SPECTRUM

Technology Highlights and R&D Activities at FEV

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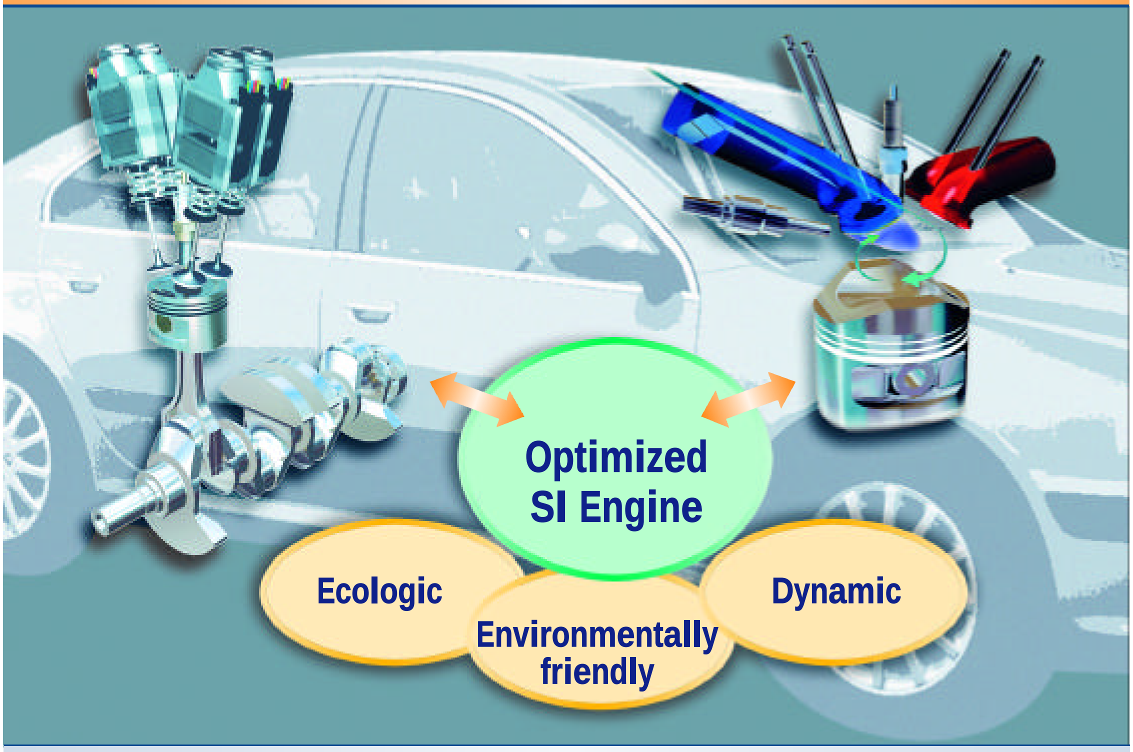


Synergies of Variable Valve Actuation and Gasoline Direct Injection

Since both Direct Injection and Variable Valve Actuation gasoline engines are now produced in volume production, a combination of the two technologies represents a promising next step in the evolution of the gasoline engine. The initial engine concepts that combine the advantages of variable valve actuation and direct injection are nearing the start of production.

SUMMARY

A major advantage of both approaches is the essentially unthrottled engine operation. In practice, unthrottled DI gasoline engine operation cannot be maintained over the complete engine map and under all operational conditions. Typically, at low loads, the engine must be partially throttled to maintain an exhaust temperature level that is suitable for catalytic aftertreatment. At higher loads, lean engine operation must be abandoned, despite the thermodynamic potential, due to the strong increase in NO_X emissions. With fully variable valve actuation, it is possible to limit excess air without throttling, thus avoiding gas exchange losses, even under high loads. In this manner, the combination of gasoline direct injection and variable valve actuation permits better exploitation of their individual potentials.

Partial throttling is required to achieve the necessary pressure differential to drive external exhaust gas recirculation in direct injection gasoline engines and, hence, reduce NO_X emissions. This EGR method also commonly causes intake valve deposit problems. With variable valve actuation, it is possible to implement internal EGR, avoiding these problems and, con-

PREFACE

Dear Readers,

Automotive powertrains have undergone more improvements related to specific power, fuel consumption and emissions over the past 10 years than in many of the preceding decades combined. Direct injection diesel engines with variable charge air systems combine excellent fuel economy with superior driving performance. As a result, diesel market penetration has doubled over the past decade. New technologies for improved fuel economy have also been developed for gasoline engines, including fully variable valvetrains, direct injection and increased specific power through improved supercharging systems. In parallel, natural gas engines and hybrid powertrains are now offered and the introduction of fuel cell power plants has been announced.

