FEV has proven the feasibility of the electromechanical valve train (EMVT) concept by demonstrating the conversion of a conventional, camshaft-driven vehicle to this technology. Significant advantages regarding in-vehicle fuel consumption and emissions have been demonstrated. The EMVT-Vehicle achieved a fuel consumption improvement of greater than 15% in the NEDC in comparison to the baseline (camshaft) vehicle and meets EURO IV emission limits.

A fully variable valve train offers many more advantages than simply avoiding pumping losses at part load. At each operating point, this technology enables much more parameter variation and allows a point-wise optimization in the engine map. Therefore, many effective solutions are possible to achieve optimal fuel economy and emissions.

A number of different mechanisms have been suggested to achieve this, including hydraulic, mechanical (MVVT) and electromechanical valve trains (EMVT). Both MVVT and EMVT are currently being developed toward production feasibility. For the EMVT concept, new magnet-controlled valves offer the possibility for individual control of the opening and closing times of the intake and exhaust valves. Hence, they provide the best utilization of the potential for reduced fuel consumption and emissions.

In realizing this concept, the actuators as well as specialized electronics have been developed by FEV. These actuators must be able to open the valves within 3 ms over a lift of 8 mm. In addition to meeting durability requirements under all foreseeable environmental conditions, the acoustic behavior of an EMVT engine must be equivalent to a modern gasoline engine with a conventional camshaft.
The actuators are designed on the basis of the electromechanical theory. A moveable armature is guided between an upper and a lower magnet. When no magnetic force exists, the armature is held by an upper and a lower spring in the middle position between the two magnets. This condition, corresponding to the valve half open position, occurs when the engine is shut off. During engine operation, a current in the coil of the upper magnet is used to hold the armature against the upper magnet so that the valve is in the closed position. To open the valve, the current is interrupted and the armature is moved by the spring-forces to the lower magnet.

By providing a current to the coil of the lower magnet, the losses during the movement are compensated and the valve is held in the open position. To close the valve, the current is interrupted in the lower magnet and the current is re-applied to the coil of the upper magnet.

The valve seating velocity and the velocity of the armature upon contact with the magnet have a significant effect on wear and acoustics. These velocities are determined by the shape of the current curve during armature movement. FEV has developed a Closed-Loop-Control system that allows valve-to-seat velocities below 0.05 m/s.

Dear Reader,

downsizing with supercharging, direct injection and fully variable valves are new technologies which will improve future SI-engines.

This issue of Spectrum contains the description of an electromechanical valve actuator system. This unique device allows the individual timing control of each valve at any engine operational condition, resulting in various improvements of the engine properties: Maximum torque can be reached already at lower rpm, fuel economy at part-load improves considerably, rough emissions are reduced and the 3 way cat technology can be used.

At FEV we are convinced that after long years of intensive development work EMV now is technically sufficiently advanced to be introduced in mass production engines.

Yours sincerely,

Peter Walzer, Vice President

Peter Walzer, Vice President
FEV has conducted many test cell investigations to demonstrate the potential of the EMVT engine. The benefits are not simply limited to the attainment of unthrottled load control. The most important benefits are summarized below:

- Residual gas control
- Gas motion and turbulence control and tuning
- Realization of various cylinder deactivation concepts
- Idle speed reduction
- Cycle-synchronous control of mixture quantity, residual gas fraction, ignition time and injection event
- Improved cold start and warm-up behavior through special valve-control algorithms

It was an important step to demonstrate these potentials in the vehicles. Moreover, FEV desired to show that combination of the EMVT with turbocharging is not only possible but presents a useful concept. Since load-control in EMVT engines is no longer achieved by the throttle but, rather, by the valve-opening-time, a completely new vehicle ECU using a torque-based structure was developed for the EMVT-vehicle. FEV used the ETAS ASCET SD system for the development of specific functions for valve train actuation and the various control signals. New functions included an air-mass-model, a residual-gas-model, as well as idle control and lambda control.

