FEV-Spectrum

Technology-Highlights and R&D Activities at FEV

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Gasoline Direct Injection

Gasoline Direct Injection is one promising answer to the necessity of fuel economy improvements for future passenger car powertrains. Taking the drastically increasing demands of the environment, comfort and reliability into consideration, the development of DI gasoline engines for use in mass production vehicles involves new challenges for FEV Motorentechnik.

Our solutions are based on a simultaneous development of the combustion system, the catalytic converter technology and the electronic engine management in order to make a breakthrough in engine technology.

As far as the combustion system is concerned, there are various competing approaches. An essential criterion required for improvements is the lowest raw emissions at the highest operational stability. FEV's unique charge motion controlled DISI concept is an approach, which combines these features in a wide speed/load regime of the engine map running at stratified charge.

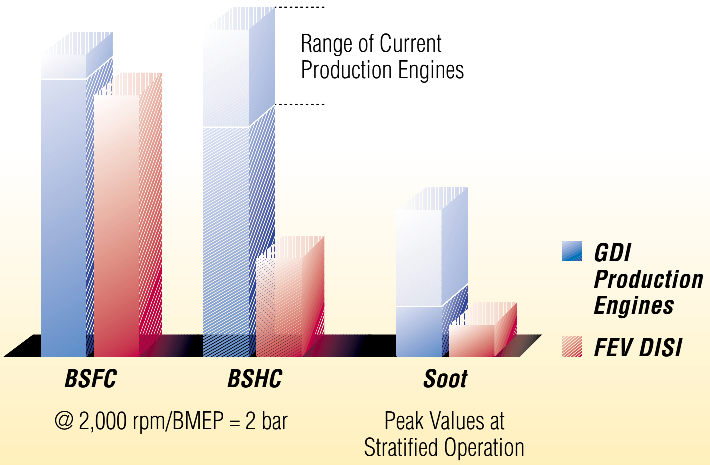
With regard to these targets, current GDI production engines demonstrate significant differences when compared to FEV's DISI engine, which shows considerable advantages in fuel consumption as well as in hydrocarbon and soot emissions. The air guided system of FEV's DISI engine results in a significantly better emission behavior. In stratified operation, mean Bosch smoke numbers of 0.2 have been measured with peak values not exceeding 0.4. In comparison peak values of up to 1.9 have been established with wall-guided combustion at low engine speeds, which indicates insufficient charge motion support during mixture formation.

The key reason for these improved values is that FEV's air-guided DI combustion process provides maximum free spray propagation in order to avoid severe wall wetting. Since the engine concept includes variable charge motion, the ▶

mixture formation and stratification process can be controlled in a wide area of the engine operational map.

Moreover, the charge motion controlled combustion system has a high potential in terms of operational stability. Current GDI production engines showed misfiring frequencies of up to 8 per thousand cycles at stratified operation in our benchmarking tests. FEV's development target is to have no misfiring frequencies even in a defined tolerance band of injection and spark timing. This can be reached through a careful coordination of charge motion, combustion chamber shape and an optimized geometric allocation of the injection jet cone and the spark plug.

Combustion System Performance



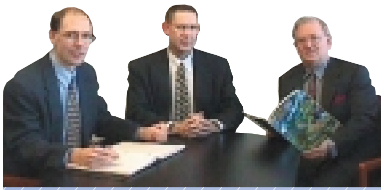
Test cycle simulations based on the use of contemporary vehicle/gear configurations, show that the largest part of the New European Driving Cycle is run in the engine speed of up to 3,000 rpm, with the engine load rarely exceeding a brake mean effective pressure of 5 bar. The FEV combustion process allows this speed/load regime to run at lean mode while lean operation can be extended up to loads of bmep = 6 bar. This can be done when an additional operation mode with a homogenous lean mixture in the upper load area is applied. Therefore, this process makes it possible to transfer as much of its fuel economy potential as possible into vehicle fuel consumption benefits.

An essential aspect for staying below future exhaust gas emission limits with lean operated engines is the achievement of high exhaust gas recirculation rates, even during dynamic operation. In this way NOx raw emissions can be minimized. Along with the high EGR tolerance of the combustion process, the dynamics of the exhaust gas recirculation system comprise an essential part of the optimization process.

Since the combustion system is based on a tumble concept that enables maximum intake port flow capacity, the full load performance is excellent (see figure). Another result of this principal design parameter is the fact that the FEV concept is as close as possible to current mass production engines and therefore can be machined on common transfer lines.