The timing for market introduction and potential market penetration will depend on factors such as production costs and the availability of sulfur-free fuels.

FEV's market development prognosis for the next 10 years is shown in the figure below. In Western Europe, the Diesel market share is likely to increase to over 40% of all new passenger cars. Almost all new gasoline engines will employ one of the new technologies that have been mentioned. FEV predicts that the so-called alternative power plants will attain a market share of about 5%. To achieve mass production, all of these new technologies require additional engineering development efforts. Consequently, engine developers face another decade of interesting challenges.

At FEV, we look forward to meeting the challenges facing the industry.

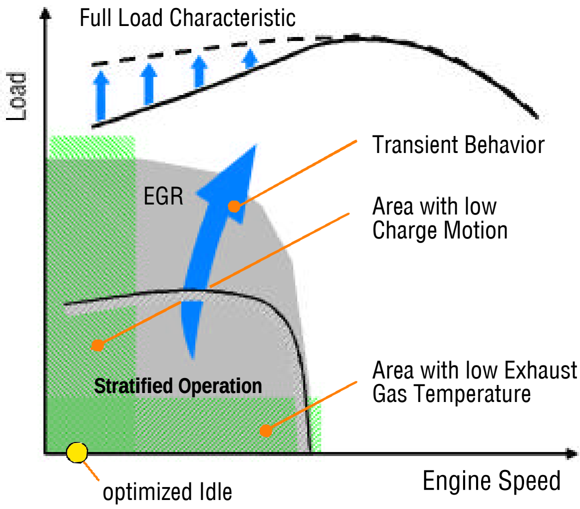
Yours

Prof. Dr.-Ing. Peter Walzer
Executive Vice President

Continued from Page 1

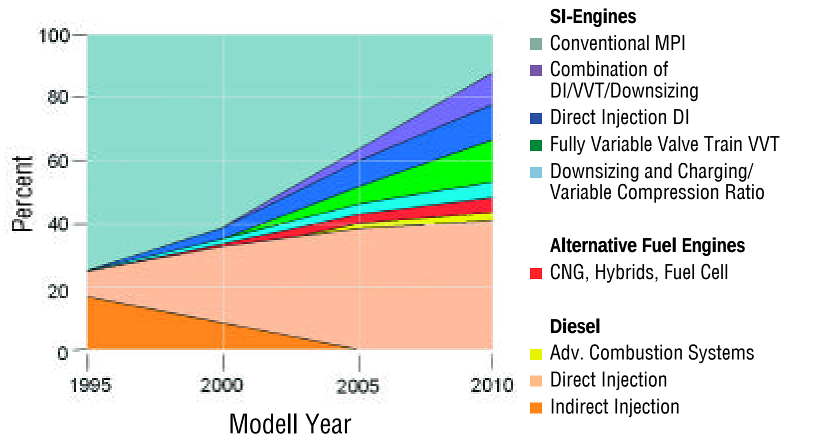
currently, increasing the process temperatures, improving inflammation conditions, and stabilizing combustion.

The variability of the valve train can also be used to influence in-cylinder flow. In this regard, combining a controlled intake valve lift ramp and asymmetric shrouds around the valve seats has proven to be very effective. With this combination, it is possible to generate a charge motion that meets the demands of stratified operation, even at low engine speeds. This can also be used to effectively lower the idle speed, in addition to the benefits associated with using variable valve timing to reduce the residual gas fraction.



Important synergies result from the potential for cycle synchronously control of both the gasoline and air quantities, as well as the amount of residual gas. This allows much easier and more exact transient

