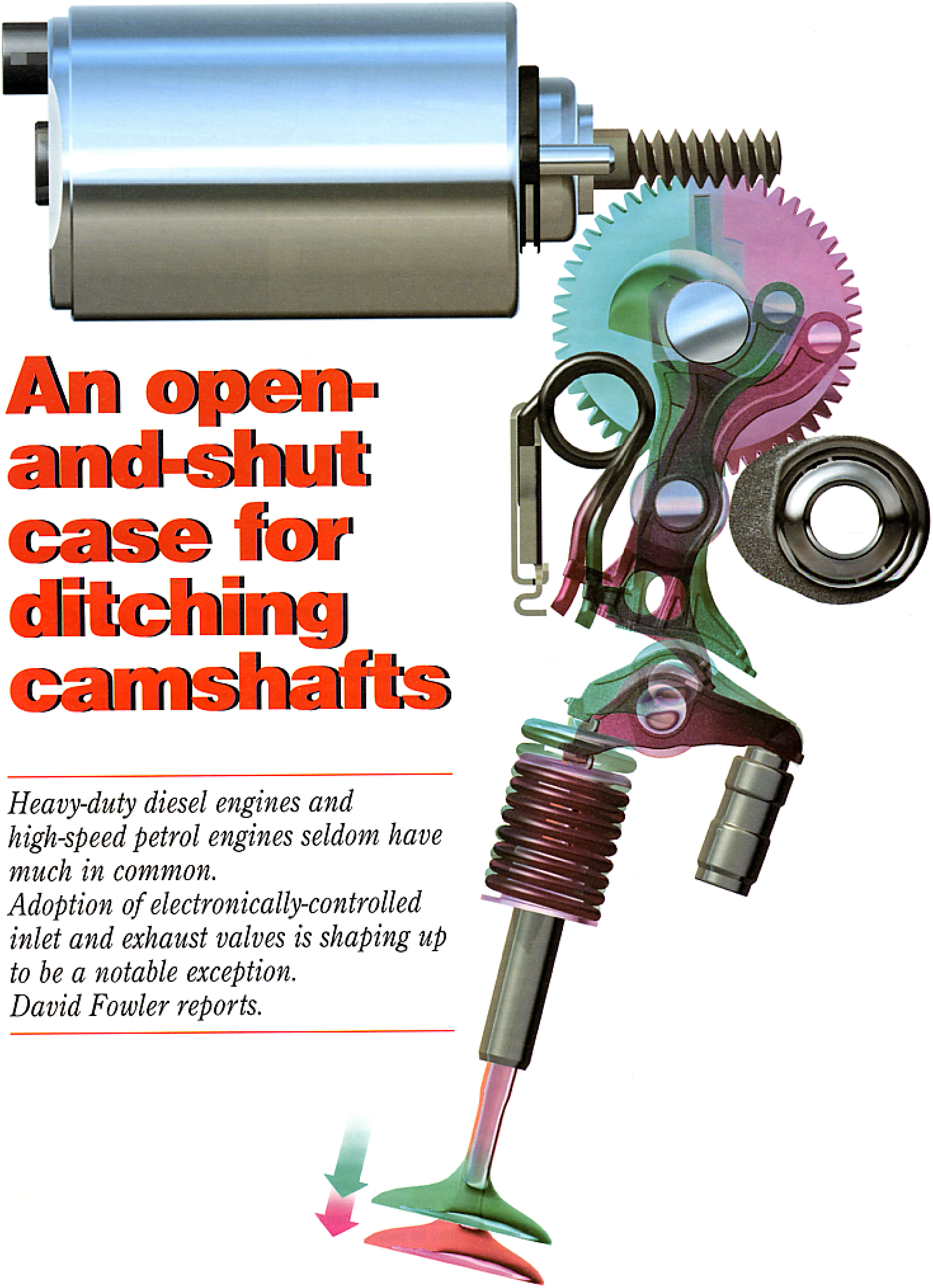
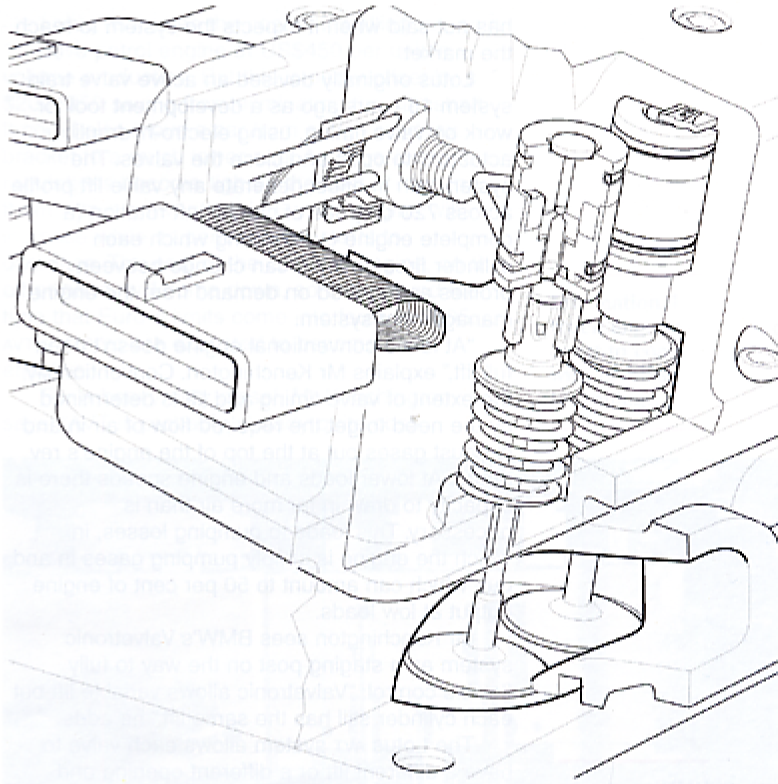


