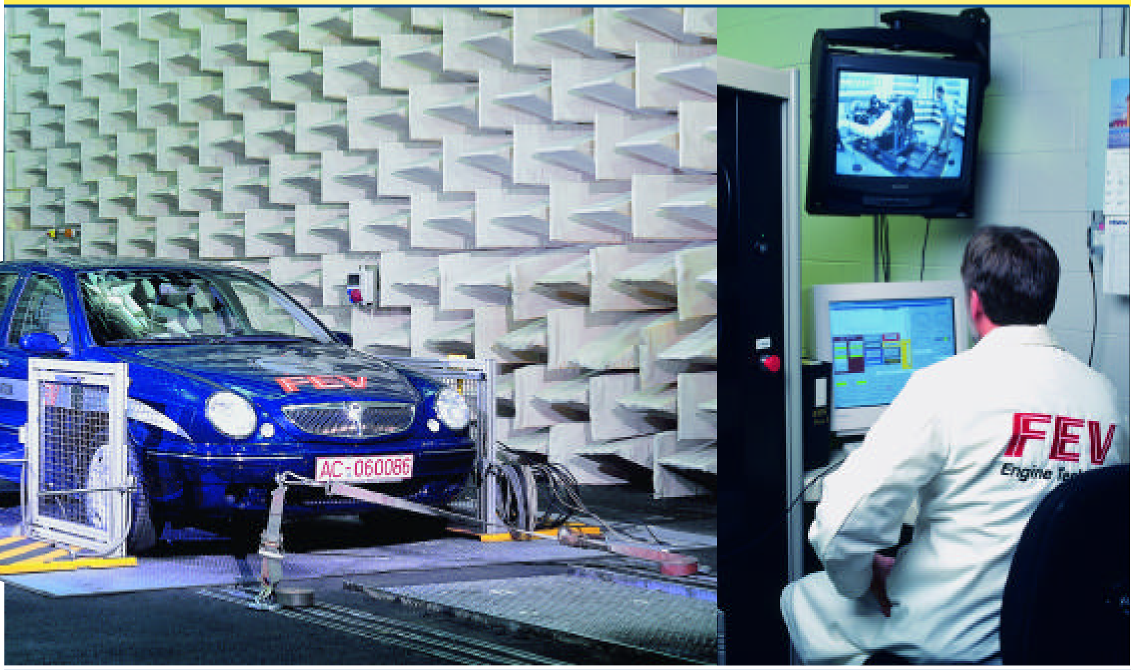
SPECTRUM

Technology - Highlights and R & D Activities at FEV

Issue 18, September 2001



From Sound Pressure Level Measurement to Corporate Sound Design

FEV develops solutions to vehicle powertrain noise and vibration issues for the global OEM and Tier supplier industry. We look back with pride on 30 years of development experience, characterized by systematic and efficient methods of problem solution that are compatible with the systems and methodologies employed by our clients. In FEV's development projects, NVH is completely integrated into the process with:

- The latest proven prediction tools,
- Systematic sound testing of early prototype powertrains,
- Sound-oriented vehicle calibration and packaging,
- Tolerance analyses in support of eventual SOP.

SUMMARY

Over the past 30 years, Product Quality - where noise and vibration are primary components - has developed into a critical sales attribute. Based on research results from the Institute for Internal Combustion Engines (VKA) at the Technical University in Aachen, Germany, chaired by Prof. Franz and Prof. Stefan Pischinger, NVH has been an important field of activity for FEV ever since the company was founded. As a result of the tremendous progress that has been achieved since then, FEV today employs over 80 engineers and technicians worldwide who strive to develop solutions to the industry's complex NVH problems. NVH engineering at FEV includes problem solutions at the early prototype stage as well as trouble shooting during vehicle mass production. The methodology of engine NVH is characterized by continuous progress. In the 1970s, there was significant focus on the measurement of sound energy and experimental proof of the relevant engine noise sources. Sound radiation measurements - which at times went on for months - represented the starting point for noise encapsulation. For the first time, it became evident that the experience of FEV as an independent engineering services provider was indispensable in the evaluation of the individual noise sources as FEV's customers addressed the engineering targets for vehicle compliance with pass-by noise regulations.