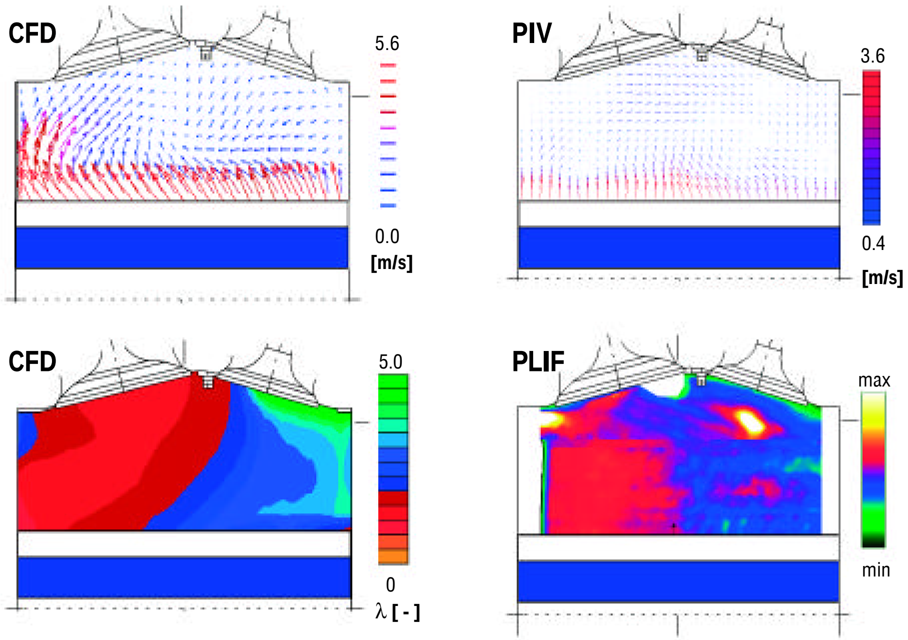
Share of Advanced Engine Technologies in Vehicle Model Year, West Europe



changes between various operating modes including, for example, the regeneration of the NO_X-adsorber catalyst and changes between load dependent operating modes. Operating mode transitions can be realized without obvious impacts on comfort and with only minimal efficiency related drawbacks. Since most of the complex compensation functions are no longer necessary, there is a benefit in terms of reduced calibration effort, in addition to the stated consumption and emissions advantages.

The combination of gasoline direct injection and variable valve actuation leads to a number of complementary combinations of their individual potential. Test bench and simulation results from engines equipped with these technologies indicate a potential reduction in fuel consumption of up to 23% compared to conventional PFI engines. The fact that these two technologies complement each other so well in terms of reducing legislated emissions and improving full load performance will continue to drive the concept in the future.

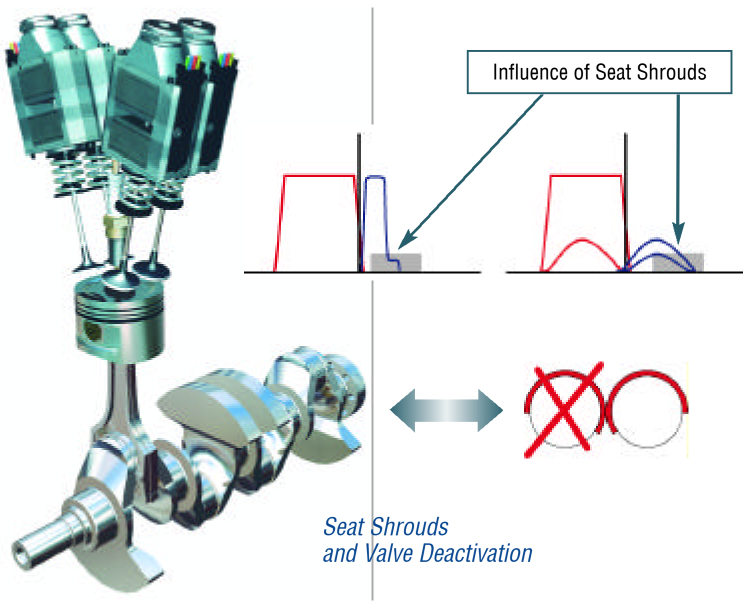
The combined cycle-synchronous control of mixture quality and quantity also induce a more spontaneous "throttle" response. During load reversal, these advantages remain effective and have a positive influence on emission behavior. The necessity of applying compensation functions is also largely reduced in this case. Cycle-synchronous engine control presents a substantial (and simple) premise for realizing cylinder deactivation.



For direct injection gasoline engines, it is necessary to keep the exhaust gas temperature within the optimal range for the NO_X-adsorber. Currently, this requires partial engine throttling at low part load and, due to emission restrictions, the abandonment of the advantages associated with lean operation at higher load. With the help of variable valve actuation, the amount of aspirated air can be controlled without throttling.

Variable valve actuation also allows minimization of start and warm-up emissions by applying targeted valve timing control strategies. These strategies can be further optimized via their combination with gasoline direct injection. In particular, post-injection strategies to speed up catalyst heating are worth consideration.

