engine technology international

Special issue: Industry showcase

Back with a bang

Exclusive details on Lamborghini's all-new V12

January 2011

DESIGN RIGHT
What will tomorrow's fuel-efficient cars look like?

KAP DOWN
Hyundai has a new take on engine downsizing

AIR BRUSH
Three-cylinders are impressive, but Fiat's latest MultiAir engine needs just two

www.enginetechnologyinternational.com

CASE STUDY: FEV

Plug-in powertrain

ETI has gleaned early details on an innovative prototype vehicle due next year that will be powered by a state-of-the-art three-cylinder IC engine with e-drive capability

WORDS: **DR FRIEDRICH-WILHELM SPECKENS AND DR DEAN TOMAZIC**

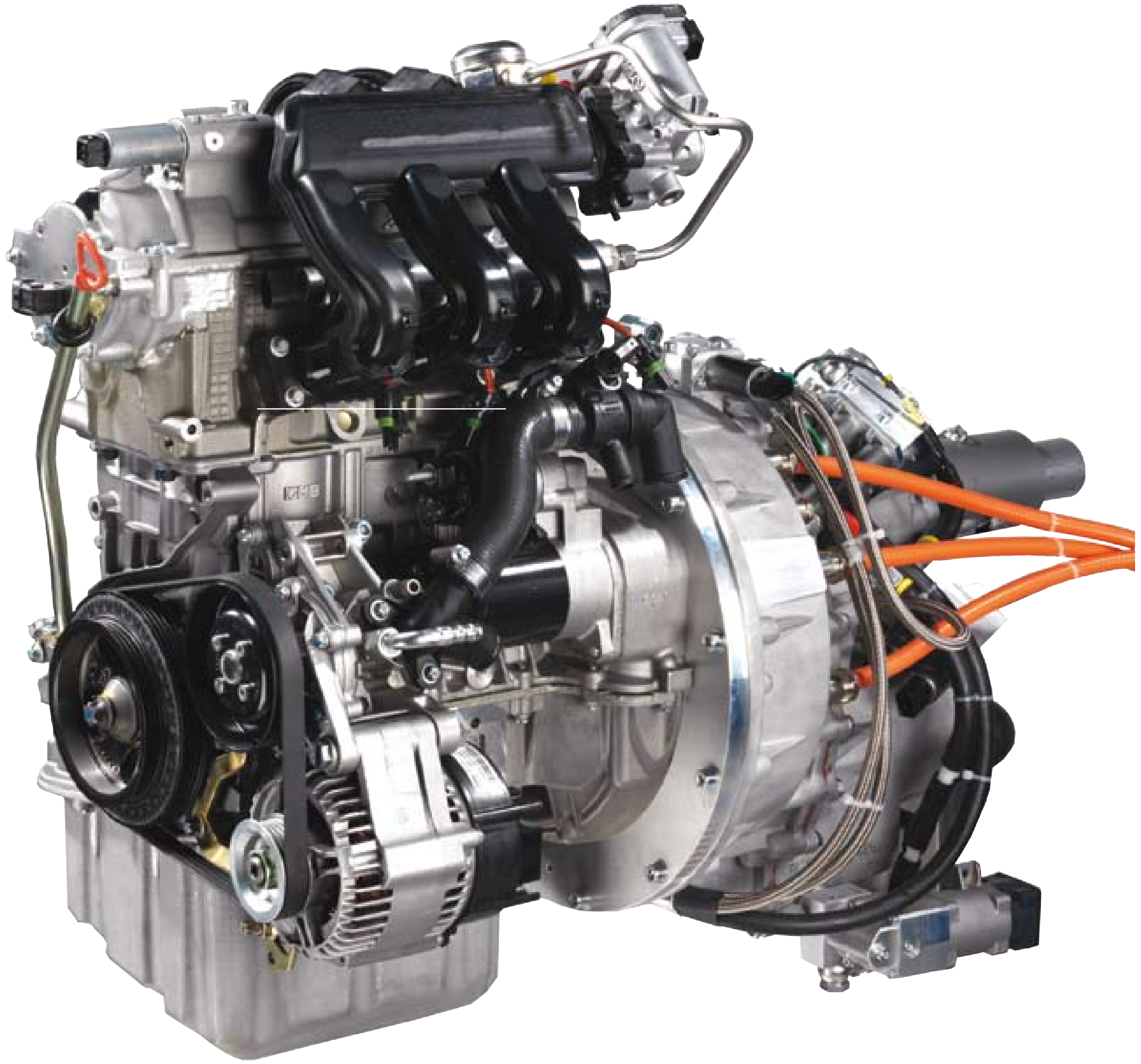
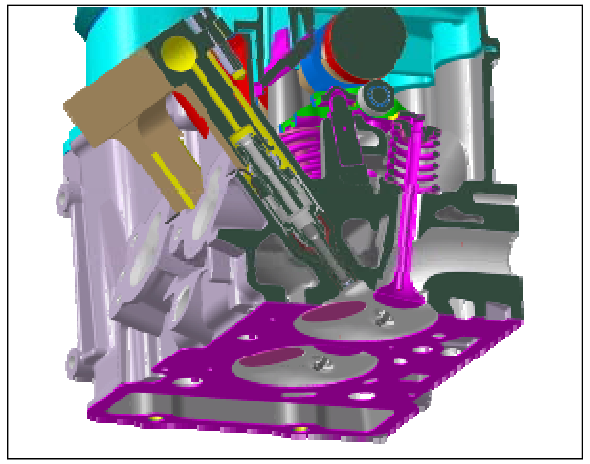
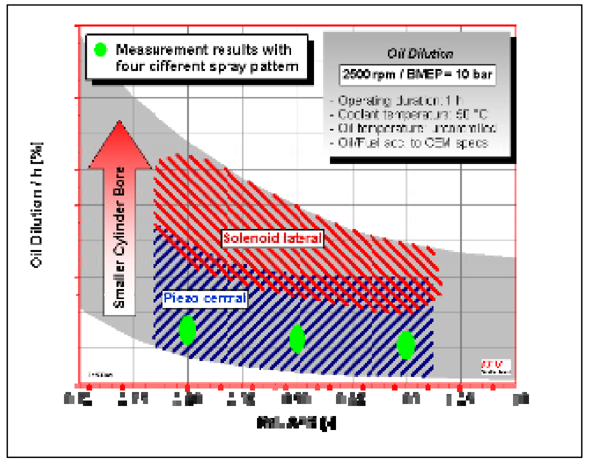


