadyne's VLD (valve lift and duration) design, the same type of concentric camshaft carries two sets of lobes per inlet or exhaust valve set, operating them through a compound roller rocker that sums the profiles.

Retaining the camshaft in the same position as a conventional engine was one of the primary reasons Mechadyne went for the concentric approach, says technology director Dr Tim Lancefield. "It means that if you design an engine incorporating our system, you can begin with conventional fixed camshafts, then stage through the twin-phaser approach and then on to the full VLD, giving you degrees of modularity in the system.

"Engine speed limits are dictated mainly by the extra mass of the valve train components and (in EGR applications) the proportion of the main event lift taken up by secondary events. We have designed systems that will run up to 6,500-7,000rpm in valve-head throttled SI applications. In any event, these types of systems are targeted more at improved efficiency and emissions than ultimate power, so high speed is not an issue.

"Duration control range of the compound-rocker VLD is about 100º of crankshaft rotation, the turn-down ratio of lift is about 10:1, secondary valve lifts can be generated with a range of 50-70º, with lifts up to about 60% of the main valve

MAGNETIC PERSONALITY

by Jonathan Lawson

The concept of electromagnetically operated valve systems has been studied for years by various companies, but without any great commercial success. This could be about to change as Valeo is making great strides with a camless system it has been studying since 1998.

Loosely based on an idea originally from FEV, Valeo believes that the time is nigh for electromagnetics. A Valeo spokesman told *ETi*: "The reason this technology has not been a commercial success in the past is that the electronics relating to the actuator have not been good enough. Also both engine design and electronic engineering need to be married in the right way." Valeo is confident that the design currently under development will be in the showrooms early in the next decade. Initially, high-CO_2 emission gasoline engines will benefit, as the fuel economy changes for diesel are less pronounced. However, as the Valeo spokesman continues, compression ignition is also of interest: "There are definite benefits for diesels as far as closed loop control and mixture management goes."

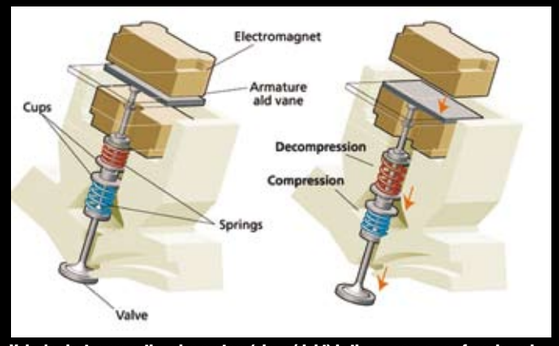
Increased fuel economy, up by 15-20% on the petrol test engines, is not the only benefit of the system, as torque improves by a similar margin, depending on the state of tune. Valeo claims the system offers "the economy of a diesel with the performance of a petrol."

The intake system is camless, while the exhaust side features a hydraulic cylinder deactivation system. In fact, to be strictly accurate, Valeo refers to the design as "half camless." The reason for this is that the forces required to operate the exhaust side are so high, the performance benefits are off set by the increased parasitic losses. The spokesman adds: "The main benefits are on the inlet side as pumping losses can be reduced. We concluded that if 80% of the benefit is on the inlet side, then this is the best balance."

To get round the low voltage problem that plagued the actuators in the past, Valeo uses an intelligent way of stepping up the 14V vehicle architecture to 42 volts by means of a DC/DC converter. Although there is a small weight penalty, the gain is well worth it. The spokesman continues: "This was one of the mistakes made years ago. When it was clear that 12 volts would not be enough, some tried to make the whole vehicle 42 volts which would have worked out prohibitively expensive." Power consumption has traditionally been the system's Achilles Heel, but Valeo has now reduced the demand by 50% to an acceptable level. On the four-cylinder test car, power consumption at 5,500 rpm is 450 watts. Initially the system consumed 2 kW.

