FEV-Spectrum

Technology - Highlights and R&D Activities at FEV

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Utility Vehicle Engines of the Future

Due to economic globalization and increasing e-commerce, the volume of transportation will increase dramatically in the future. However, the potential to increase transport capacity, especially in central Europe, is limited. Consequently, better utilization of the commercial motor vehicles will be indispensable in the future. Apart from intelligent logistics concepts, optimization of the vehicle itself is an indispensable prerequisite to formulating an ecologically justifiable and economically efficient long-term transportation plan.

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For future heavy-duty motor vehicles, this means an enlargement of the loading volume as well as additional loading potential. Since an increase in the admissible total weight of the vehicles is rather improbable, due to legislative restrictions, the vehicle weight must be reduced to offset the additional loading volume.

The engine is a key factor in this optimization process since the weight-to-power ratio (kg/kW), the specific displacement (m^3/kW) and the absolute power have a major impact on the transport vehicle performance. Durability and future potential market possibilities are the significant benefits while the cost related factors include base price, fuel consumption, and the maintenance effort. The challenge is to reach the lowest possible cost/benefit ratio for every development process. Furthermore, compliance with emission legislations is mandatory for product competitiveness and marketability.

In developing truck engines, careful consideration must be given to stringent ecological and economic boundary conditions. The development process must follow a clearly organized path from the very beginning to the final product.

For FEV, this process begins with an intensive dialogue between FEV, as the development partner, and our client, to define the engine concept and the performance specifications.

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A predictive assessment of future development trends is necessary to establish the performance specifications. FEV uses "road maps" for this purpose. The figure on the next page shows this type of road map for an European long haul truck.

Common Rail (CR) injection systems will also play a dominant role in the future for truck engine applications. These systems offer the highest amount of flexibility, with continually increasing performance. Injection technology is one of FEV's traditional playgrounds. An example is the piezo-electrically driven fuel injection system. The following figure on page 4 shows a CR system for passenger car application and the variety of possibilities this system offers due to the high velocity and accuracy of the piezo-actuated valve. FEV is also working on a new CR Injector for heavy duty applications.

To meet future stringent emission legislation in mass production, the use of integrated emission control systems appears inevitable. Nevertheless, some open questions remain to be answered before introduction into mass production can be considered. These include the assessment of: fuel sulfur content, ash content and OBD. FEV has extensive experience in the systems development and integration of emission control systems for both particulate filters and advanced NO_x reduction systems.

There is a trend toward clear and simple base engine concepts followed by the provision of highly integrated, multi-functional add-on modules. This results in advantages in production manufacturing and maintenance. The future standard, even for higher power outputs, will be the in-line 6-cylinder engine due to inherent structural benefits compared to V-engines. These benefits are increasingly important with higher peak pressures. For an engine with a swept volume of about 12L specific power outputs above 30 kW/L are possible, allowing engine outputs greater than 500 hp. This allows greater market possibilities for larger line-haul truck applications. BMEP levels of 20 bar at rated power and 25 bar at maximum torque must be obtained. Supercharging plays a major role in reaching these values. Charge air pressures above 3 bar are a precondition to achieve a low soot level on for established combustion systems. Although VNT chargers can produce such a pressure level in a single stage process, two-stage charging may become interesting in order to improve transient response. Two-stage intercooling, although expensive, can improve the engine behavior further. With respect to cost, a combination of a fixed-geometry and a waste-gate charger should be comparable to a VNT charger. To support the complex interaction between the engine and the turbocharger(s), FEV is

Preface

Globalization - may we accompany you?

Globalization is the name of the game: Markets grow together, and car manufacturers are looking for synergies through strategic alliances. As a result of local legislation, tastes and boundary conditions, more product versions are on the market. Development time is consistently reduced as a result of the high level of competition in the automotive market.