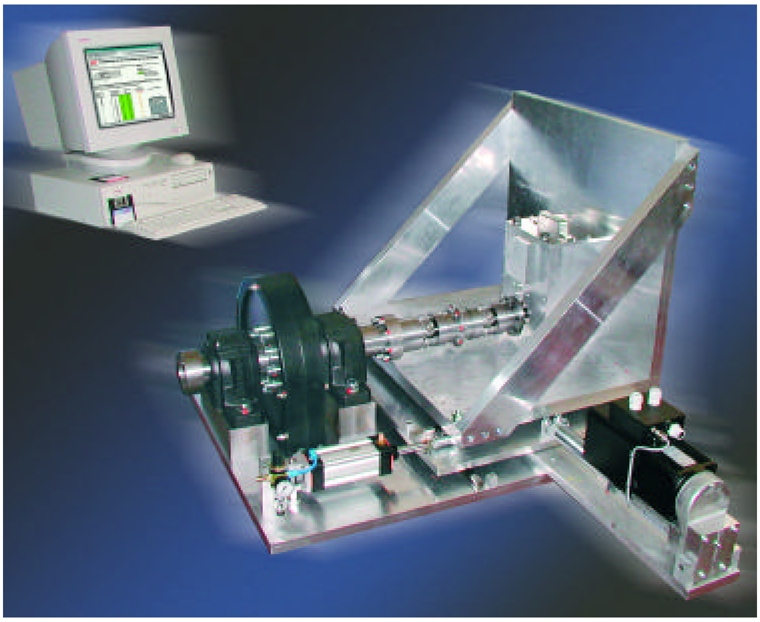
Both gasoline direct injection and variable valve actuation are well known for their superior torque characteristics in the lower engine speed range. Combining the two technologies provides the complementary effects of in-cylinder cooling and optimized gas exchange, resulting in significant reduction in knock tendency and the possibility to considerably increase compression ratio.



Seat Shrouds and Valve Deactivation

Dr.-Ing. Wolfgang Salber
Dr.-Ing. Peter Wolters

Test Cell for Simulation of Torsional Vibrations in Mechanical Testing



Torsional Vibration Generator

The excitation of the crankshaft plays a dominant role in all combustion engine sub-systems that are used for driving accessories or the camshafts themselves. The excitation primarily consists of torsional vibrations that are superposed on the constant rotation. The excitations are caused by the gas and mass forces acting on the crankshaft. This angular vibration is usually quantified by the amplitude of the superposed oscillation angle. Investigations conducted with operating engines have shown that this amplitude primarily consists of the dominant sinusoidal main harmonic order.

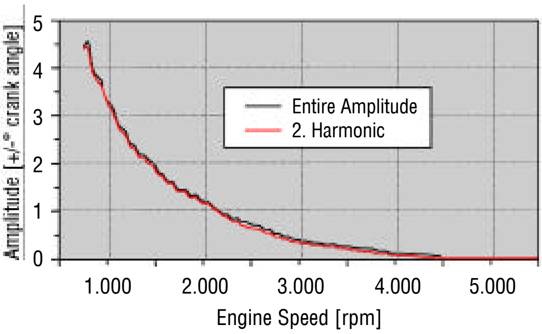
The crankshaft excitation must be considered in the investigation of gear boxes, timing- and accessory drives, as well as single components of these systems, to provide representative results about the dynamic behavior. Based on the current state-of-the-art, torsional vibrations can only be applied by an actual combustion engine, driving the investigated system. This requires a fired test bench and the corresponding effort for installation and operation of the combustion engine. Furthermore, only the crankshaft torsional vibrations that are specific to this engine can be provided for the investigations. Because of this, investigations in motored test benches are typically done with no excitation or, in the best case, constant excitation over the entire engine speed range. Both methods present the disadvantage that realistic simulation of combustion engine behavior is not possible.

The Torsional Vibration Generator developed by FEV enables the user to add a sinus shaped second harmonic order to the incoming constant rotational speed of a standard electric motor. With this technique, the dominant harmonic order of a four-cylinder engine can be simulated with the use of a standard low-cost motored test bench.

With the use of specialized, additional gear boxes, the dominant harmonic orders of 3- and 6-cylinder combustion engines can be simulated as well. The amplitude of the torsional vibration can easily be programmed over the entire engine speed range by means of a standard PC. It is also possible to download actual engine measurement results and reproduce them on the test bench.

The technical principle is based on the kinematic creation of a 2nd harmonic torsional vibration via the combination of two high precision cardan joints. A flywheel serves as a support and avoids, via its large moment of inertia, any feedback from the test sample into the drive. It is possible to adjust the amplitude of the torsional vibrations to within an oscillation angle of 0.1°. The omission of any length compensation at the cardan drive leads to a movement of the complete testing device on perpendicularly arranged high precision linear guides.