http://www.fev.com

PREFACE

Dear Readers,

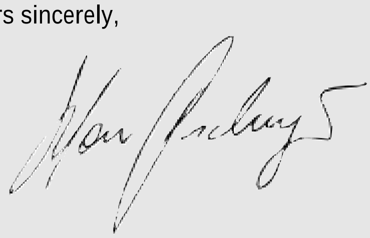
The increased pressure on development cost and time no longer allows additional iterations in the late phases of a powertrain development. In order to avoid unexpected problems that could become critical for SOP, appropriate measures have to be taken early in the development phase. FEV has developed new methods and tools in the NVH and Mechanics areas in order to address the CTQ's ("Critical to Quality") early enough to effect a remedy. FEV's interior vehicle-sound synthesis based on powertrain measurements represents an important step in this direction.

Development methods as well as new engines and technologies are major topics of this year's 10th Aachen Colloquium for Vehicle and Engine Technology. With 1.500 participants and 79 exhibitors last year, it was the largest event of this kind in Europe.

It will be a pleasure to welcome you in Aachen from October 8 - 10.

We look forward to your participation in the colloquium.

Yours sincerely,

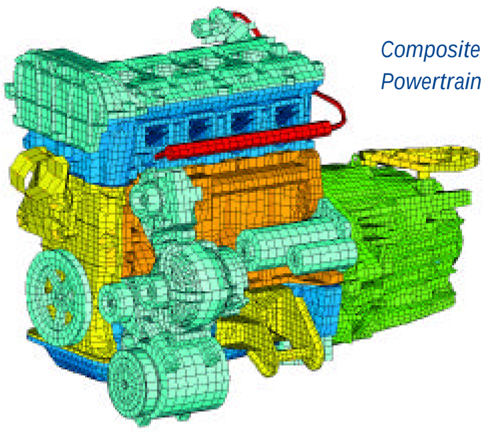


Prof. Dr.-Ing. Stefan Pischinger
Executive Vice President

Continued from Page 1

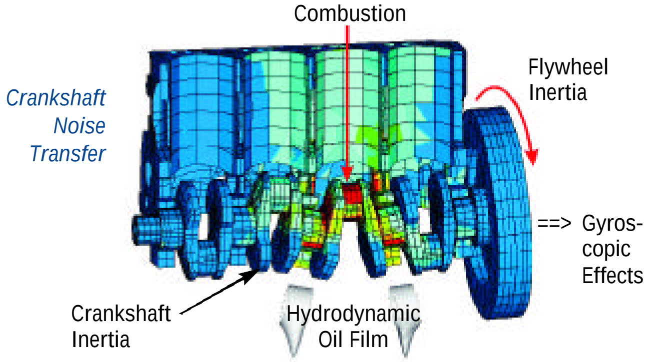
In the 1980's, new, emerging possibilities for the application of computer aided testing were rigorously explored. FEV developed a signal analysis tool (called SIAN) that, for the first time, enabled a thorough cause analysis. This new tool also facilitated the differentiation between critical engine excitation processes - such as Diesel engine impact noises and gear meshing from structural weaknesses due to component vibrations. Dominant noise sources were systematically eliminated as development efforts were optimized.

The development of predictive tools that began early in the 1990's was a complex and costly process. Since this effort began, FEV has been at the forefront of dynamic structural design and optimization. These new tools allowed FEV engineers to reliably predict the behavior of NVH transfer between solid bodies. Since then, FEV has optimized the structures of over 200 different combustion engines with regard to vibration and high-frequency noise. Our effort consisted of using commercial computer codes and adapting them to the demands of the field of powertrain acoustics. Experience has shown that low frequency powertrain vibrations have grown increasingly important due to greater application of body encapsulation. Consequently, calculation procedures and testing were soon extended to all of the auxiliary components.



Composite Powertrain Model

Meanwhile, computer performance has rapidly developed, making possible significant advancements in the capabilities of the calculation tools for excitation processes. Since excitations often have an impulse-like character, the simplified notion of periodic vibration is usually inappropriate. It became necessary to demonstrate the exact time sequence of the interaction between different mechanical systems such as coupling of crankshaft bending and housing deformation with the changing elasticity of the dynamically displaced oil film with respect to both time and location.



It was only possible to find representative parameters for such complex calculation models through extensive experience. Conversely, the comparison of different analytical approaches led to detailed models that could be verified experimentally. Thus, the prerequisite was created for understanding the annoying and often sound-dominating impulses and to eliminate them systematically during the development process.