Figure 1: A highly integrated combustion electric powertrain





The mission hasn't changed, but the size has. Making engines smaller, lighter, more efficient and more powerful is what the global automotive industry strives for. Today's engineers are continually faced with these challenges, but instead of starting with a 5-liter V8 powerplant, today's entry point into this optimization process is an already relatively refined four- or six-cylinder passenger car unit, making a tangible optimization step perhaps more challenging than it has ever been. Over the next few years, the electrified drivetrain will gain a considerable share of the market. In addition to reducing climate-relevant CO_2 emissions, this development also contributes to improving local air quality, reducing traffic-related noise pollution, and increasing driving and operating comfort.

As a result of these factors, in the foreseeable future plug-in hybrids will play an important role alongside pure electric vehicles. These plug-in hybrids can be operated in a pure electric-drive mode, preferably from electricity produced through regeneration. Conversely, the hybrid drive can be fully used in daily operations, at higher vehicle speeds and also under difficult climatic conditions.

Project HiCEPS

FEV powertrain engineers faced this task within the EU-funded Highly Integrated Combustion Electric Powertrain System (HiCEPS) project. The Tier 1 supplier recognized that further improvements had to come from an integrated systems approach, rather than improvements to the individual components. The result of FEV's subproject is a very attractive version of a new highly integrated combustion electric-powertrain system (Figure 1), developed by a team of FEV engineers from a clean sheet of paper to demonstrate the improvement potential of a plug-in hybrid powertrain with an integrated IC engine, an automatic transmission, electric motor (project partner ELDOR), actuation system and control strategy. In designing and developing this new concept, FEV was responsible for full simulation of the hybrid system and designing all the components. A multi-disciplinary team of FEV engineers performed the full layout and design, including CAE work on the housing, planetary gearsets, clutches and shafts. FEV's engineering team was also responsible for the complete downsizing effort associated with the IC engine.

Figure 2 (above): The arrangement of the injector and spark plug in the combustion chamber

Figure 3 (right): Positions of engine bore influence in favorable spray geometry

> **VITAL STATISTICS**
>
> **Engine:**
> **Torque** – 105Nm at 1,800rpm
> **Power** – 60kW at 6,000rpm
> **Idle** – 600rpm
>
> **E-motor**
> **Diameter** – 300mm
> **Length** – 381/357mm (EH / EH actuation)
> **Torque** – 143/250Nm (continuous)
> **Power** – 20/38kW (continuous)

The engine concept is a turbocharged, two-valve SOHC three-cylinder SI engine with 698cm³ displacement based on the Smart Brabus engine. FEV engineers replaced the original twin spark ignition with a single spark plug on the exhaust side, combined with a high-energy spark plug coil. The position of the replaced spark plug on the intake side was then used as the location for the DI injector. The arrangement of the injector and spark plug in the combustion chamber is shown in Figure 2.