Following an integration wave of rigidly centralized organizational structures, a change in course is now being recognized: centralized management dictates corporate strategy and functionality but local organizations receive larger responsibility for the operational side of the business. With respect to product development, this means that local organizations are becoming more self-sufficient and have autonomy to modify products for the needs of their respective markets. We understand, that the car industry is continuously faced with new challenges and support our customers by:

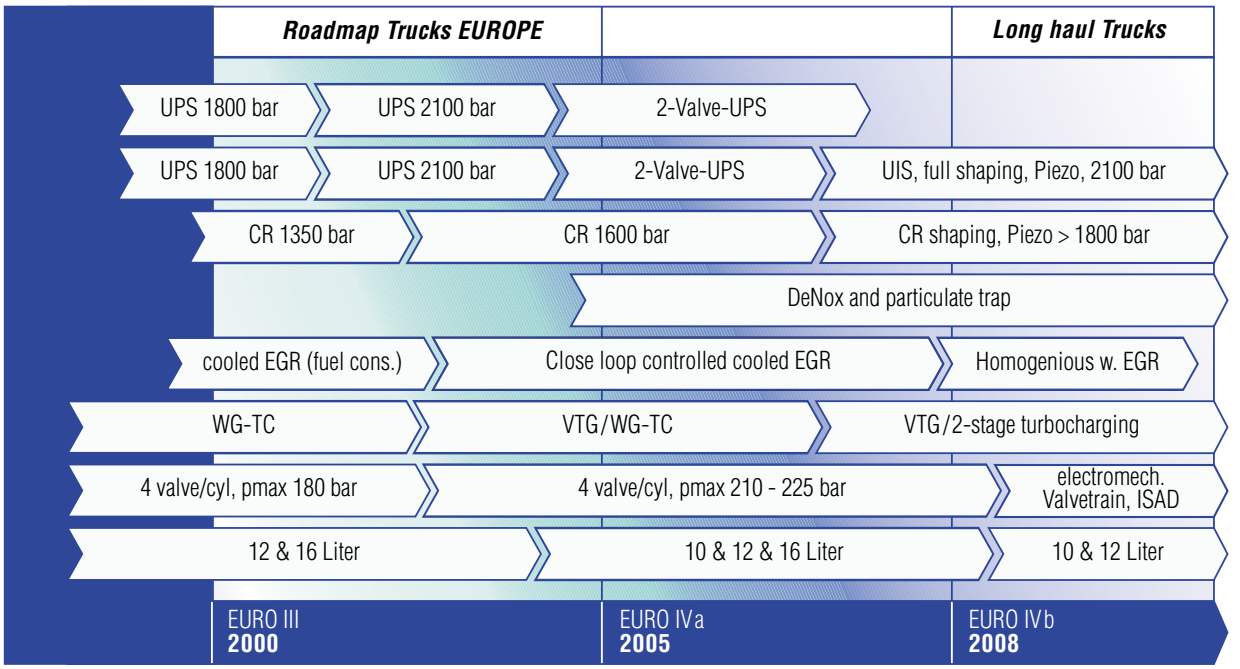
- *providing local personnel and facilities to develop products to meet local boundary conditions,*
- *providing vehicle application services necessary for more vehicle versions than ever before,*
- *providing instrumentation for local facilities,*
- *providing advanced end-of-line testing for engine production plants all over the world, and by*
- *providing assistance to suppliers as they enter foreign markets.*

The FEV R&D centers in Germany and the United States as well as its subsidiaries and agents in Japan, China, Korea, Taiwan, India, Thailand, Malaysia and other regions are standing by to support you.

For us, development partnership includes our efforts to accompany you on your way to new international cooperations.