Initially, the engine control unit was pre-calibrated with the results from steady-state test cell investigations. After integration of the EMVT-specific components into the vehicle, calibration of the functions for vehicle driveability were accomplished in combination with evaluation and optimization of the fuel consumption and emissions behavior within the New European Driving Cycle (NEDC). The operational modes of the EMVT concept are determined within an engine map, that specifies, as a function of engine speed and load, whether the engine should be driven with 2, 3 or 4 valves, and whether individual cylinders should be deactivated. FEV's evaluations revealed that, within the urban driving cycle, an advantage with regard to vehicle fuel consumption of about 23% is reached. In the complete NEDC, a 16% improvement was obtained. The transmission and the engine combustion stability at low loads can be used to decrease idle speed. Here, an additional 1.5% reduction in fuel consumption can be obtained. The utilization of valve and cylinder deactivation strategies provides the balance of the total 16% fuel economy improvement that was measured with the vehicle. This enormous potential is

Map of the Operating Modes for Valve and Cylinder Deactivation

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value of the baseline vehicle. This would provide a further reduction in fuel consumption of an additional 4%. Improving alternator efficiency from about 50% to 80% would provide an additional 2% improvement in fuel consumption. Adaptation of the transmission due to the increased low-end-torque of the engine would allow a further reduction in fuel consumption of approximately 4%. By using all possibilities mentioned above, an overall fuel consumption benefit of 25% can be reached.

In comparison with conventional valve opening times, the movement and turbulence of the mixture can be intensified by late opening of the intake valves to optimize cold start and to stabilize combustion with lean mixtures during the warm-up phase. Consequently, on the very first cycle, the air/fuel charge burns with a high peak pressure. No misfiring or delayed combustion effects occur in the subsequent cycles. Through a very late opening of the exhaust valves, it is possible to improve post-combustion in-cylinder oxidation and to increase the exhaust gas temperature while achieving low raw emission levels. This results in a clear decrease of more than 50% in cold start HC emissions compared with conventional control-strategies. In contrast to a throttled engine, the start-up emissions with EMVT engines can be minimized by precisely controlling mixture quantity and the consequent reduction in the start-fuel quantity.

In addition to the special measures that are possible with EMVT, conventional measures to increase the exhaust gas temperature were also used in the vehicle. With this combination, the exhaust gas temperature could be increased by more than 200°C and catalyst light-off occurred before the end of the first driving pulse. Despite the use of an exhaust gas turbine, the cumulative emissions, measured with the test vehicle, were only 50% of the allowable EU IV emission limits for all pollutant components.

Based upon the results obtained at FEV, the electromechanical valve train represents an extremely interesting concept for reducing fuel consumption in concert with simultaneous fulfillment of very challenging future emission limits.

For additional information, contact Dr. Martin Pischinger at FEV Motorentechnik GmbH.
One of the most promising approaches to achieve a distinct reduction of fuel consumption for SI engines is the direct fuel injection. At part load operation Direct Injection Spark Ignition (DISI) engines combine the benefits of lean combustion with a nearly throttle free operation. This is a major step to overcome the principal disadvantages of SI engines compared to Diesel engines. At full load operation in-cylinder charge is cooled by the fuel spray evaporation. This increases both volumetric efficiency and reduces knock sensitivity, which results in a higher full load performance.

StarCD is used to simulate in-cylinder flow and mixture formation in part load conditions. The transient simulation covers the complete intake and compression stroke taking into account valve and piston motion. The hexahedral mesh consists of several subgrids, which are connected by arbitrary sliding interfaces. ProStar events are used to generate the grid motion and cell layer addition or deactivation.