The development of exhaust gas aftertreatment technologies for gasoline direct injection engines will continue to focus on NOx adsorber technology. Hydrocarbon emissions must be given the same priority as the nitrogen oxides, because there is a significant trade-off between NOx storage capacity and hydrocarbon emissions. This is due to competing reactions of HC and NO at the catalytic Pt contacts inside the adsorber. This is why the demand for

Zum Geleit



Dear Readers,

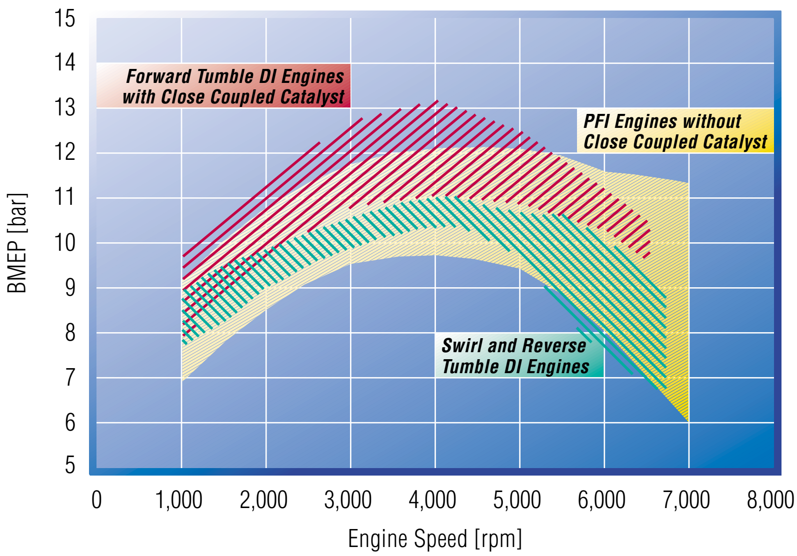
with this issue of Spectrum, we welcome a new century and the SAE International Congress and Exposition 2000. This Congress highlights the development of advanced technology in the automotive and heavy-duty diesel industries, which focuses on continued improvements in fuel economy, exhaust emissions, integration of electronics and control systems, improved reliability and cost reduction. With over 950 people in the FEV Group, we support customers around the world with advanced engineering services and test equipment to address these challenges, while meeting production release timing, cost and reliability targets.

In North America, FEV Engine Technology, Inc., continues the expansion of its Technical Center and the assignment of wellknown experts. We are excited to announce the addition of Prof. Dr. Peter Hofbauer as Executive Vice President of Research and Development, and Dr. Joachim Wolschendorf as Vice President of Engineering and Chief Technical Officer. With this expert team FEV Engine Technology, Inc. adds proven experience in powertrain research, design and development which will focus on the economic and environmental goal of customers in North America, as FEV Motorentechnik supports its European and Asian client base.

Gary W Rogers

Gary Rogers, President and CEO,
FEV Engine Technology, Inc.

Full Load Assessment of 4-Cylinder DISI Engines



Electronic development increasingly takes place in a virtual environment with the engine and exhaust gas aftertreatment system appropriately modeled. For the coordination of complex engine management, processes have been developed at FEV, which enable "off-line" preliminary data settings of many functions and an evaluation of these functions at early project stages. The interaction of engine behavior, management functions, vehicle and driver is simulated in real time. The controller is coupled to the simulation environment via real time interface cards ("hardware in the loop"). The implementation of new control algorithms to the engine management takes place at FEV with the help of various systems, both off-line and online in bypass operation, e.g. Matlab-Simulink and ASCET-SD.

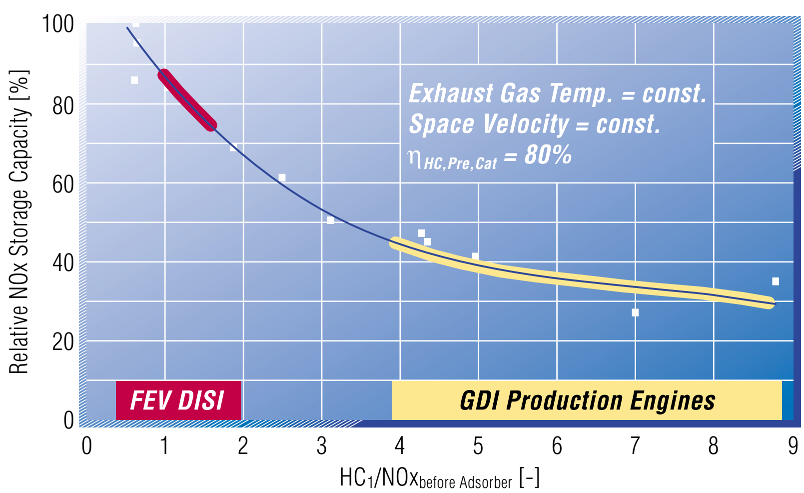
DI combustion processes with low HC raw emissions is high, and therefore has recently been established as an essential development target. This shows that combustion systems like FEV's air-guided concept, which include minimal wall wetting of the injected fuel, have an additional advantage.