Yours sincerely

Dr. Ernst Scheid
Vice President

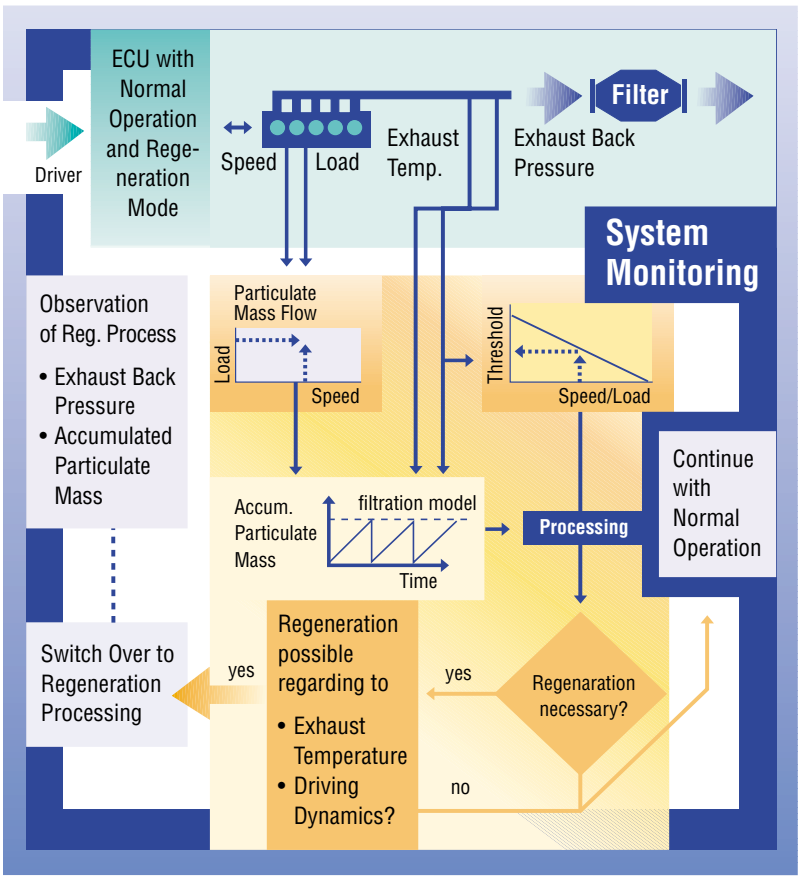


currently working on model-based intelligent control strategies, which will contribute to further optimization of dynamic charging behavior.

Noise Vibration and Harshness has become a major issue due to more stringent legislation and increased customer demands in this area. Because NVH optimization as an "aftertreatment" is always difficult and expensive it is important to take NVH performance into consideration early in the design phase. Modern simulation tools can be utilized to predict and modify the acoustic behavior of the entire powertrain. Combined with mounts and defined transfer functions, it is possible to tailor the cabin noise and, thus, the driver's perception.

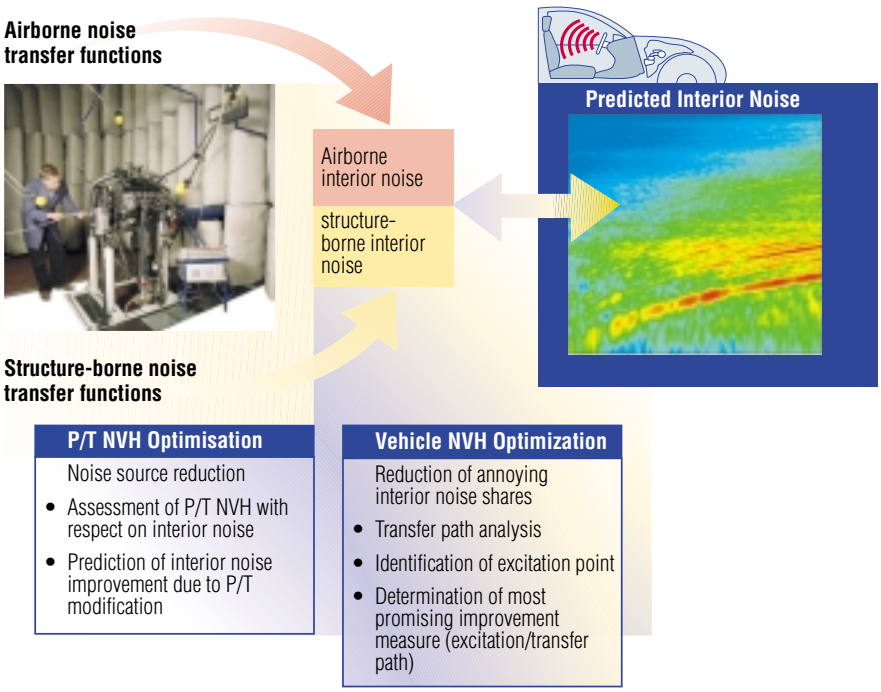
In the design process, state-of-the-art tools are appropriately used to compliment our clients' standards.