The secret of the system's success is the balance of the valve verses the spring. This is complemented by a highly optimized actuator, all governed by the most modern electronics. The spokesman notes: "The electronics just wasn't available ten years ago." Hall effect position sensors are completely embedded in the design, while two microprocessors do the thinking.

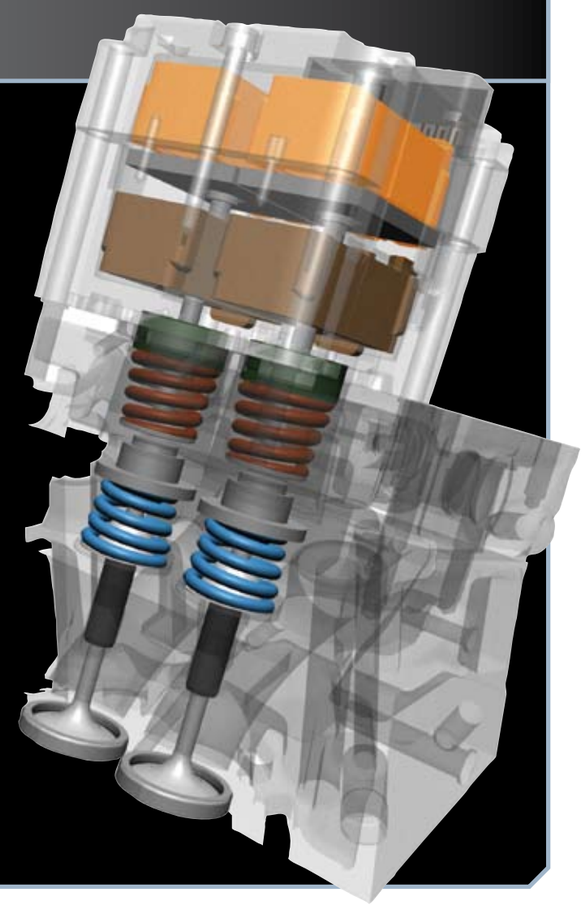
Valeo is working on electromagnetic valves. The concept features an intake system that is camless, while the exhaust side has a hydraulic cylinder deactivation feature



Valeo's electromagnetic valve system (above/right) is three years away from launch

Valeo is currently fine tuning the software and simulating system reliability. It looks like with the current design, it would be good for at least 120 million actuator cycles which is equivalent to 90,000 miles at full load. "We will meet any durability targets that an OEM sets" adds the spokesman. No maintenance would be required for this design.

The project has been combined with a mild hybrid based on StARS+X technology. In addition to the start-stop function which cuts off the engine when the vehicle is at a standstill, this system features a regenerative braking function, where energy generated during braking is recovered. Dubbed LOwCO2MOTION™, the two concepts together have been given a dramatic boost by the award of US$108 million from the French Industrial Innovation Agency (Agence de l'Innovation Industrielle).



BMW's Valvetronic technology continues to be the only true variable lift and duration design on the market, as featured in a vast range of BMW products, including 3 Series

Valvetronic technology varies timing and lift of intake valves. Valvetronic system has a conventional intake cam, but it also uses a secondary eccentric shaft with a series of levers and roller followers

event. In general terms, we find that there is no problem in using the standard valve springs."

The latest profile-switching system to hit the market is Audi's Valvelift, fitted to the company's FSI V-engines, beginning with the 2.8-liter V6. The roller rocker design switches between adjoining full-load and part-load cam profiles by shifting the whole camshaft longitudinally by around 7mm, the motion being triggered by a fast-acting actuator pin for each inlet shaft that momentarily engages a shallow, spiral groove cut in the shaft circumference. A second groove and pin combination reverses the motion, with the shaft being retained in either position by a sprung ball and indent system.

The full-load profile gives a lift of 11mm, the part-load an asymmetric 5.7mm and 2mm for the two valves, promoting a swirl and tumble motion to the intake flow.