With respect to the calibration of the engine in the vehicle new tasks must be completed. The discontinuous operation of the engine, typical of NOx adsorber technology considerably extends the requested functionality provided by the engine management used. At FEV the use of dynamic engine test benches is a standard development tool that allows for the preparation of new engine management functionalities to be accomplished in the shortest possible time.

These test benches include road load simulation, constant volume sampling and bag analysis to investigate the dynamic engine performance and emission behavior. They have proven their capability to provide reproducible emission results in numerous projects. Due to the lack of driver influence, it is possible to evaluate even the effect of slight modifications on emissions behavior. By means of a special cooling system, up to four cold start emission tests per shift can be performed. Furthermore, hardware modifications, which often must be made during the development of new exhaust gas aftertreatment systems, can be implemented easily with less packaging restrictions. Overall, the use of transient test benches results in a considerable reduction of development times.

The whole development process represents a cooperation of the engine and vehicle manufacturers and their suppliers. In this context an engineering service supplier like FEV acts as a mediator between research, which pursues all possible alternatives, and production development, which concentrates on short-term and cost oriented practicability. ◆ *Dr. Peter Wolters*

HC/NOx Trade-Off of NOx Adsorption Catalysts



End-of-Line Hot-Test

The Test and Instrumentation division of FEV has so far been known for their high-quality products for research and development of combustion engines. This field of operation has now enlarged.

Not only that you can get the full FEV engineering service all the way from a clean sheet of paper through to vehicle application, you can find us at the end of your engine assembly line, too.

FEV has entered the area of production hot-test and the various philosophies of EOL-testing (End-Of-Line) so that your engine with all its requirements and peripherals could even be supplied as a turn-key package from design to EOL-testing.

Your benefit from an FEV production test bed is that FEV with their engineering background know the key-problems of an internal combustion engine.

We know what to look at, check and assure quality for before it fails. FEV can design your engine-specific test cycle so that if an engine or component is bound to fail, it fails on the EOL-test-bed, not at your consumer plant or even in the field.

Loading side with sliding door

Along with this specific test cycle goes the appropriate hardware for the production circumstances. Hardware that assures short cycle times and low investment, hardware that withstands the everyday challenge of a production environment, an environment consisting of spillage, dirt and little maintenance. Hardware that allows an up-time of 95% and more. In one word: Hardware of the known good quality you are used to from all the FEV products.

Since FEV manufactures complete test-cell-compartments either for inside or outside use, without or with operator control-room which can be fully equipped to what ever your needs are, it mainly becomes your decision which set-up or fraction of the entire system you need.

This module is a specially designed and dedicated steel construction that comprises everything an EOL-test-bed needs for the demanding present and future. It is a mostly self-sufficient test-cell-module with hardly any requirements to infrastructure. It is the most handy way to start a new production plant / EOL-test or to refurbish an existing one.

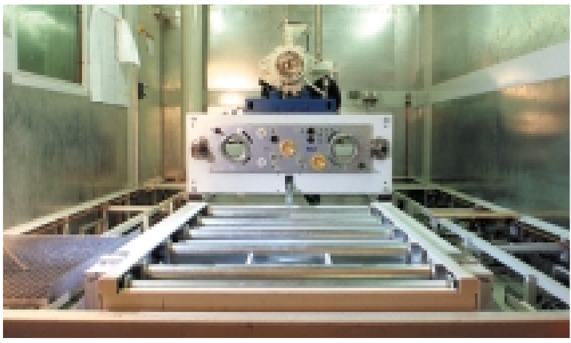
The key characteristics of the test-cell-module concept are economy, flexibility, and short manufacturing and installation times.

The modular construction allows an easy increase of test capacity by adding module by module e.g. as you are ramping up your production output.

Replacement of a complete test-cell is possible without a significant drawback on the operation of the neighbouring test cells.

Upgrading of the test cell equipment by utilisation of pre-manufactured equipment-modules, make a quick adaptation to new measuring tasks possible without tremendous costs.

The key part of the modular concept consists of the test cell itself. Its primary functions are to provide mounting facilities for the test cell components, to act as attenuation for noise and vibration, and provide operator and facility safety, all in one.



Docking system with roller conveyor segment

The modules are suitable for engines up to 500 kW including their auxiliary components.