In addition to standard applications including Catia, I-DEAS, ProEngineer, Star CD and GT-Suite, to mention only a few, FEV also uses internally developed codes representing nearly all disciplines. FEV also cooperates with software suppliers, e.g. ADAMS. In combination with powerful hardware and experienced specialists, this results in a network of support ensuring highly efficient development from the very beginning of the process. By cooperating with highly specialized companies in the area of "rapid prototyping" the future product can be developed up to prototype status. FEV's own prototype workshop can assemble up to 200 engines per year, based on single shift operation. The associated development tasks, including mechanical or combustion development, are topics traditionally covered by FEV. In these areas, the company has demonstrated long-term experience and state-of-the-art equipment. The combination of these tools ensures that projects will be conducted with a target-oriented approach.



Regeneration Strategy and System Monitoring

Interior Noise Synthesis

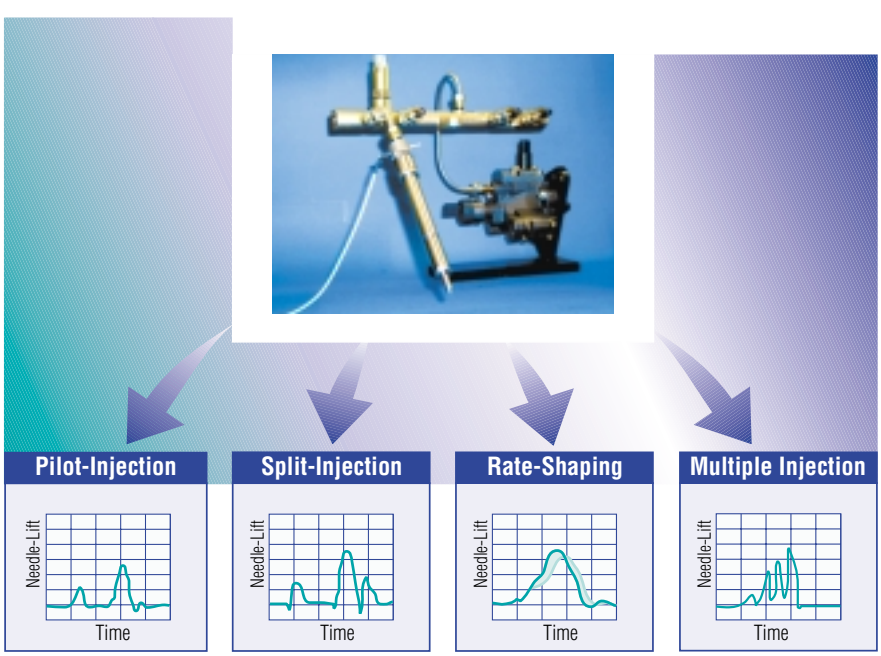


If desired, the client can also be assisted in the fields of production planning and the start of production.

FEV's demonstrated abilities cover the spectrum of engineering services and thus can act as a competent partner throughout the entire development process of new generations of engines. FEV looks forward to working with you to demonstrate our capabilities as your development partner.

◆ *Dr. Hans-Peter Frisse*
◆ *Helmut Pleimling*

FEV Piezo Common Rail Injection System



Project-management

Professional project management is a key element in FEV's strategic approach to its partnerships with the automotive industry. The highly effective and application-oriented project management system at FEV was developed on the basis of a critical analysis of well-established methods within the automotive industry, combined with the cumulative experience of many engine development programs.

This general approach represents a general FEV guideline that is adapted to the specific requirements presented by a particular customer and project.

Smooth-running projects are enabled through the establishment of project centers which bring together key project participants.

The primary elements in FEV's project management system include:

- Qualified project managers
- Tight integration of the customer in decision making and project planning
- Presentations and discussion to support decision making which consider relevant aspects (including costs, etc.)
- Concentration of decision makers in a project center
- Use of a matrix structure for the project team to guarantee the best possible integration of all of the technical experts
- Extensive application of Simultaneous Engineering
- Consideration of series production-related aspects early in the process, beginning with the concept stage and the first prototypes.

A robust project management system must be able to adapt to an ever-changing

situation once the project begins, considering new insights and input from all of the functional groups involved in the project. This change of outlook needs to be constantly updated, including a "buy-in" by all of the partners, involved in the project.