An open-and-shut case for ditching camshafts

Heavy-duty diesel engines and high-speed petrol engines seldom have much in common.
Adoption of electronically-controlled inlet and exhaust valves is shaping up to be a notable exception.
David Fowler reports.



Lotus AVT: flexible control over valve lift and timing.

Electronic control of fuel injection and ignition has become such an integral part of modern engine technology that it scarcely merits a second thought.

But until now a crucial part of the engine has remained the preserve of a mechanical system — partly because it is relatively simple and robust, and partly because of the complexity of devising an electronically-controlled alternative. We are talking about use of a camshaft to open and close the valves which let the fuel and air mixture in and the exhaust gases out.

Electronics have made variable valve timing possible, and BMW's Valvetronic system adds an electro-mechanical system working in conjunction with the camshaft to allow variable valve lift. But inexorable tightening of emissions regulations means that before too long engineers are likely to have to embrace full electronic control, dispensing with the camshaft because valves will be opened and closed by electromagnetic or electromechanical actuators. This will permit the sort of flexibility which powertrain engineers at present can only dream about.

Optimise combustion

"It's like an empty room, where we now have the opportunity to furnish it as we like," says Lotus Engineering chief control engineer Steve Kenchington. Lotus has been working on an electronically-controlled camless system called "active valve train" (AVT). "For petrol and diesel engines alike, smart controls, direct injection and active valve train provide the opportunity to optimise the combustion process rather than just manage it," says Mr Kenchington.

Flexible control over valve lift and timing will improve efficiency and economy. It will allow "controlled auto-ignition" which has the potential to reduce emissions of nitrogen oxide dramatically (see below).

Under low loads, individual cylinders can be completely de-activated, or the engine can be run as an "eight-stroke" rather than a four-stroke with each cylinder firing half as often. For diesels, torque can be improved at the same time as smoke and particulate emissions are reduced.

"There's been a lot of interest from diesel engine manufacturers, particularly from heavy-duty diesel makers," says Mr Kenchington. "There is great value to them in integrating AVT." Exhaust gas recirculation, to reduce production of oxides of nitrogen during warm-up, can be built in without the need for a separate EGR valve. The effect of an exhaust brake can be reproduced in the engine's cylinders by keeping the valves closed.

Lotus is close to signing a deal with a "tier-one" (top-rank) supplier to develop its system for production for petrol engines, so that it could be on the market by 2006 or 2007, says Mr Kenchington. The company is also working with another partner on its first application specifically for a heavy-duty diesel.

Elsewhere, BMW is believed to be working on a system which will go beyond the capabilities of the Valvetronic system, while Caterpillar is also developing a camless diesel (*Transport Engineer* April).

In January 2001 an International truck using camless technology completed a 7,600 mile endurance trial, crossing the US from San Francisco to New York City. But still International

CONTROLLED AUTO IGNITION

In auto-ignition the presence of a certain amount of hot exhaust gas remaining in the cylinder of a petrol engine from the previous cycle allows the fuel/air mixture in the cylinder to ignite without a spark. The mixture burns more slowly than under spark ignition and burning starts simultaneously at several points in the combustion chamber. This avoids the pressure and temperature peaks of normal spark ignition which encourage NOx formation. So NOx is typically reduced by over 90 per cent.