For EOL-testing the procedure can happen fully automatically. When the engine leaves e.g. the waiting station the prepared setup is loaded to the module. The engine is safely mounted on the hot-test-pallet.

The connections to the docking unit are performed by dedicated rigging-sets. When the pallet enters the test-cell, it gets clamped to the test-cell's base frame, fully automatically. At the same time the docking unit will engage. Simultaneous to this the dynamometer's drive-shaft engages. While this is happening the test-bed-ECU gets programmed for this very engine type/ variant. Even maps, unique for this particular engine, may be produced further into the test.

After all necessary safety-checks have been completed the engine will be primed with water, fuel etc. The test-cycle, specific to the requirements of your engine is performed.

Needless to mention is that all safety relevant data is permanently monitored. Needless to mention is that all meaningful data is acquired, calculated, evaluated and stored.

Last but not least, needless to mention is that all this happens automatically. Nevertheless, you can at all times interfere if so foreseen in the user definable set-up.

Finally the engine will disengage, the doors open and it will leave the station with a marked data tag, telling everybody who wants to know: O.K. / N.O.K. and more.

The whole process starts all over. ◆

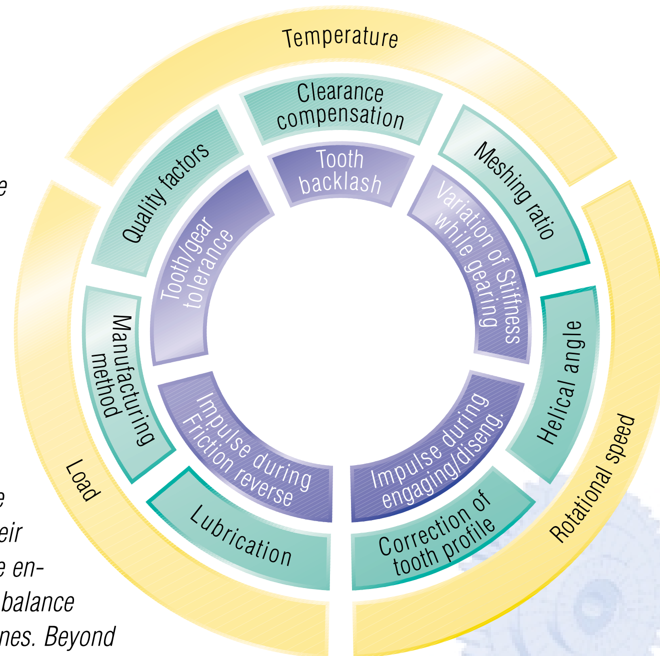
Bernd Ansorge

CAE-Support of Gear Train Development

Due to the high transmissible torque and the durability, gear trains are established in heavy duty and industrial engines. They serve as drive systems for camshafts, injection pumps and accessories. The absence of any engine relevant speed limit compared to chain drive systems is the reason for their use as timing drives in race engines and 2nd order mass balance systems in production engines. Beyond the performance and durability, the low space requirement is a significiant advantage of gear trains enabling the designer to realize a compact timing drive system resulting in short engines. Current development activities, especially for modern diesel engines with high pressure injection, profit by this features.

With the help of comprehensive simulation tools, the dynamic behaviour of gear trains under engine operating conditions can be investigated. The gained data are feed back into the gear train design and the tooth layout resulting in an optimized gear train layout and tooth shape.

Multi-Body Simulation Model: Timing Drive of a DOHC V-Engine



Gear Train Noise – Influencing Quantities

Gear Tooth layout

Besides the dimensioning of gear teeth, a careful layout of the tooth profile is one of the essential steps in a tooth layout process to comply with the acoustic requirements. The change of the contacting flanks, the impulse during engaging and disengaging and the variation of stiffness while gearing are some of the causes for the noise emission of a gear couple. These and further influencing quantities have to be minimized by the choice of an adequate tooth profile, profile corrections, meshing ratios and minimized tolerance values.

Within the tooth layout process following stresses and safety factors against failure are determined under consideration of material and geometry data, manufacturing sequences, quality levels and loads:

- hertzian pressure at flanks (pitting)
- tooth root stress (failure/breaking)

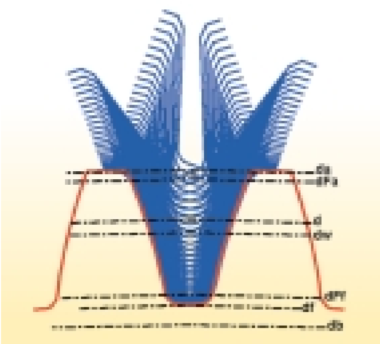
- seize temperatures acc. DIN "Integral- and Blitztemperaturmethod" (seizure)
- parameters of specific sliding (wear)