The torsional vibration generator is designed to simulate all values that may occur during actual engine operation. At low engine speeds, amplitudes up to +/- 6° oscillation angle are possible; the maximum engine speed at the output shaft is 6000 rpm.



Crancshaft angular vibration simulated with the FEV Torsional Vibration Generator for the investigation of timing drives on a diesel engine

The Torsional Vibration Generator that is described has proven to be an inexpensive and flexible alternative to the use of a fired combustion engine for the investigation of sub-systems such as belt and chain tensioners, as well as for the complete systems. The maximum transmittable torque is sufficient for a fully loaded accessory drive. Other potential applications are durability tests and investigations concerning the noise radiation of chain drives or gearboxes at idle.

Dipl.-Ing. Ulrich Krahnen

New Engine Concept for Natural Gas Vehicles, NGV's

Natural gas, called CNG (Compressed Natural Gas) in its compressed form, is globally recognized to be one of the most important alternative fuels for spark ignited vehicle engines. There are various causes for this, occurring essentially as a result of the favorable chemical composition of CNG compared to gasoline as well as and its specific characteristics. In particular, high knock resistance, superior mixture formation in air, and low CO_2-production levels as well as the inherent reduction in non-methane-hydrocarbons (NMHC) can be identified.

The potential CO_2 emission reduction is the motivation for CNG vehicle production. CNG vehicle CO_2 emissions are calculated to be about 25% lower than conventional gasoline vehicles, if the effective efficiency is kept constant.

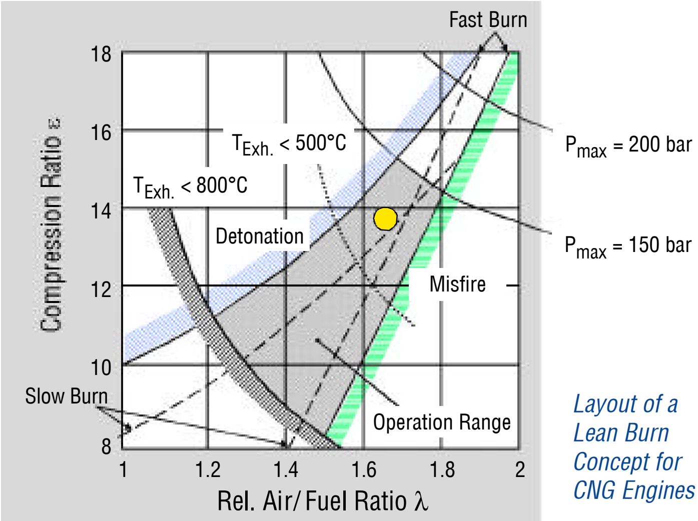
Despite the greenhouse effect that, for CNG operation, arises primarily because of the Methane related HC emissions, a Greenhouse emission bonus on the order of 20% remains (Fig. 1). In view of the expenditure that would be necessary to obtain similar greenhouse emissions benefits for gasoline engines, natural gas is the most efficient measure with short-term implementation potential.

Emissions	CNG compared to gasoline	
Evaporation	■ no	
NO_x	■ less	
CO	■ less	
NMHC	■ less ■ no aromatics	
Methane	■ Ozon formation potential -80% ■ toxic. harmless	■ Greenhouse-effect + 5% (Basis CO_2)
CO_2	■ -25%	

Total Greenhouse effect: -20%

Emission Behavior of CNG and Gasoline Operation

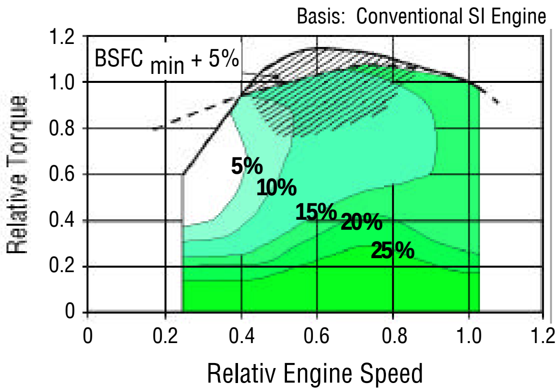
The turbocharged, lean-burn engine represents a concept that can consistently use the advantages of CNG. The bandwidth for the allowed range of A/F Ratio and Ignition depends on the quality of the combustion process. As shown in Fig. 2, the usable area regarding A/F Ratio and Compression Ratio (CR) is limited at high air/fuel ratios by the misfire limit. The lower air/fuel ratio limit is limited by knocking. Through application of a high-turbulence combustion process with comparably higher burning velocities, the A/F Ratio bandwidth can be significantly increased and Full Load can be extended to higher Compression Ratios (CR).