Auto-ignition was discovered accidentally in two-stroke engines where, at anything other than full load, exhaust gases are always present during combustion. A conventional four-stroke engine will not run with more than 20 per cent exhaust gas recirculation. Lotus has been able to run engines with around 50 per cent recirculation by "controlled auto-ignition", with timing of the spark retarded so it acts as one of the simultaneous ignition sites.

Auto-ignition is also promoted by varying the valve timing so both inlet and exhaust valves are closed for significantly longer, to increase the pressure in the cylinder. Lotus says the high degree of control over valve opening and closing provided by AVT is needed to make this work.

David Blundell of Lotus's powertrain research group says that AVT opens up the prospect of improving fuel economy by 25 to 50 per cent. "We're still scratching the surface of what's possible with everything infinitely variable," he says. "Once you have full control of the gas exchange process you can do virtually anything."

has not said when it expects the system to reach the market.

Lotus originally devised an active valve train system 13 years ago as a development tool for work on valve timing, using electro-hydraulic actuators to open and close the valves. The system can in effect generate any valve lift profile across 720 degrees of crankshaft rotation (a complete engine cycle during which each cylinder fires once). It can change between profiles as required on demand from the engine management system.

"At idle a conventional engine doesn't need full lift," explains Mr Kenchington. Conventionally, the extent of valve timing and lift is determined by the need to get the required flow of air in and exhaust gases out at the top of the engine's rev range. At lower loads and engine speeds there is capacity to draw in far more air than is necessary. This leads to pumping losses, in which the engine is simply pumping gases in and out, which can amount to 50 per cent of engine output at low loads.

Mr Kenchington sees BMW's Valvetronic system as a staging post on the way to fully flexible control: "Valvetronic allows variable lift but each cylinder still has the same lift," he adds.

The Lotus AVT system allows each valve to have a different lift or a different opening and closing point from those on other cylinders. Or a valve can be switched off altogether. It will allow lifting in two stages or multiple valve openings in one cycle. Whereas a plot of the opening of a cam-controlled valve against time is a smooth curve, electronic control will allow rectangular or trapezoidal profiles, in which the valve opens and closes to its full extent almost instantly. This type of profile will become typical, according to Mr Kenchington. The electronics can still be configured to give a "soft landing" (low seating velocity) to minimise stress and noise.

For various reasons, however, the research system was not suitable for volume production. It would be too costly, and its double-acting actuators sap too much power and take up too much room.

Lotus engineers drew up a set of performance targets for a production version. Valve lift, opening and closing and phasing would be variable, with lift ranging from 0 to 15mm. Opening and closing velocity would be 5 metres per second, reducing to 0.05–0.1m/s at the point of closing. Individual valve actuation and cylinder deactivation would still be possible.

All this would be achieved at engine speeds of up to 7,000rpm for petrol engines and up to 2,400rpm for heavy-duty diesels.