Recent FEV developments address the sound pressure level and sound quality potential:

- Powertrain component tuning
- Focusing powertrain optimization on weaknesses in the vehicle body, and
- Supporting critical developmental trends such as lightweight design, downsizing and higher specific power.

FEV's NVH chassis dynamometer began operation in 1998, providing a basis for our Sound Design work. FEV has developed innovative tools for this purpose:

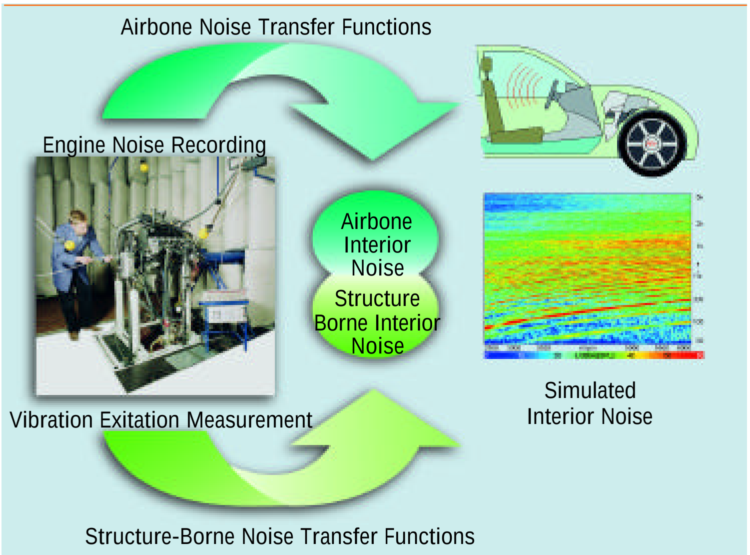
- Interior Noise Simulation
- Transfer Path Analysis and External Noise
- Source and Component Evaluation
- Integrated NVH and Thermodynamic Cell

In the powertrain NVH cell, noise excitations are recorded at locations such as the main bearings, structure-borne noise transfer paths, and noise radiation are determined.

The novelty of the approach is to conduct - using true Simultaneous Engineering - early application of the engine control strategy as well as mechanical investigations at an early development stage, without requiring an additional NVH prototype. Multi-channel simultaneous measurement technology permits the efficient, while simultaneous verification of any sources of noise and vibration as well as fine-tuning with regard to component loading, performance and exhaust gas emissions.

On the NVH chassis dynamometer, time-saving updates can be made on exhaust and intake systems with regard to orifice noise, surface radiation and stress as well as acoustically relevant vibrations. Detailed evaluation of the individual noise sources and radiation behavior are also performed on the chassis rolls. FEV identifies weaknesses in the tuning of the drivetrain/chassis system as well as the chassis insulation and recommends appropriate solutions.

FEV is pioneering new solutions in transfer path analysis. Using primarily experimental reciprocity, vehicle body characteristics can be determined without extensive disassembly, thereby minimizing the development expense. The critical transfer paths can thus be determined early in the project schedule.



Interior Noise Simulation

Since 1997, FEV has been superimposing model-based excitation signals and transfer path analyses with a new method of Interior Noise Simulation. Interior noise synthesis predicts audible interior noise on the basis of early measurements of noise and vibration signals from the NVH test cell. The individual components of the engine/transmission system, including auxiliary components, can be quantified regarding their respective contributions to interior noise. Measures for level and sound improvement are defined by calculation or by experience and acoustically simulated. Vital aspects are short-term coordination in the project team and instant feedback regarding costs, production and sound acceptance.