Suzuki has also followed an axial-movement path with its concept Miller-cycle valve-throttled engine, but here the 3D-ground cam lobes slide back and forward along their shafts under electronic control and mechanical actuation. Because its camshaft drive and phaser layout is conventional, the 3D head can be virtually a direct replacement.

In the realm of vane-type hydraulic phasers, BorgWarner Morse TEC has developed what it calls its cam torque activated (CTA) and torsional assist (TA) units, which make use of camshaft torque reaction and timed opening and closing of valves in the inter-chamber oil passages to promote a faster phase shift. Actuation rates of 150/sec are claimed at low oil pressure and idle engine speeds, while the phasers have less than half the oil flow of conventional vane designs. They are also less sensitive to oil pressure and temperature variations, says the company.

Meanwhile, Denso has taken an entirely different route in its electric motor driven phasers, introduced by Toyota as VVT-iE in the 2007 Lexus LS460. In place of hydraulic phase shift mechanisms, the Denso system uses an electric motor in the actuator mounted axially with the inlet camshaft that spins faster than the shaft to advance the timing, and slower to retard it. Benefits claimed include better response at low engine speeds and temperatures, positive camshaft positioning for starting, and a greater adjustment range.

Lotus has plumped for the electro-hydraulic route to full VVA, primarily because of the company's expertise in advanced hydraulic switching, gained from its active suspension Formula 1

ROTARY BRIDGE

While looking at the technology of valve trains, it is easy to assume that the poppet valve will continue as the dominant technology of the future. Not if a dedicated group of believers in the merits of sleeve, piston-port and rotary valves have their way. Though all of them suffer from an inherent difficulty with variable timing, the many patents filed each year relating to valve systems have included enough rotary ideas to keep the flames of hope burning.

One of the more promising of the rotary brigade is the Coates spherical valve. The basic idea was patented by founder George J Coates in 1990 and has been quietly worked on since by the Coates International company which he founded.

The Achilles Heel of every rotary valve system yet developed has been combustion product blow-by or leakage of the intake mixture. The Coates design claims to have answered this with floating ceramic seals carrying two piston-type rings that are momentarily pressurised against the valve shaft by combustion pressure vented behind them. In other words, the seal is at its most effective when most needed. At other parts of the cycle the pressure is relieved, reducing wear between seals and shaft.

The Coates technology has yet to be applied to a production automobile, though the company has developed an on-site electrical power generator based around a six-cylinder in-line natural gas-powered CSRV engine of 855 cubic inches displacement and an output range of 174 to 280bhp.

project of the early 1990s. As Jamie Turner, the company's chief engineer, powertrain research, explains, its whole AVT (active valve train) project sprung from one of those 'what if?' conversations, following the development of the active suspension system: "Somebody speculated that similar electro-hydraulic technology could be used in opening valves. We built a prototype, but then we made the mistake of showing a client who said, 'We'd like one'."

Then followed development of a research VVA system that has gone on to be widely used in combustion research, with 25 in service at the present time. One of Lotus' clients for the unit was a European heavy-diesel manufacturer who expressed interest in a production version. A three-way collaboration between the client, Lotus and Eaton Corporation is currently working towards that goal.

The production system offers less flexibility in lift and timing than the research design, but compensates by being simpler and considerably less expensive to produce. It uses conventional closing springs for valves, plus solenoid switching and actuator valves in place of the wildly expensive four-way electro-hydraulic servo valves that are the heart of the AVT research.

Performance parameters for the system included individual valve operation with continuously variable lift between zero and 15mm, unrestricted valve timing and phasing, lift repeatability of 1%, timing repeatability of 1° of crankshaft angle, and a maximum engine speed of 7,000rpm for SI/HSDI and 2,400rpm for heavy-duty diesel. Because of the nature of the servo valves it uses, the research AVT has a speed limit of around 4,500rpm.