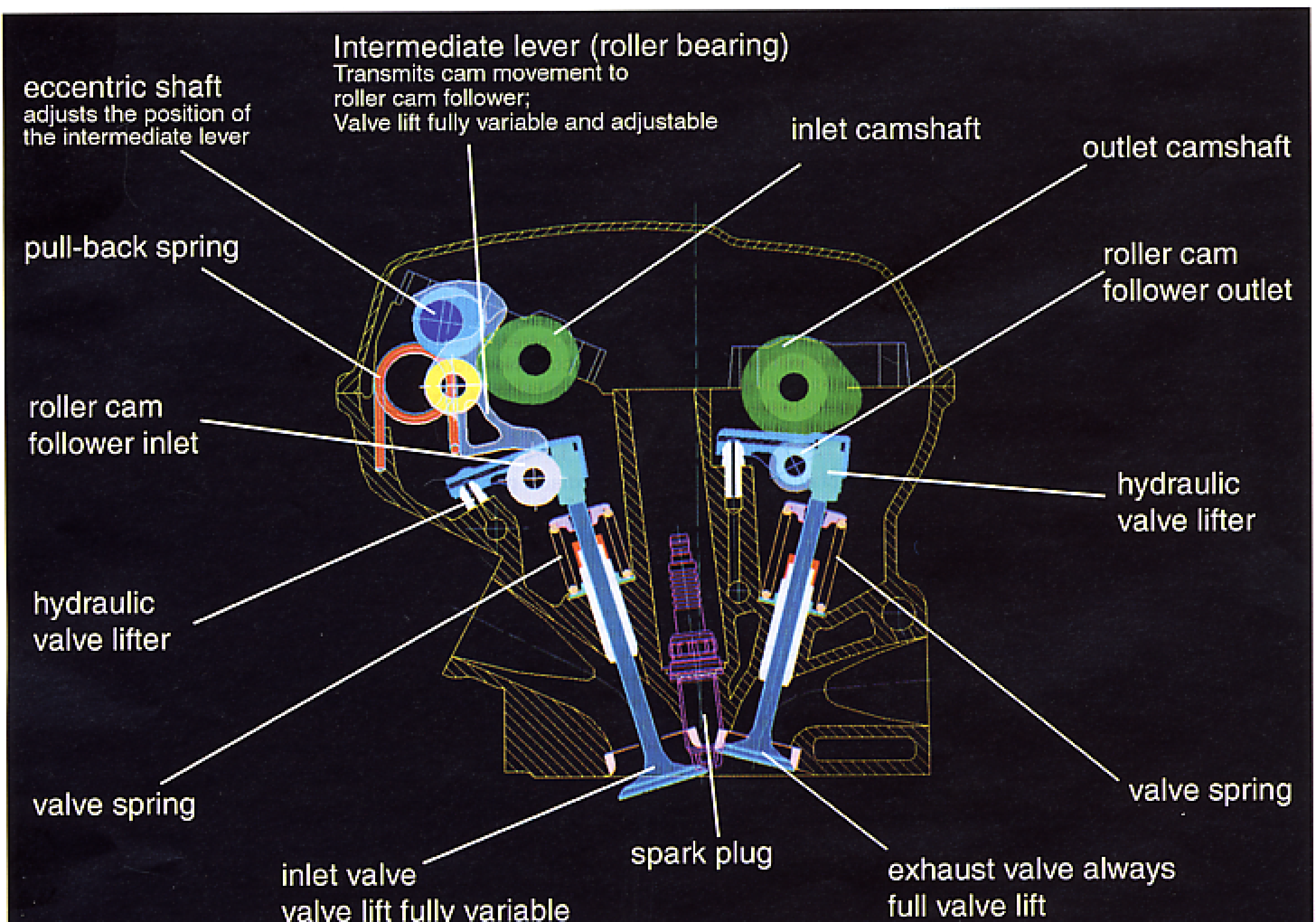
Electromagnetic actuators

Lotus decided to stick with electro-hydraulic rather than electromagnetic actuators even though they need more power. Electromagnetic actuators cannot provide variable lift or soft touchdown, or cope with the high cylinder pressures demanded by diesel engineers.

An engine-driven hydraulic pump drives the system and control system inputs are RPM, driver demand, crank position and engine temperature. "But we needed to reduce the cost appreciably by comparison with the research system," says Mr Kenchington.

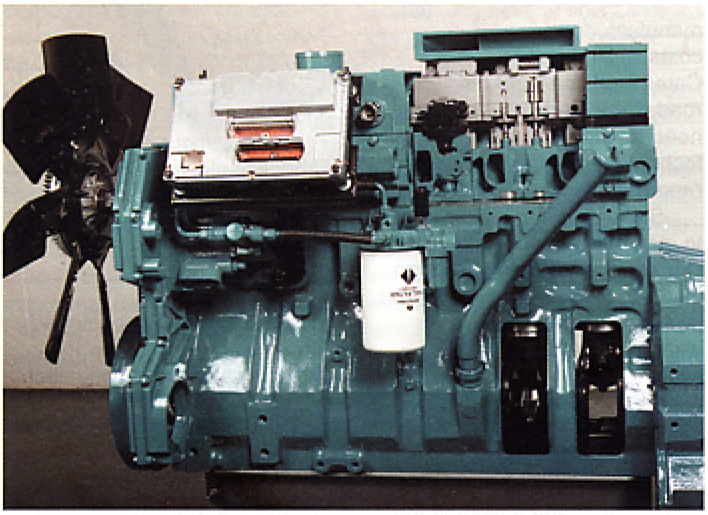
The first decision was to retain conventional

BMW Valvetronic: seen as a "staging post" on the road to fully flexible valve control.



valve springs to close the valves. This means energy is only absorbed when the valve is being opened, whereas a double-acting actuator uses energy both to open and close the valve. This also means all the valves are closed at engine start up, whereas with an electromagnetic system the valves would come to rest half-open. Single-acting actuators are also only about half the length of their double-acting equivalents, which are around three times the length of their stroke.