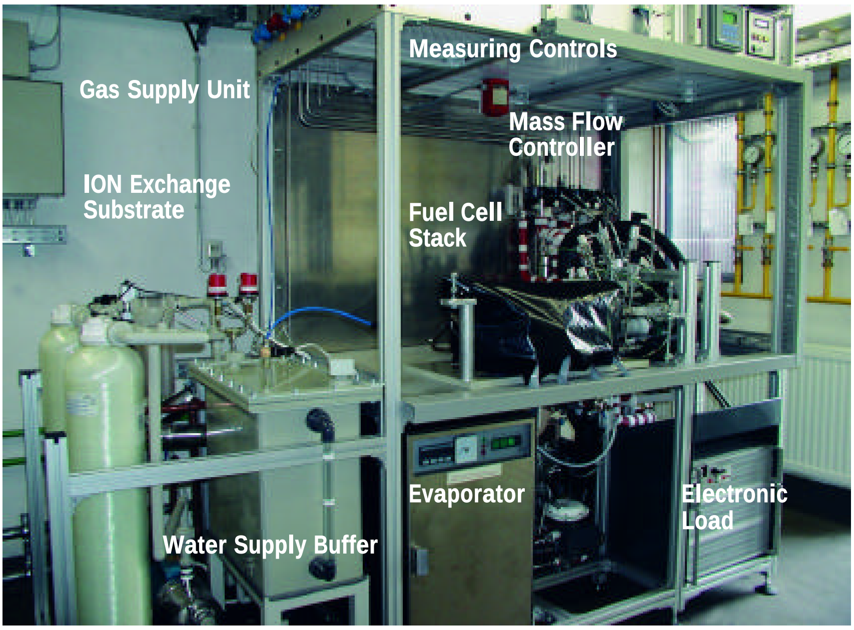
For good sound - as well as for a good reputation - early and firm integration of engine and vehicle acoustics engineers into the development team is decisive. Progress in lightweight design as in NVH can only be obtained when the entire system is considered. Such progress is not possible by taking an isolated look at individual components. Successful NVH series development is characterized by close cooperation between an OEM, its suppliers and FEV.

Dr.-Ing. M. Schneider

FEV Commissions a New Fuel Cell Test Bench

FEV commissioned its new fuel cell test bench early in 2001. This new test bench allows analysis of the dynamic behavior of water-cooled PEM fuel cell stacks up to 5 kW.

The fuel cell anode is supplied with clear hydrogen or a synthetic gas mixture as a substitute for reformer-gas. The cathode side is provided with dry, oil-free air from a compressed air system. Both the hydrogen and the air side are humidified with steam from deionized water. The system pressure is adjusted with pressure valves behind the fuel cell to simulate the dependence on charging.



Control and data acquisition are achieved through the implementation of the ADAPT process control system with integrated SPS. The control unit may be connected with a Matlab / Simulink based system simulation tool to perform in-the-loop testing of the stack under real-life, reproducible and transient operating conditions.

The test bench will be used to determine the stack operational characteristics as a function of pressure, relative humidity, gas composition and temperature as well as for durability tests.

Dipl.-Ing. J. Ogrzewalla

Intelligent Mechanical Development Using Specialized Measurement Techniques and CAE

Mechanical testing represents a substantial proportion of an engine development program with regard to both time and cost. Consequently, in order to effectively perform mechanical testing, it is necessary to optimize the various test cell evaluations and to carefully plan the sequencing of the tests in a manner that ensures early detection and correction of potential errors.

In addition, the test plan must be flexible to allow changes in the test routine in response to unforeseeable events.

The basis for an individual test program for an engine development program is the FEV test catalog.

During the last few years, this test catalog has been built up, on the basis of a large number of development programs.

Functional testing of single components (e.g. valve train) or subsystems (e.g. lubrication system) is assisted by the use of CAE models. It is possible to introduce optimization measures very quickly. Pulse testing with parallel strain measurements help to verify FEM calculations and to predict the probability of component failure.

Each test specification sheet contains the information that is necessary for the test, for example, the test bench set up, installation of measurement equipment, the measurement program and rating sheets.

If a specific problem with a particular component is identified as a result of the tests, the follow-on procedure can be generated with support of FMEA.

The possibilities here include, for example, further tests with intensive application of advanced measurement techniques, material analyses and new CAE-based component calculations.

Examples might include the measurement of the cylinder deformation under fired conditions (LINDA), strain gage measurements using multi-channel telemetric systems, dynamic temperature, pressure and flow measurements, and friction analysis of single components.

In this manner, stress measurements on the combustion chamber side of the cylinder head can serve to determine the load status in operation and to optimize test cycles for the verification of the optimization.

The use of these special measurement techniques accelerates mechanism development and, together with CAE, a significant step towards "intelligent mechanical development".