Clearly, efficient project management is not necessarily effected by rigidly following a set of established rules but, rather, relies on the definition of principal "milestones," where past experience is drawn upon to assist in the fundamental decision-making process. In this article, selected aspects of FEV's well-established project management system are illustrated.

Kick-Off Meeting

At the initiation of a new project, FEV and its customer make several key decisions:

- Assignment of tasks and responsibilities
- Project organization
- Time schedule, definition of "milestones"
- Reports on project progress
- Exchange of information
- Documentation and reporting

The following tools are essential to ensuring a smooth-running project.

- Mutual Action Item Lists ("To-Do-List").
  These define responsibilities and priorities as well as the project time schedule. This list will be constantly checked to identify and counteract potential delays early in the project.
- Regular updating and exchange of the current time schedule including documentation of the project progress.
  This tool is a mechanism for announcement of potential omissions or the identification of incidents that might endanger timely project completion. Regular agreement on project status and confirmation of attained milestones.
- Application of "technical risk management", so that technical problems can be detected and mitigated accordingly.
- Definition of "escalation paths". Here measures are defined in the event that significant problems arise, i.e. technical or organizational problems that could endanger the progress of the entire project.

All of the elements that have been identified above, are addressed at a project "Kick-Off" meeting. During this meeting, FEV's suggestions are discussed with its engineering partners and – after potential modifications – agreements made. The continuing adequacy of these tools will be routinely questioned over the life of the project. When necessary, adjustments are made.

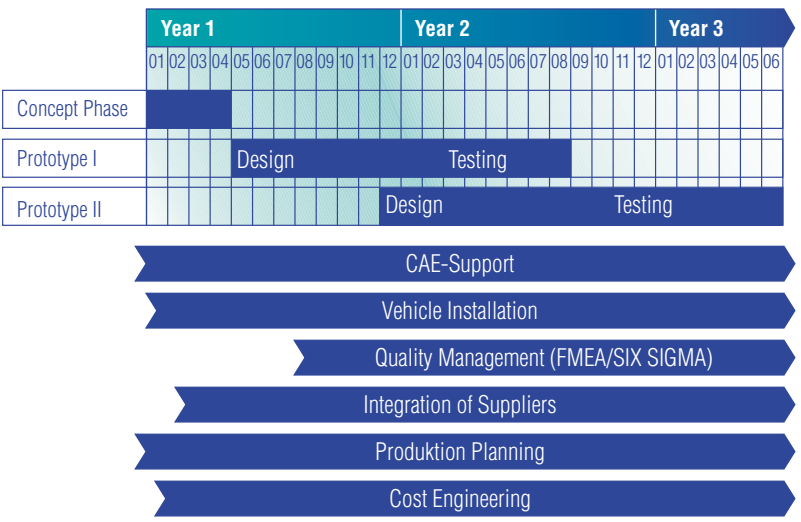
Extensive Application of Simultaneous Engineering

Since it is typical in this industry for development work packages (e.g. a first prototype) to be handled on a fixed price basis, it is essential that technical risks are minimized while retaining the focus on outstanding engine characteristics.

In order to design a new engine with the best possible characteristics, it is important for all of the technical groups that are involved in the project to continuously review and understand the current state-of-the-art. This is especially true during the concept phase where the boundary conditions for attaining the desired engine properties are documented and will serve as the basis for each department's desired feature set. These feature set lists are considered in combination with additional boundary conditions such as customer preferences, packaging restrictions, existing production lines, benchmarking, etc., and the basic engine specifications are defined and initial sketches are made. At this stage, important engine characteristics are predicted and compared with the state-of-the-art (i.e. "Best in Class" engines). Possible deviations from these predictions that might come up during the subsequent specification and design stages will be called to the team's attention. It is FEV's goal that the first prototype demonstrates the predicted characteristics.

General development trends will also be taken into account and factor into FEV's recommendations regarding evolutionary steps and potential variants that should be considered for the engine concept. This methodology ensures the engine's future competitiveness. Thorough application of CAE is the most important measure to reduce technical risk. Today, to realize a first prototype, CAE and CAD capacities are

„Simultaneous Engineering“ in the first Step of Engine development



used nearly equivalently. It is important that the CAE experts show an interest in a detailed comparison of calculation results with later empirical measurements, since this allows a constant refinement of the simulation tools that are being utilized and minimizes technical risk. FEV further recommends that design modifications be simultaneously examined via CAE modeling so that support can be provided for potential problems occurring during the development phase or in series production.