To simulate the fuel spray propagation and evaporation, StarCD’s built-in Lagrangian droplet phase treatment is used to describe droplet motion and evaporation as well as droplet break-up and collision. These capabilities are extended by user routines for spray atomization modeling developed by FEV. This atomization model describes the break-up of the liquid sheet formed at the nozzle exit of the high pressure swirl injector and determines the size and velocity distribution of the primary droplets. An exact description of the primary droplet characteristics and their subsequent break-up is essential for an accurate simulation of momentum, heat and mass transfer between droplet and gas phase in the combustion chamber. Hence, the CFD modeling and its results have been carefully compared to experimental data. These have been obtained in a high pressure – high temperature injection chamber with an optical access to the spray. In Fig.1 StarCD results of spray propagation and evaporation are directly compared to Schlieren spray images at discrete time increments after the start of injection. Due to the temporal delay of the swirl flow development during injection, the injection starts with a straight pre-jet and subsequently turns to a hollow cone spray. This effect is clearly seen in the visualization and accounted for in the FEV atomization user routines linked to StarCD.

Using the validated DISI injection model, full simulations of the in-cylinder processes are performed. The aim is to investigate the interacting effects of tumble charge motion and spray propagation on mixture formation. The results of an optimized engine design in Fig.2 show the spray and fuel vapor distribution at an early injection phase, end of injection and ignition timing.

In conclusion it can be stated, that the use of StarCD helps to improve the understanding of the interaction between flow field, spray propagation and evaporation. In effect this enables us to guide the optimization of the flow control and to predict optimized injection parameters.
Large Bore Diesel and Gas Engine Business Area

Large bore engines are used for ship propulsion, in locomotives and power plants. World wide transportation of goods is mainly serviced by large bore engines and they are also increasingly used to generate electricity. Both fields of application show the immense economic importance of these engines.

Large bore engines are categorised above heavy truck engines. They can be divided into three classes:

- Slow speed 2-stroke engines, which represent about 75% of installations for ship propulsion. Normally they are directly coupled to the propeller. 12 cylinder in-line engines, producing more than 68,000 kW at less than 100 rpm, with a weight of up to 2,000 tonnes, impressively demonstrate this engine technology.

- Medium speed 4-stroke engines in the range of 1,000 to 30,000 kW and speeds between 350 and 1,200 rpm, operating in combination with marine gear boxes, to propel large ships, or directly coupled for large generators in power plants.

- Fast running, high output engines, 500 to 7,500 kW at 1,000 to 2.30 rpm for smaller, high speed ships, generators and special vehicles.

A rapidly growing application for large 4-stroke engines are diesel locomotives. Using the most modern electronic propulsion systems these machines, equipped with engines up to 5,000 kW, demonstrate immense tractive forces, combined with high economy and reliability. Of increasing importance are large gas engines, which are normally derived from the diesel version and are used in combined heat and power stations, which require minimum emissions such as in greenhouses and medical centres.

Future large bore engine development will mainly concentrate on the improvement of emissions due to upcoming regulations, which are already well established within the vehicle engine sector. Mainly engines for river and coastal navigation, locomotives and power plants will be affected, that is, medium and fast running 4-stroke engines. In order to maintain an economic advantage under the constraint of dramatically reduced emission values the thermal and mechanical efficiencies of these engines which are already high, have to be improved further. This will require an optimisation of all components, interacting in the engine. It is not sufficient to optimise each component individually, which is currently the case and mainly done by subsuppliers. Particularly in smaller companies, it will not be possible to solve such complex development in-house. Due to the long production life of these engines, there are relatively long intervals between successive development projects. Therefore, even if the development is performed in-house, the expertise cannot grow continuously and there will be long and uneconomic stand-off periods for the specialists involved. However, FEV has established a new business area for large bore engines, in which all projects will be concentrated. The large bore engine division is an experienced team, which, under the well-proven approach established at FEV, co-ordinates this expertise with our Research, Calculation and Test Departments to optimise the whole engine in a single focused project.

Parallel to this a completely new large bore engine test cell was erected, in which complete fast running engines up to 4,000 kW and single cylinder test engines up to a weight of 8 tons can be installed. The basis for the single cylinder testing is a FEV developed universal test engine, using a heavy casted GGG50 crank case in which customer specified cranking and cylinder head units can be installed thus providing a “close to serial engine” testing.

FEV development: V12/V16 locomotive engine
bore: 255 mm, power: 3,180/4,240 kh,
stroke: 310 mm, speed: 1,000 rpm