- Turbocharged 2.0L I4 SI Engine
- Full Load @2000 min⁻¹
- BMEP ~ 18...20 bar
- RON ~ 98

● **A**dvanced **T**urbulence **A**ssisted **C**ombustion System

Layout of a Lean Burn Concept for CNG Engines



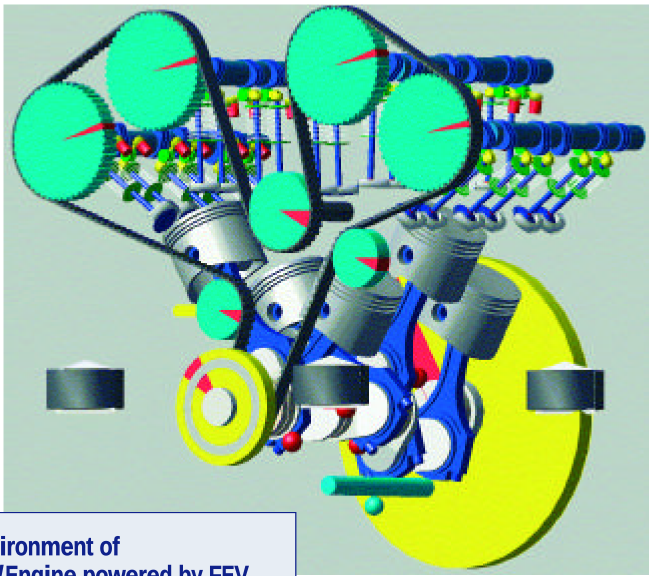
Fuel Economy Benefits of the ATAC Lean Burn CNG Engine

The ATAC high turbulence combustion process, developed at FEV, enables the excess air necessary for NO_x reduction by using these relationships in parallel with efficiency-favorable compression ratio over the entire engine map. The results of investigations with a 1.9L, 4-Cylinder Engine are shown in Fig. 3. The relative efficiency advantages are shown in comparison with a modern naturally aspirated gasoline engine with port fuel injection. Compared with other gasoline fuel consumption concepts, the lean burn gas engine introduced here is characterized by both outstanding part load fuel consumption and, uniquely, by full load fuel consumption that is in the range of a modern direct injection turbo-diesel engine. Consequently, extremely low fuel consumption values can be implemented with this combustion process, not only in the New European Driving Cycle but also in typical customer operation.

Dr.-Ing. José Geiger
Dr.-Ing. Markus Umierski

ADAMS/Engine powered by FEV

February, 2002, the new Cranktrain Module that was developed at FEV was released for delivery. In combination with the existing **ADAMS/Engine powered by FEV** modules it is now possible to simulate the mechanics of all engine subsystems as well as their interactions.



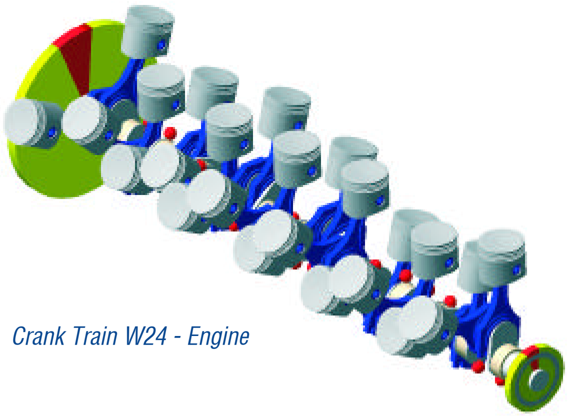
The environment of ADAMS/Engine powered by FEV

- Valve Train Dynamics
- Timing Chain
- Timing Belt
- Gear Train
- Accessory Drive
- Base Crank Train
- Advanced Crank Train

The cranktrain module consists of two products: Base Cranktrain and Advanced Cranktrain. Together, these two products represent a global tool for the analysis and optimization of cranktrain dynamics. In developing the product, FEV put special emphasis on the flexibility of models depth. For example, model allows representation of the crankshaft initially as a rigid model, then with more sophistication as a torsional structure, and eventually as a beam model. This simple numerical basis is a perfect approach for completing a series of parametric studies in the shortest possible time. Simulations with flexible FEM structures for the crankshaft and engine block as well as their coupling by hydrodynamic bearing models enable detail investigations with the highest calculation accuracy.