Dynamic Simulation

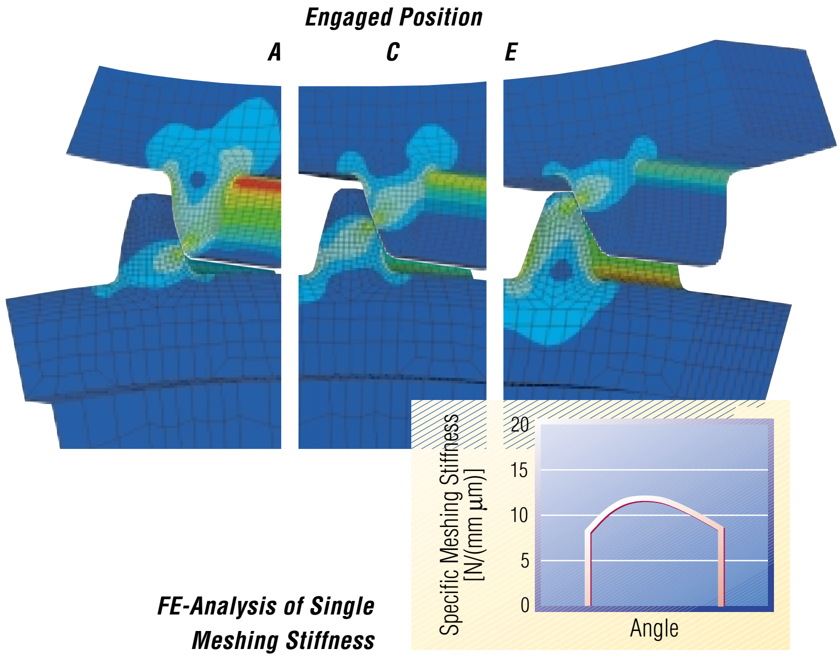
The activities in a gear train development process are mainly focused on the simulation of the dynamic gear train behaviour with the help of multi-body analysis (MBA) tools.

In a tooth layout process the dynamic load of a complex gear train with several gear couples as well as the gear body movement behaviour is approximately captured by influencing factors. These factors do not differentiate between the individual engine excitation character. To get the information about the dynamic behaviour of gear trains, FEV uses multi-body analysis and finite-element simulation tools. By simulation of the rolling procedure of a manufacturing tool the coordinates of all tooth profiles will be performed. This "virtual" tool profile considers the possible tolerances and deviations as well as the predefined profile corrections. A subsequent FE-analysis determines the single meshing stiffness between each gear couple. The geometrical and structural data serve then as input for the physical meshing model in the multi-body analysis. It is described by a set of contact definitions with the applied varying quantities along the tooth profile and the tooth width. By the help of physical meshing models the consideration of the following load- and speed dependent effects is possible:

- meshing ratio
- characteristic of meshing stiffness



Simulation of Rolling



FE-Analysis of Single Meshing Stiffness

- impulse during engaging and disengaging
- impulse during friction reverse.

Furthermore, this model considers the

- backlash clearance and tolerances
- damping in non contact situations
- stiffness of the support structure
- driving torques
- crankshaft excitation.

The automated modeling procedure in the MBA-software environment is realized by the help of FEV-own computer code.

The results of the dynamic simulation of gear trains inform about the dynamic meshing loads, the load distribution on the single teeth, contact patterns and the gear body movement behaviour (torsional vibration, tilting, axial movement). This calculation results are fed back in an optimized tooth layout. By analysing different gear train models, the impact of

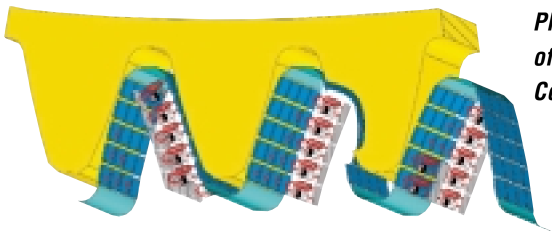
- different layout concepts
- various tooth backlashes simulating the thermal expansion of different materials
- clearance compensating elements
- various stiffnesses of support structure

can be investigated and dynamic loads and undesired gear body movement can be minimized.

Manufacturing

Considering the manufacturing sequence, all geometry data of gear teeth and manufacturing tool, tolerances, profile corrections, check dimensions, material data and gear couple related data are summarized in a data sheet for each gear which completes the comprehensive gear train development process. ◆

Stefan Trampert, Markus Duesmann



Physical Model of Meshing Conditions

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