Early integration of eventual production suppliers is very important. Ideally, all of the major suppliers should already be determined at the end of the concept phase when modules are being designed in close cooperation with system suppliers. These modules will then be delivered pre-assembled and quality-checked at the production stage. Based on the initial engine concept studies, the suppliers and designers will exchange specifications and boundary conditions. The suppliers design the modules, drawing on experience while considering issues related to the use of existing production equipment. Tightly integrated communications between all involved parties is essential during the design phase, since all of the engine parts are subject to continual modification. Optimized data exchange systems featuring broad and high speed CAE/CAD data access is necessary to facilitate communication between all members of the project team. Before the finished module design can be confirmed for prototype production, it will be extensively quality-checked by FEV. Once the quality approved parts are delivered, the initial engine durability test runs can be conducted. Subsequently, all of the components will be handed over to the suppliers for further examination.

Production and Assembly Considerations During the Concept and Prototype Stage

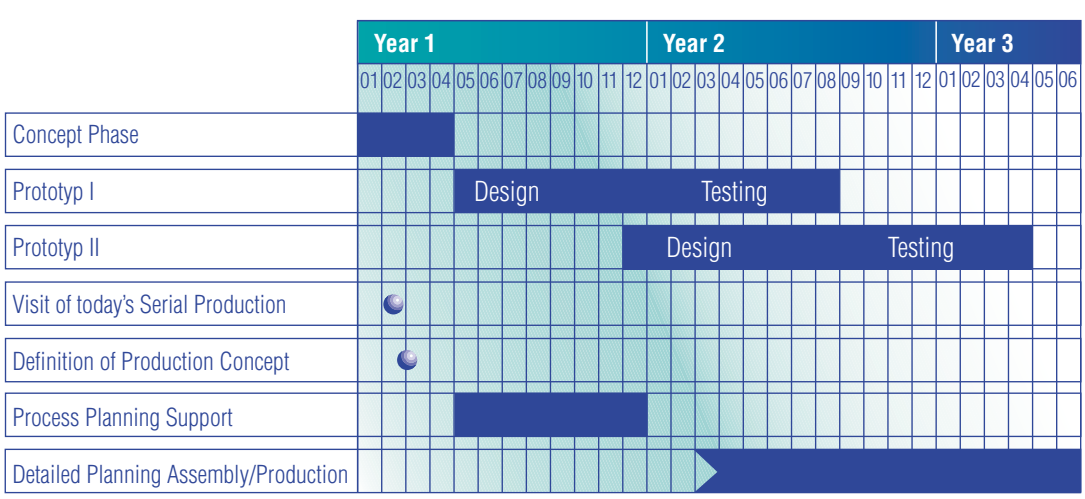
If production and assembly-related aspects are considered early on, both development costs and future unit costs for the engine can be substantially reduced. This will minimize the number of design changes required later in the development process, and ensure appropriate concept decisions with regard to series production issues.

During the concept phase, the potential use of existing facilities as well as prospective processing and assembly concepts (e.g. sequential vs. agile production lines) should be agreed on. To achieve the best possible results in this important ”simultaneous engine-ering” aspect, FEV cooperates closely with a consultant specialized in production planning and value analysis. This consulting firm, Platos, has more than 15 years of experience in planning and optimization of engine production and assembly. The close cooperation between FEV and Platos has been successfully demonstrated in numerous engine development programs.

Due to the consistent application of Simultaneous Engineering, including early consideration of production and assembly issues, one full prototype stage can be essentially omitted from the engine development program. FEV is capable of detecting potential weaknesses at the very first prototype stage and implements any necessary countermeasures. For the second prototype, detailed production planning is considered, enabling a second prototype that is near series production quality. This second prototype can then be used to begin with series calibration.