It is now possible to simulate various tasks in the engine development process such as free forces and moments, crankshaft torsional vibrations or bearing load predictions, based on one unique database, instead of transferring data between several individual simulation tools. Using **ADAMS/Engine powered by FEV**, a great deal of redundant work associated with the collection and preparation of data may be avoided. The concept of enabling various levels of refinement permeates the complete product. For nearly all potential cranktrain components, the user can select different approaches. For example, a conventional flywheel may be easily replaced by a dual mass flywheel. Moreover, the user has an option to select between a linear or nonlinear representation of the flywheel. To describe the torsional damper, in addition to rubber and visco-damper models, a linear formulation is also available. The same is true for the engine mounts. The software allows the user to decide the level of complexity of the simulation model. In combination with the template based architecture, which has no limitation concerning model topology, this is a significant advantage compared to single purpose software that can only provide results for predefined application areas.

In addition to predefined templates for the most common engine types, template wizards are provided to assist the user in creating customized configurations covering every conceivable cylinder arrangement. Engines up to 24 cylinders, distributed over as many as 12 banks can be considered.



Crank Train W24 - Engine

The cranktrain module of **ADAMS/Engine powered by FEV** delivers solutions for the following tasks that frequently occur during the engine development process:

- Free forces and moments for engine mount layout
- Ignition or Influences studies
- Torsional vibration analyses of the crankshaft and damper layout
- Crankshaft bending dynamics and main bearing loads
- Bearing orbits with minimal oil film thickness
- NVH excitation spectra
- Disturbances in speed ununiformity as a timing mechanism excitation
- Load cases for detailed stress investigations

The software has been developed by experienced engine development engineers and has been developed to fulfill the specific requirements of modern, CAE supported engine development process.

Philipp Kley

Fuel Cell Vehicle in Winter Test

Using brake energy recovery with supercapacitors appears to be a promising approach regarding reductions in fuel consumption, especially for hybrid electric concepts. In addition to brake energy recovery, supercapacitors can also be used to cover short power demand peaks, providing the possibility for small scale and light weight fuel cell system designs.

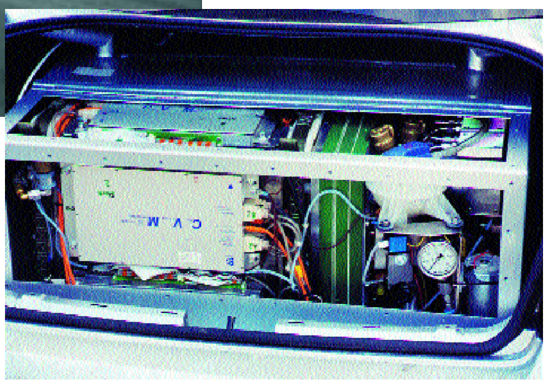
The Paul-Scherrer Institute and FEV Motorentechnik GmbH in close cooperation with Volkswagen AG have developed a hybrid electric demonstrator vehicle with fuel cells and supercapacitors. The vehicle delivers the targeted brake energy recovery and provides sufficient performance.

The "HY.POWER" demonstrator vehicle performance was successfully demonstrated in the presence of Volkswagen board member Martin Winterkorn and several journalists under extreme boundary conditions on January 16, 2002 during an excursion over the Simplon pass (altitude 2005 m) in Switzerland, even though limited use of the advantages of the hybrid concept could be realized under such boundary conditions.

The powertrain of the Volkswagen Bora "HY.POWER" includes a fuel cell system with 6 single PEM fuel cell stacks and a net power output of 40 kW. The supercapacitors are able to provide a shortterm power output of 50 kW for approximately 15 seconds, to provide additional improvements in the dynamic system behavior. The 1850 kg vehicle uses the advantages of the hybrid concept to accelerate from 0 to 100 km/h in 12s.

FEV was responsible for the complete air supply of the fuel cell system. The system pressure can be held at a level of 2 bar using a screwtype compressor with integrated water injection. This leads to high specific power output as well as higher humidity in the cathode air, with a reduced amount of water, due to the increased pressure level. The development focused on the design of the DI-water resistant injector and the calibration of the humidity control system with regard to transient requirements. Additional heat energy for water vaporization is brought into the system by an integrated air preheating system, so that a relative humidity of over 70% at a maximal air outlet temperature of 70°C is realized over a wide area of the operating range.

Compressor efficiency is increased due to the internal cooling by vaporization, so that the drawbacks of the preheating can be overcompensated. The NVH behavior of the air supply system is inconspicuous and cannot be detected as a primary noise source in the entire system.



Picture left: "HY.POWER" Volkswagen Bora passing the Simplon Pass in the Swiss Alps

Picture right: View of the Fuel Cell System in the Trunk of the Car

Following this successful winter test the vehicle was publicly presented at the Geneva Motor Show in 2002. The fuel cell system will be further optimized and will be presented during the Aachen Colloquium in October, 2002 within FEV's booth.