In the production design being developed, a valve event is triggered by solenoid switching valves that introduce hydraulic pressure to the bigger actuator valves. The latter are set to allow some controlled leakage that lifts the valve off its seat, replicating the heel ramp of a conventional cam lobe. The actuator valve then opens fully for a faster opening rate, then closes near full lift, with the built-in leakage allowing the valve to slow.

Approximately halfway through the valve event, the switching valve will move to return (closed) mode, the actuator valve leakage now allows the valve to begin closing slowly under spring pressure. Open fully, the actuator provides a faster closing rate, finally closing once more near the end of the event, the leakage rate and the reduced spring strain promoting a soft landing.

Valve position is controlled via a closed loop, with the position sensor being in the actuator body: it is wrapped round the hydraulic chamber, the target for the sensor being the hydraulic piston.

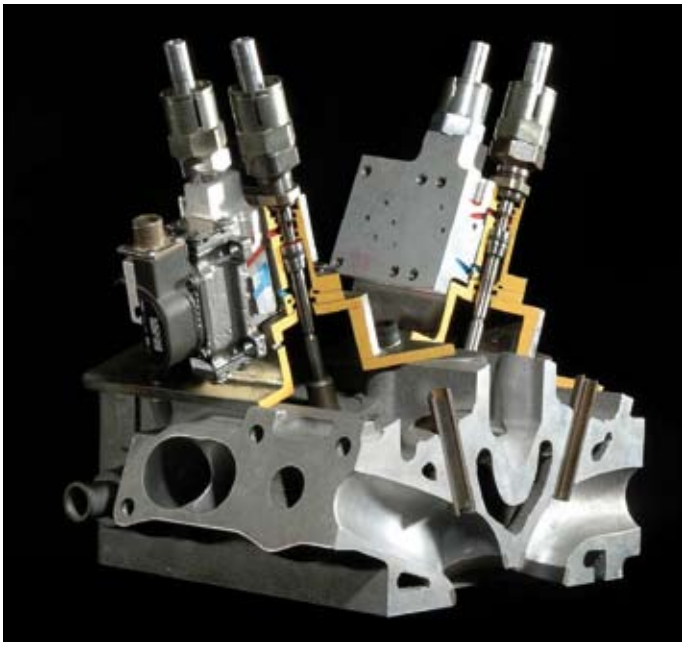
The debut of the production AVT design is expected to be at least three or four years away, says Turner. "But beyond that, once engineers have started thinking about the wacky possibilities that open up once the camshaft has been tossed in the waste bin, there are plenty more things you can do. They include separate exhaust ports to send blow-down pulses to turbines at points in the cycle, or a more sophisticated control of two-stage charging systems.

"You can rid yourself of the requirement to run a four-stroke cycle, full stop. In some of the work we've done, we've shown the ability of light-duty auto valves to be used on a two-stroke cycle. Going the other way, you can just as easily have six or eight cycles. That's not just skipped cycles; there will be dedicated events on every stroke"

Turner continues: "Beyond that, again there are such things as pneumatic hybridization. Imagine an engine in which a dedicated valve is connected to a receiver. When you lift off the accelerator, the engine switches from a four-stroke combustion mode to a two-stroke compressor, still unthrottled because it's a fully variable valvetrain. This charges the pressure receiver so that when the vehicle moves off from rest, the engine acts as a two-stroke air motor. You have an opportunity to provide parallel hybridization within the engine itself, as a very cost-effective alternative to batteries and electric motors. Our current estimates for production AVT are that it could, in suitable volumes, be cheaper than electric hybridization." ETi

"Our current estimates for production AVT are that it could, in suitable volume levels, be cheaper than electric hybridization"

JAMES TURNER CHIEF ENGINEER, LOTUS



Using expertise gained from its 1990s Formula 1 project, Lotus is working on full VVA

The Lotus AVT research engine uses conventional closing springs for valves