◆ *Dr. Michael Houben*

„Simultaneous Engineering“: Early Integration of Production Planning into Engine Development



Large Bore Engines

FEV offers a full range of engineering services for Large Bore Engines, similar to its offerings for automotive engines. These services include component development as well as complete development support for a new engine from the concept phase through the start of serial production. All of the state-of-the-art tools that are necessary to cope with the varied demands of Large Bore Engine development are available at FEV.

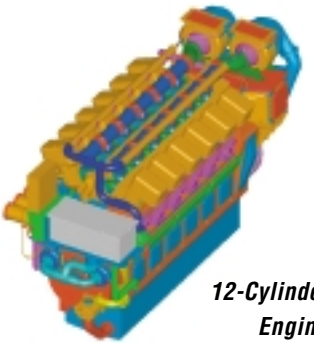
12-Cylinder-Engine, Prototype

In the conduct of a project, FEV offers a full range of services including market studies and benchmarking. Concept studies can be performed for particular project components or for the complete project. FEV compiles and summarizes the results of the study in a bound document that serves as the foundation for the development program to follow.
The most modern tools and methodologies are employed for analysis, simulation and in design. Structural analyses for the optimization of components regarding mechanical and thermal load, deformation, etc. support the design work from the beginning. The approach represents a significant time and cost savings since a considerable part of typical experimental mechanical development testing can be avoided. FEV maintains a wide range of CAD and CAE tools. Consequently, in most cases, we are able to support our customers in their native CAD platforms.

At FEV, process Development (injection, combustion and turbocharging) is a core engine development technology.

At FEV, mechanical development includes functional testing as well as endurance testing of individual components and full fired engines. Depending on the power and size of the engines, tests with multi-cylinder engines can be performed at FEV or within the customers facilities. These decisions are primarily made on the basis of the required investment and program cost.

FEV has developed a special single cylinder research engine that is adaptable to different engine configurations (e.g. bore and stroke). The engine can be operated with distillate fuel as well as heavy fuel oil and gases.