Dr.-Ing. Andreas Wiartalla

Analysis and Assessment of Production Engines

A variety of promising new technologies with the potential to help achieve future combustion engine development goals is currently becoming available in the automotive market. For the engine developer, knowing the potential of these technologies and the possible issues relating to a smooth implementation for volume production is a significant decision making aid in selecting future strategies.

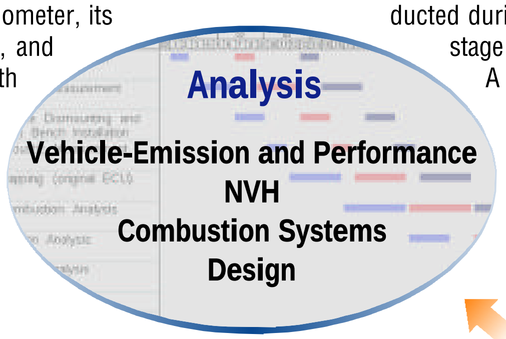
The entire range of available technologies, from the 3-cylinder inline engine to the 12-cylinder V-engine, has been assessed within the framework of customer projects at FEV, including both gasoline and diesel engines featuring various design concepts from all the important markets. The integration of the combustion engine into the particular vehicle powertrain concept has also been considered by FEV, which has been particularly useful e.g. in the cases of hybrid technology and various transmission concepts.

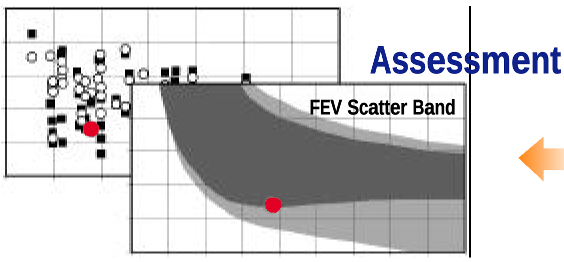
Within a full benchmarking program, the engine is assessed with regard to vehicle application, vehicle and powertrain NVH, thermodynamics, design, and electronics components. The vehicle-specific investigations include analysis of the vehicle's emission behavior on a chassis dynamometer, its overall on-road performance, and its acoustic characteristics with regard to interior and exterior noise as well as its vibration behavior.

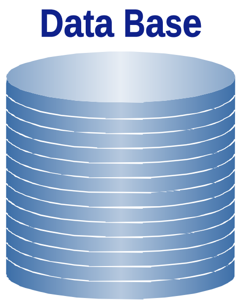
The NVH evaluation is followed by a detailed investigation of the engine or powertrain in a semi-anechoic test cell. The engine's thermodynamic characteristics are analyzed during dynamometer testing. Here, the engine is assessed while operating with the production ECU and with standardized operating parameters. A detailed friction analysis is conducted to assess the mechanical characteristics of the engine and a final design analysis of all relevant engine components contributes to a detailed understanding of the overall engine construction. To ensure the highest possible consistency and comparability in the measured results, standardized boundary conditions and testing procedures are applied. It is also possible to extend the benchmarking program to consider concept-specific engine design features.

FEV is able to draw upon its comprehensive databases to assess the results. These databases contain the results of the analyses of a large number of competitor engines and development projects and thus provide a unique representation of the state-of-the-art. The benchmarking of production engines has a long tradition at FEV. For over a decade, FEV has been conducting an extensive engine analysis program commissioned by a consortium of automobile manufacturers. The value in analyzing competitor engines is demonstrated by the fact that automobile manufacturers have commissioned FEV to benchmark their own production engines. Such analyses are also conducted during the engine's development stage and prior to series production. A thorough analysis of prototypes is likely to yield fruitful results, for example, with regard to the early detection of any shortcomings.

Dipl.-Ing. Bernd Haake







CONTACTS

FEV Motorentechnik GmbH
Neuenhofstraße 181
52078 Aachen Germany
Phone (+49) (0) 241/56 89 - 0
Fax (+49) (0) 241/56 89 - 119
E-Mail marketing@fev.com
Internet http://www.fev.com

FEV Engine Technology, Inc.
4554 Glenmeade Lane
Auburn Hills, MI 48326-1766 USA
Phone (+1) (0) 248/373-60 00
Fax (+1) (0) 248/373-80 84
E-Mail marketing@fev-et.com
Internet http://www.fev-et.com

Editor
A. Wittstamm

Layout
G. Perseke

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