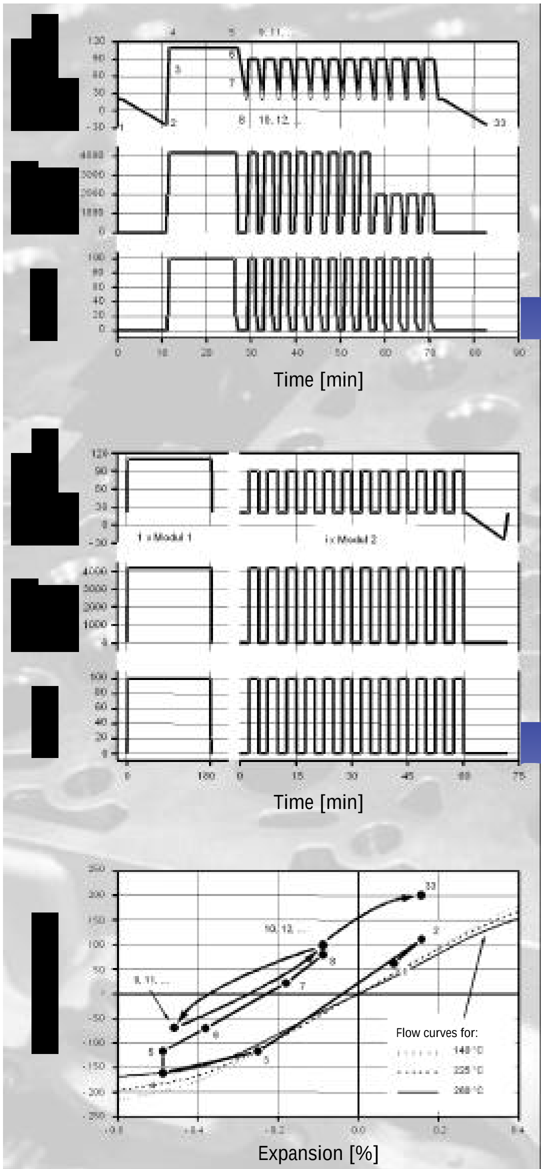
Efficient "intelligent mechanical development" by means of CAE and specialized measurement techniques offers the following advantages:

- The early application of CAE reduces the number of problems, since it provides knowledge of critical areas.
- The resulting detailed knowledge of component parts assists in introducing specific optimization measures rather than employing trial and error.
- Test cycles can be optimized.

As a result of the described flexible program for individual mechanical testing programs, including special measurement technique and CAE Tools, FEV's customers gain the benefits of FEV's extensive experience as well as the potential of comparing their own data from other engines.

Dr.-Ing. F.-W. Koch

Optimization of endurance Cycles, Thermoshock, Example: Cylinder head



Thermoshock Test

Thermoshock Test Tension-Expansation Diagram

Proposed Optimal Thermoshock Test

Trends in the Design of Gasoline Engines

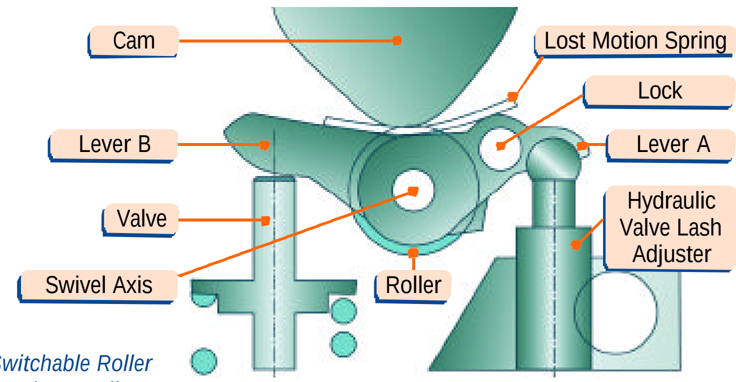
Current trends in the design of gasoline engines point toward the following emerging technologies:

- Fully Variable Valvetrains
- Direct Injection
- Variable Compression Ratio

From the design standpoint, these technologies result in challenging new tasks, in particular in view of the fact that is not yet clear what strategy will eventually be successful. For this reason, FEV has developed cylinder head concepts that generally enable both dethrottling principles (direct injection or fully variable valve trains). These considerations result in a unique set of constraints. For example, the size of the valve angle must be chosen so that, on one hand, there is sufficient space for the actuators that operate the valves with a electromechanical valve train (EMVT). On the other hand, the valve angle must be suitable to allow placement of the injectors below the inlet ports in the case of direct injection.