The spray pattern layout was optimized using FEV's own fuel injector layout tool chain. The injector characteristics were optimized to ensure the most favorable injection spray geometry and reduced wall wetting – not a trivial engineering challenge with a 66.5mm bore diameter. The general effect of different injector technologies, positions and engine bore influence is shown in Figure 3. The resulting homogeneous combustion system specification includes a multihole injector with solenoid actuation, asymmetric spray pattern with five spray cones, single piston high-pressure fuel pump (200 bar), an HP pump driven by an additional cam-on-cam shaft, and a cylinder head adaptation for different injector suppliers.

The main focus for injector layout in small DISI engines is to prevent wall wetting, thus ensuring low fuel content in the oil. At 66.5mm, the bore diameter of this downsized engine is smaller than all competitor engines currently on the market.

Seventh heaven

FEV's project goal was to develop a parallel hybrid powertrain that could deliver pure electric driving as well as boost and recuperation modes. To make the concept work, engineers integrated FEV's newly developed planetary gearset transmission. The seven-speed electrically assisted hybrid automatic transmission has been designed for transverse (FWD) applications. The transmission, rated at 200Nm, is very compact and supports full hybrid functionality (Figure 4).

The hybrid transmission is equipped with three planetary gearsets (PGS), three clutches, and two brakes (Figure 5). The first PGS is coupled to the engine and electric motor. Two additional PGS are coupled to a differential to achieve the desired seven-speed hybrid functionality. The e-motor and engine are controlled with three clutches and two brakes. The existing gear ratios of the PGS can be multiplied with the clutches/brakes to generate additional ratios.

Vehicle launch can be performed either in pure electric mode or by using one of the clutches as a launch clutch.

> "The engine concept is a turbocharged, two-valve SOHC three cylinder SI engine with 698cm³ displacement based on the Smart Brabus engine"

To maximize fuel economy, FEV's design and engineering team developed a means of actuating the clutch without hydraulics. A direct mechanical actuation of the clutches and brakes is possible. The electromechanical clutch actuator for this application helps to achieve the fuel economy benefit by staying in its open or closed position, even when it is not being energized.

The transmission design also features a cam disc. Additional coupling of non-linear stiffness compensates for clutch wear and thermal strain. FEV engineers built component test rigs equipped with force, speed, current and position sensors to validate the functionality of the electromechanical actuators. Tests showed that, even in the worst-case scenario, the engagement time for the transmission remains below 140ms. The design of the electromechanical actuator is still under mechanical development. The current version of the transmission still uses electrohydraulic actuation until the mechanical development of the electromechanical actuation system is complete.

The transmission, with electromechanical actuators, can contribute to fuel consumption reductions of up to 9% and a reduction in total driveline losses of approximately 60%.

Combined, the parallel hybrid powertrain system provides key benefits, such as stop/start function, two-speed pure electric driving, seven-speed IC engine drive, boosting and recuperation, restart of the IC engine out of e-drive, full powershift capability, no torque drop while shifting, integration of the electric motor with 20kW continuous and 38kW peak power, three-shaft compact design with seven forward gears realized through three clutches and two brakes, and an electromechanical or electrohydraulic actuation.

Three-cylinder heart

With funding by the EU, FEV created a small direct-injection turbocharged version of a three-cylinder gasoline engine equipped with a SOHC and two valves per cylinder (Figure 5).

Figure 4: The transmission is compact and supports full hybrid functionality

Due to the small single cylinder displacement of 233cm³ and a cylinder bore diameter of 66.5mm, the injector layout and its adaptation to the combustion chamber was a key factor during the concept phase to avoid oil dilution effects. By using the existing and proven FEV tool chain (which considers injector spray characteristics, combustion chamber geometry, piston movement and in-cylinder charge motion effects), a very low oil dilution level was realized. The level of oil dilution is in the lower range of the scatter band of all engines in this class of series production direct-injection gasoline engines, despite its comparatively very small bore diameter.

The overall fuel consumption advantage of using the small, boosted engine during the NEDC is 16% compared with a naturally aspirated 1.4-liter engine with similar driving performance. By introducing further powertrain and vehicle-related CO_2 reduction measures, an overall fuel-consumption improvement of 29% is achieved. Combined with a mild hybridization strategy, a CO_2 level below 95g/km over the NEDC is possible.

FEV's complete project involvement covered the following areas: hybrid system simulation and the definition of components; hybrid powertrain concept, including layout and design; CAE for housing, planetary gearsets, clutches and shafts; downsizing of the IC engine (698cm³, 60kW, 105Nm); procurement of engine and transmission components; mechanical testing of engine and transmission; complete software structure for TCU, ECU and HCU; and hybrid powertrain testing on transient test bench.

Encouraged by the results of the combustion engine downsizing, FEV has continued the development of downsized engines on the basis of the HiCEPS engine. To enable fully independent phasing of intake and exhaust cams on a SOHC valvetrain, FEV engineers have worked with Mahle to integrate its cam-in-cam camshaft into the cylinder-head concept. The actuation is realized by a hydraulic-ring dual-stacked vane-cam system.