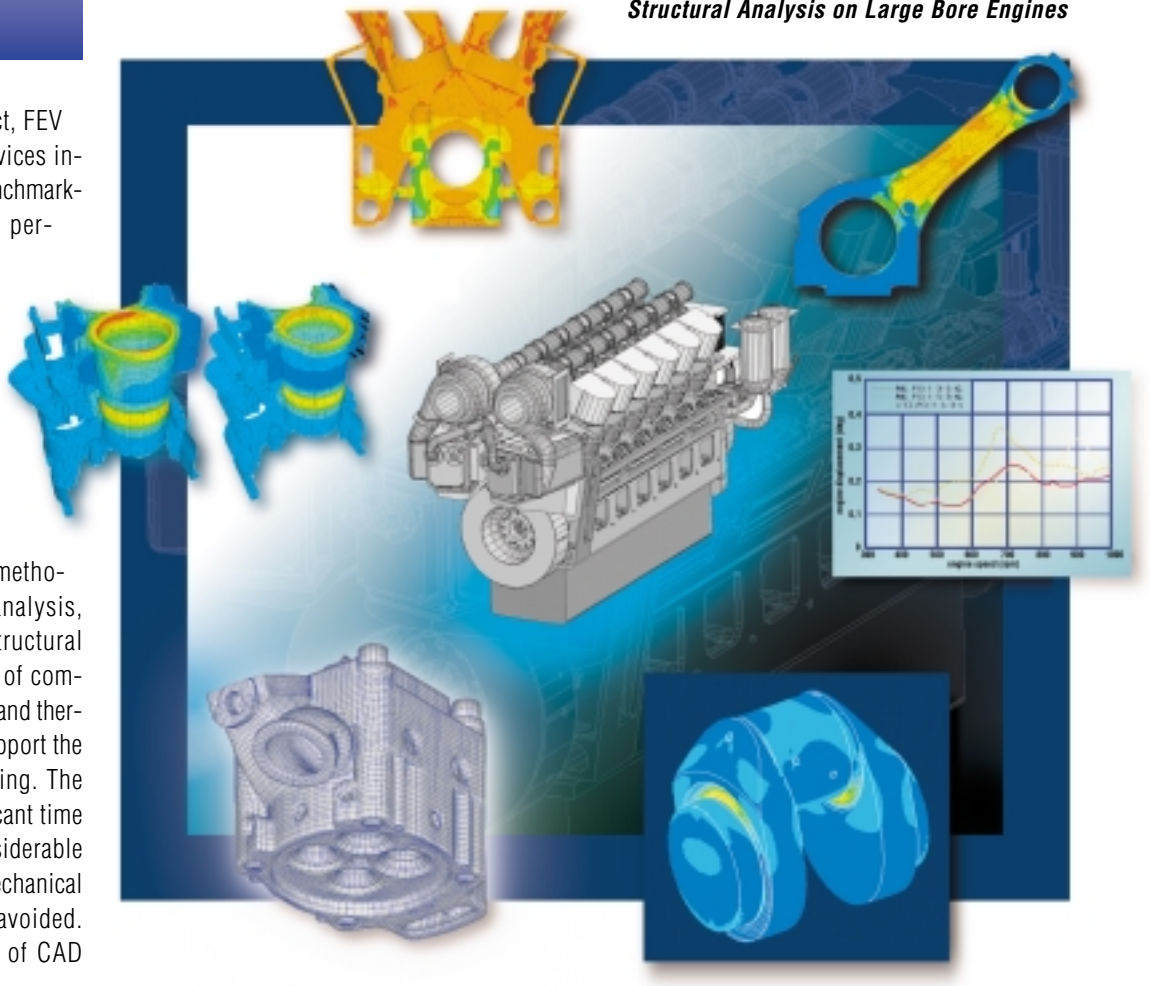
12-Cylinder-Engine, CAD-View

We are also prepared to conduct certification tests in support of the start of engine production. Field testing can also be supported and evaluated by FEV.

Application engineering is also provided within the scope of FEV's engineering services, covering a diverse group of applications such as ship propulsion, power plants or locomotives.

All work is executed in very close cooperation with the customer and its

Structural Analysis on Large Bore Engines



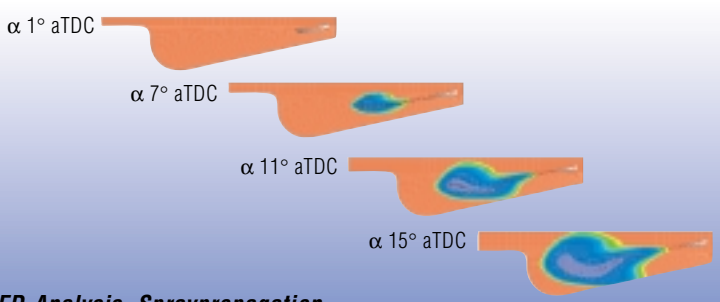
Large Bore Single Cylinder Engine on Test Bench

Large Bore Single Cylinder Engine			
		Speed (min):	250 rpm
		Firing Pressure:	250 bar
Bore:	240-320 mm	Fuel:	Destillates, Gases, Heavy Fuel Oil
Stroke:	300-450 mm		
Displacement:	13-36 Liter		
BMEP:	35 bar	Supercharging:	External 5 bar
Power:	400-600 kW	Cooling System:	External
Speed (nom.):	600-1200 rpm	Lube Oil System:	External

component suppliers. Moreover, to ensure close cooperation, the members of a project team can be located in a project center that is isolated from other project teams to ensure confidendiality.

FEV is also prepared to take complete project management responsibility, when desired by our customers, including quality management. FEV is experienced in employing all of the classic quality methodologies including the Six Sigma quality methods. The particular methods to be applied are generally selected by the customer.

◆ *Helmut Pleimling*



CFD-Analysis, Spraypropagation

Your Most Innovative Development Partner in the Automotive Industry

In a survey conducted by the magazine 'Automotive Engineering Partners', 200 leading personalities in the automotive business were asked to vote for the most innovative development partner.

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MTZ MOTORTECHNISCHE ZEITSCHRIFT
AUTOMOTIVE ENGINEERING PARTNERS

In the service sector ranking, FEV scored first place.

FEV is an independent service provider with worldwide business centres. In the past 22 years, FEV has initiated the latest trends in automotive engineering, proved out the prototypes on test benches which as fully matured gasoline or Diesel engines validate themselves every day in series production vehicles.

(Source: Automotive Engineering Partners 5/00)

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