Moreover, FEV has prepared cylinder head designs that alternatively allow either the application of EMV or standard camshaft drives. In parallel, FEV is working on mechanically variable valve trains; the bukkling finger follower for deactivating the valve is a first step in that direction.

The realiszation of a variable compression ratio is, with regard to design, the key to the success of a downsized engine concept.

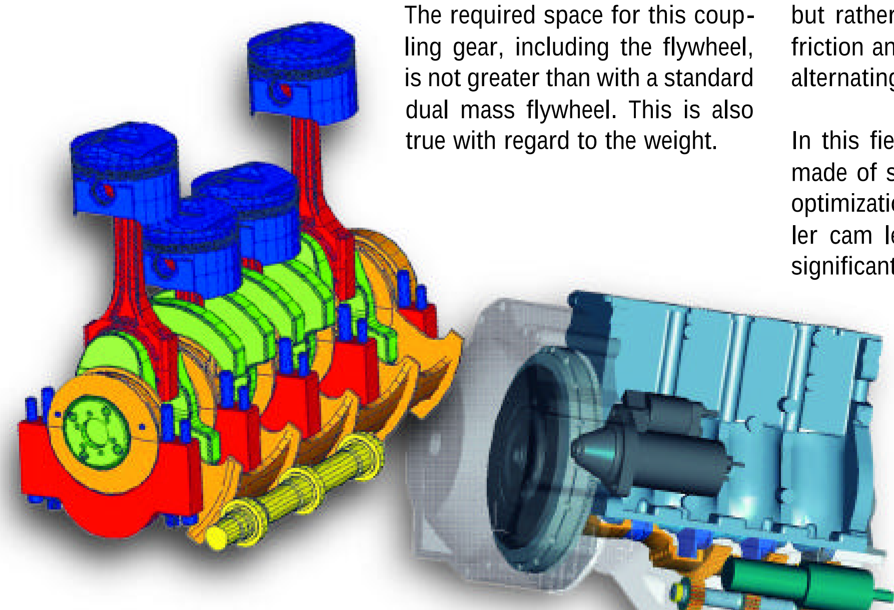


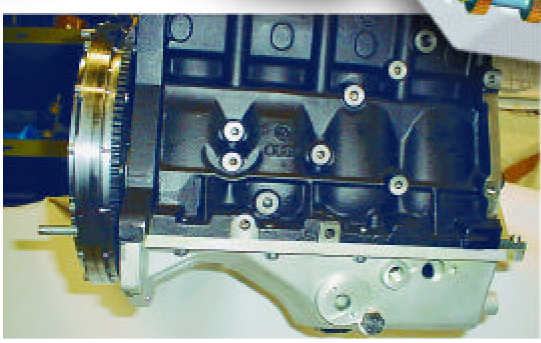
Switchable Roller Finger Follwer (FEV System)

FEV has developed a new design principle featuring an eccentrically supported crank shaft that allows continuous variation of TDC. The significant advantage of this concept is that no basic changes are required in production. The VCR system can virtually be arranged in a conventional bottom end as an "add-on".

The question of balancing the shift of the crankshaft towards the transmission drive and accessories can be simply solved by coupling elements between crankshaft and flywheel / pulley.

The required space for this coupling gear, including the flywheel, is not greater than with a standard dual mass flywheel. This is also true with regard to the weight.





Variable Compression Ratio via Crankshaft

FEV has a test cell engine configured with this VCR system that has already successfully passed durability runs. At the moment, vehicle application of this innovative new technology is being conducted in FEV's application center.

The concept is generally adaptable for the utilization of integrated starter generators (ISG), which will be most likely necessary as a result of the increasing number of engine- and vehicle related electrically driven components (accessories, water / oil pump, EMV). The ISG can be integrated in the transmission related portion of the coupling gear.

Lightweight construction and friction reduction represent further, independent, building blocks to solve the conflicting goals presented by emissions, fuel consumption and performance.

Lightweight design efforts currently focus on the crankcase, since it represents the largest share of the engines weight. The development effort is currently tending toward increased use of aluminum and even magnesium due to its low density.

However, sophisticated concepts utilizing gray cast iron, which is quite favorable with regard to strength and tribological properties, are also needed.

Reducing the oscillating masses is not interesting with regard to the potential savings in mass itself but rather, because of the associated reduction in friction and improved durability that is linked to the alternating masses.