For a typical engine with two inlet and two exhaust valves per cylinder, Lotus devised a configuration with three electro-hydraulic valves for each pair of engine valves. A three-way valve controls the flow to or from two actuator valves



which control the timing and lift of the engine valves. Splitting the two functions in this way makes the hydraulic valves more simple and costs less than combining both functions in the actuator valves.

The control electronics are designed in-house by Lotus, and would be incorporated into an application-specific integrated circuit or system-on-chip design for volume production.

Computer modelling of power consumption suggests that, on full lift, the AVT system uses only slightly more power than a conventional camshaft at low revs. Over 4,000rpm power consumption increases more steeply. But Mr Kenchington stresses that AVT also gets more power out of the engine. "The extra power consumption will be recovered by more efficient running," he says. "If there's a 14 per cent improvement in power and you use half to run the AVT, it's still a seven per cent improvement."

A packaging study on a Rover K-series petrol engine has demonstrated that overall height could be less than with the conventional valve train, because actuators can be laid down beside valves. The present camshaft chamber is used as an oil reservoir.

Most of the development targets are close to being met. Valve lift of 15mm can be achieved, as can engine speeds of 6,000rpm for petrol and 2,800rpm for diesel engines. Further development is concentrating on the electronics.

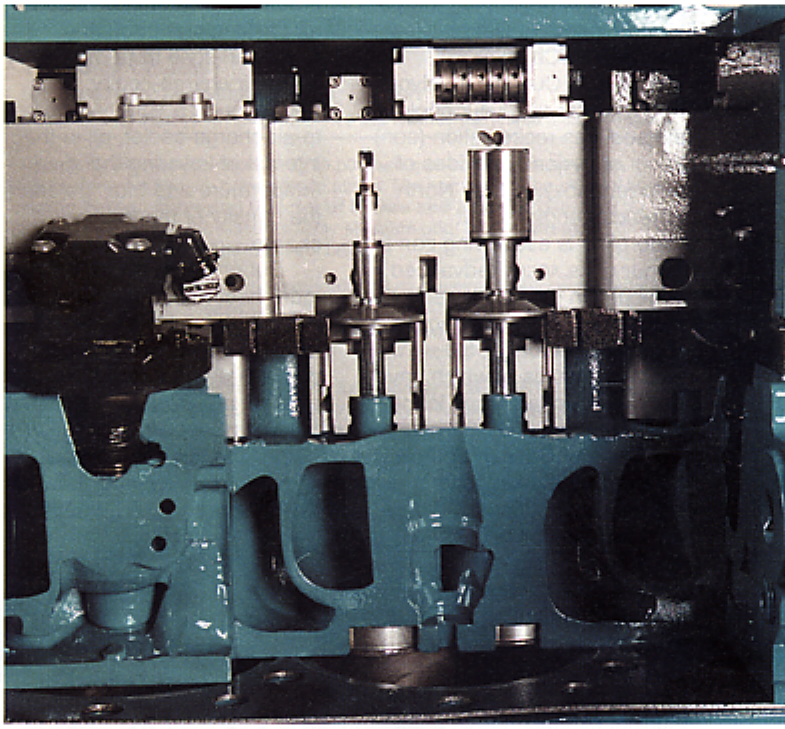
Tier-one partner

"The fact that a tier-one partner is planning to take up productionisation shows that they consider the concept validated," says Mr Kenchington. He believes a camless engine could be in production by 2006 or 2007.

Lotus estimates the cost of installing AVT on a 16-valve petrol engine at US$450 per unit in volume production. But this is partly offset by a $200–250 saving from eliminating the camshaft. It could also move a car from a high road tax bracket to a much lower one. As emissions regulations become tighter, the cost of meeting them with a conventional 16-valve engine will increase while its performance starts to decrease. The cost of the camless engine, on the other hand, will come down, so that around the time that Euro-4 limits come into force in 2005, AVT systems are expected to become cost-effective.

For a heavy-duty diesel, Mr Kenchington says: "AVT is probably already quite cost-

International truck engine: coast to coast with camless technology.



effective compared with a fully-specified diesel engine."

Whether the first production engine will be diesel or petrol may depend on whether manufacturers believe they can sell a heavy-duty diesel with AVT on this basis or whether they wait until emission regulations make it essential. "For heavy-duty diesel the emission regulations don't get stringent until 2010," says Mr Kenchington. "It's a race, and it is likely that there will be more than one winner." ■