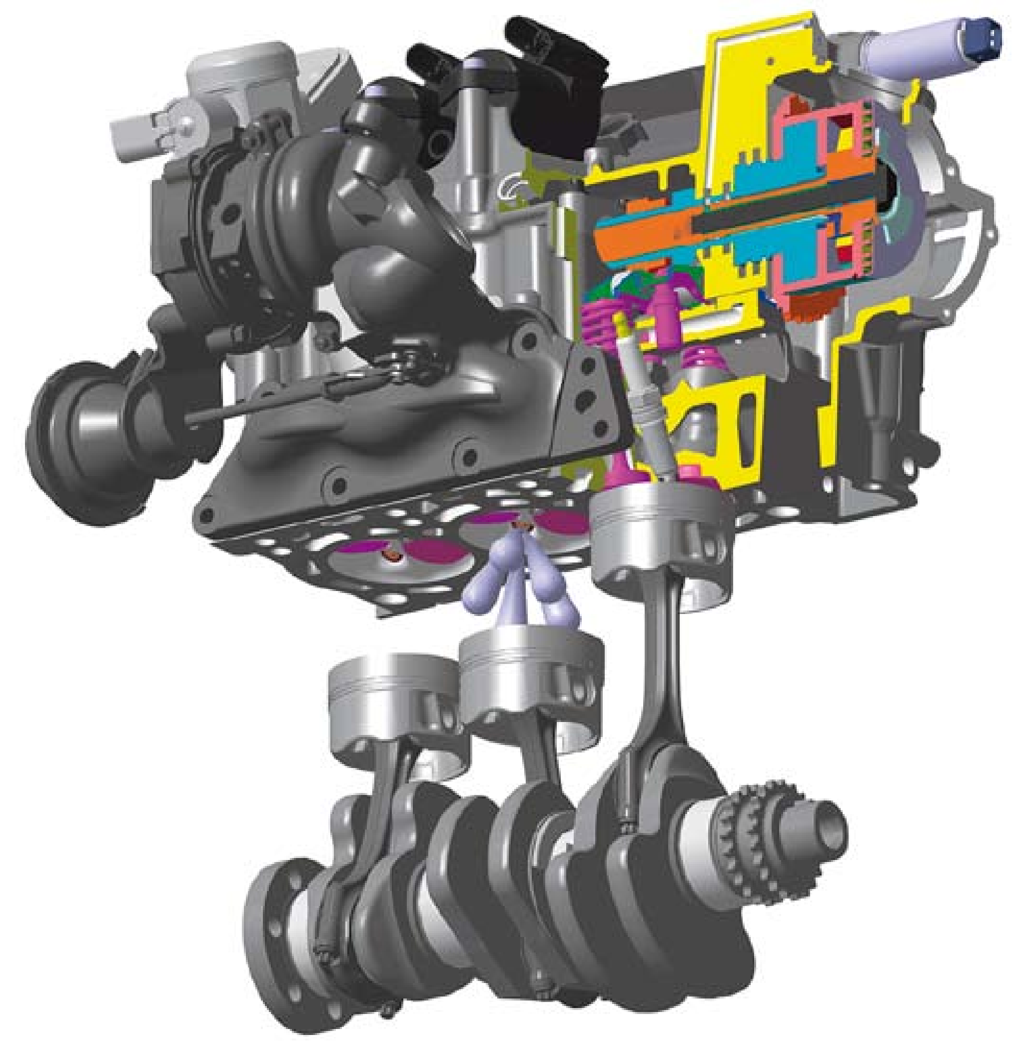


Figure 5: A small direct-injection turbocharged version of a three-cylinder gasoline powertrain equipped with a SOHC, two valves per cylinder

The cam-in-cam system enables the intake and exhaust valves to phase independently.

The phasing angle of the intake cam is 50°CA, and 40°CA on the exhaust side, enabling positive intake air during the valve overlap at full load and low engine speeds. The result is a dramatic increase in low-end torque of about 32%. Typically with downsized engine concepts, attempting acceleration at speeds above 1,500rpm creates a power lag. With the HiCEPS, there is no decrease in power. This can be achieved only with a cam-in-cam with valve overlap and a DI injector. FEV's testing also resulted in the attainment of a specific power of more than 100kWh/l (698cm³, 74kW, 130Nm), achieved without changing the turbo.

FEV has filed for patents related to the inner structure of the hybrid system and the electromechanical actuation concept, which is currently undergoing additional development at the company's test facilities in Aachen, Germany. The thought leadership and engineering intelligence in developing this concept matches FEV customers' expectations. Currently, a prototype vehicle is being developed, complete with the downsized engine and all the mechanics of the parallel hybrid powertrain. FEV Motorentechnik is leading this endeavor; the prototype is scheduled for completion in 2011.