In this field, both alternative materials (e.g. valves made of sheet metal or ceramic) as well as design optimization (valve-stem diameter, piston height, roller cam lever instead of sliding contact) represent significant potential for improvement.

Clearly, both engine weight and friction must always be simultaneously optimized. Improvements can often be realized by detail modifications of the various components. FEV is supported in this effort by a benchmarking database that is continually updated with detailed design analyses of more than 30 modern engines per year. Future gasoline engine designs will be characterized by a high level of technological diversification.

The competition among the various concepts will compel the ongoing development of the SI engine. FEV is ready to take up the challenge!

Dipl.-Ing. Ch. Tiemann

Trends in Diesel Engine Design for Passenger Car Application

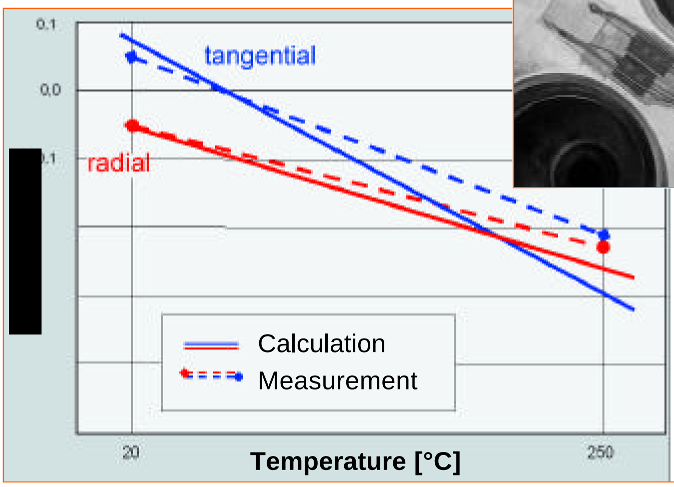
The layout and design of the primary engine components in today's production passenger car Diesel engines have changed significantly. Inline and V-engine crankcases are available in cast iron as well as aluminum alloy. Cylinder heads are primarily manufactured with aluminum alloy, however, a wide variety of different alloy compositions can be found in today's engines. A variety of cylinder head concepts exist for different intake and exhaust port configurations and the number of valves per cylinder, with both 2- and 4-valve concepts in service. Valve actuation or cooling strategies also vary from one concept to another.

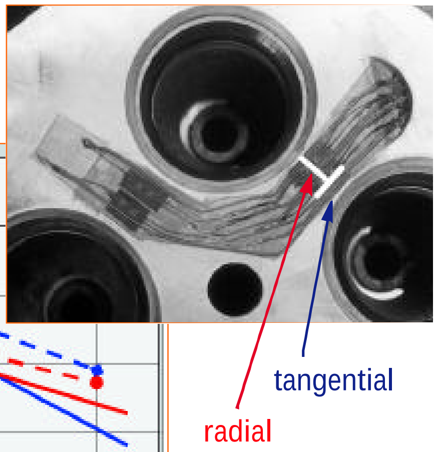
Similarly, clear concept differences are obvious in today's Diesel engines with regard to critical subsystems such as injection systems, intake systems, and charging systems. Despite these fundamental conceptual differences, today's top production engines achieve very similar levels of performance with regard to fuel consumption emissions and engine weight. Accordingly, it becomes obvious that, a "preferred engine concept" to realize the "best-in-class" engine does not exist. This trend will continue into the future, with each engine representing a "manufacturer-specific" compromise that must consider technical aspects as well as production constraints for the OEM and market positioning issues. With respect to engine technology, the DI-Diesel engine is now, at least in Europe, offered over the complete passenger car displacement range. Consequently, different priorities must be assumed for future development efforts.

Further Diesel engine improvements in all engine classes with regard to exhaust gas emission quality and NVH behavior will be indispensable. To achieve this target, contributions will be necessary from all engine subsystems including, for example, rigid base engine concepts, improved injection systems and highly sophisticated exhaust gas aftertreatment systems in addition to further improvements in engine mechanics. Increased cylinder peak pressure capability, reduced cylinder liner deformation, lower levels of engine friction and improved engine warm-up after cold start are examples of development targets for all engine sizes. Depending upon the particular engine class, further development focus with various implications will emerge. For the large capacity engines that are typical of luxury vehicles, aspects such as comfort (NVH) and weight reduction will reflect high priorities. FE methods can be used to perform detailed optimization of crankcase structures that case be produced using high-grade cast iron (e.g.CGI) or light metal designs with integrated structural reinforcements. Current development efforts have shown that, with large volume engines featuring cast iron crankcase concepts, careful optimization can result in hardly any weight disadvantages, compared to reinforced aluminum structures.

The cylinder heads in future engine generations must accept emerging injection system component improvements as well as include flow-optimized port concepts. At the same time, the cylinder head layout must accept increased thermal loading as a result of increasing specific engine output. This calls for better optimized cooling strategies. Fine-tuning the thermo- mechanical structural behavior in the performance range above 60 kW/L will determine, for each particular case, the achievable performance limit for the cylinder head. Alternative concepts with aluminum reinforcements or alternative materials will also be considered for further increases in specific output levels. In addition to the factors mentioned above, special focus must be given to engine production costs in the high production volume medium engine class. For small displacement Diesel engines, the focus is, and will be, the achievement of the best possible absolute fuel consumption and emission values. Accordingly, special consideration must be given in the development of these engines to the optimization of the combustion system and engine mechanics. At the lower end of the displacement range, the requirements for increased cylinder peak pressure in combination with cost effective products will, in most cases, result in cast iron engine structures for the crankcase. Material-related weight reduction measures in these engines will concentrate on the engine periphery and the cylinder head.

Dipl.-Ing. H.-J. Ecker





Structural Optimization of a Cylinder Head Through Calculation and Measurement

Expansion of the Vehicle Application Center

In 1998, FEV opened a new Competence Center for Vehicle Application, located about 15 km north of Aachen in Alsdorf, Germany.

As a result of growing demand from the automotive and Tier supplier industry for full-service application support, the facility was expanded in the Summer of 2000 with a new building, housing about 100 engineers and a large vehicle design and packaging center. This is the third FEV location in the vicinity of Aachen, allowing concentration of all activities related to complete adaptation of vehicle powertrains. Simultaneously, the Competence Center represents an additional tool that supplements FEV's longstanding engine development chain by adding vehicle relevant fields such as:

- Packaging of engine and peripheral components,
- Emissions calibration,
- Driveability,
- On board diagnosis,
- and NVH (Sound-design, vibration and harshness)

through the start of production. The complex houses both GIF and FEV office and test facilities. The facility makes the following testing facilities available to FEV:

- Conditioned, 48 inch emissions chassis dynamometer with two independent emission analysis lines,
- NVH chassis dynamometer for investigations up to a vehicle speed of 250 kilometers per hour,
- Test track circuit of about 1 kilometer length, for testing up to a speed of 100 kilometers per hour, including a steep gradient slope for drive-away and hill-climbing analysis and pass-by course for exterior noise measurements; for the higher speed ranges, other surfaces exist within a distance of about 1 kilometer.
- Several conditioned test cells for hot and cold start and warm-up investigations in a temperature range from -28 to +40°C (-18 to +104°F).

FEV's design and packaging vehicle workshop provides 11 vehicle assembly stations with available lifts. Additionally, an area for adaptation of engines for vehicle installation, a metalworking area and several storerooms are provided. The integration of a self-contained electronic workshop in the vehicle workshop enables the adaptation of electric / electronic systems and application of complete wire-harnesses. The electronic workshop was configured so that the complete vehicle can be worked on within the self-contained area.

An additional conditioned room with a high speed data link to FEV's network area storage devices is available for the high resolution measurements that are needed for special investigations such as engine startup analysis within the emissions relevant temperature range. High speed data acquisition is frequently required for measurements such as cylinder pressure or cycle-synchronous HC emissions during engine start.

In Cooperation with GIF

The entire site is completely fenced and equipped with security lockout devices, so that access is only possible with identification cards. Furthermore, critical areas are surrounded with a visibility barrier, to ensure appropriate shielding of prototypes. In the case of particularly critical prototypes, there are a total of five lockable garages to prevent unauthorized access. The recent addition to the office building made it possible to concentrate single project teams in a single area, resulting in a significant increase in the effectiveness of the application process as well as providing the highest possible level of secrecy. The Vehicle Application Competence Center, with its recent improvements, allows FEV to ensure effective full-service development of an engine, from the initial design phase, through the combustion process development, NVH optimization, the vehicle application phase, and ultimately, through the start of production.

Dipl.-Ing. R. Weinowski

IMPRESSUM

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