# SPECTRUM

Technology - Highlights and R&D Activities at FEV

Issue 26, April 2004


## Methodology for Developing Modern Powertrains

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25. Wiener Motorensymposium
April 29./30. 2004

The development of new powertrains takes place with the primary challenge being, $CO_2$ reduction. This challenge is balanced against increasingly strict emissions legislation, increased quality requirements and higher engine outputs. The challenges can be met through the utilization of advanced engine technology. A Direct Injection Spark Ignition (DISI) engine with variable flow devices, complex injection, performance map characteristics and variable valve actuating mechanisms are available in series to meet those requirements. In addition, engines with variable turbine geometry and variable compression are being developed. The recent increase in distribution of diesel engines has decisively contributed to the reduction in $CO_2$. However, further emission hurdles must be overcome in order to the diesel engine to be suitable for future applications. Flexibility of the injection system is also a key to the success of exhaust emission cleaning techniques. Lastly, the gearing contributes to further flexibility by utilizing more finely adjusted gear gradations, CVT-variants and various developments regarding the automatic transmission gearshift lever.

Reducing the development time from vehicle concept to Start of Production (SOP) requires a highly dynamic advancement in development methodology. FEV, as a research and development company, has traditionally put special emphasis on the development of methods

SUMMARY

# Preface

A convergent path has been established for powertrain system development in vehicles and the worldwide challenge to reduce $CO_2$ emissions. Government legislation has established boundaries that must be met, if vehicle manufacturers desire to remain competitive. Manufacturers are faced with demands for improvements in quality and increased engine output. Those demands stem from customer wishes that can be fulfilled in this economically challenging environment through global competition. The wide-ranging requirements can be addressed with advanced powertrain systems. The advanced powertrain systems include such new technology as variable valve actuating mechanisms, highly flexible diesel injection systems and various forms of gear automation.

New technology combined with the desire to shorten a product's time-to-market, requires a new development methodology. FEV, as a research and development company, has traditionally attached a high degree of importance to the development of methods, which will save our customers time and money. The development of the CAE methodology in the design phase allows for the omission of a prototype stage. The addition of variable components in the powertrain has recently led to a rapid increase in expenditures on the calibration processes. FEV's efforts during the last few years have led to the development of an efficient process, which has achieved a dramatic saving in product design and development time, in spite of the growing number of parameters.

The application of CAE has achieved a decisive upstream acceleration of time. Correspondingly, a downstream improvement in development time was successfully managed through the methodology in experimental work. The primary result of the efforts that have been achieved is a lasting accelerated development process.

We would be pleased to support your program developments through this methodology.

Dr.-Ing. Markus Schwaderlapp
Executive Vice President

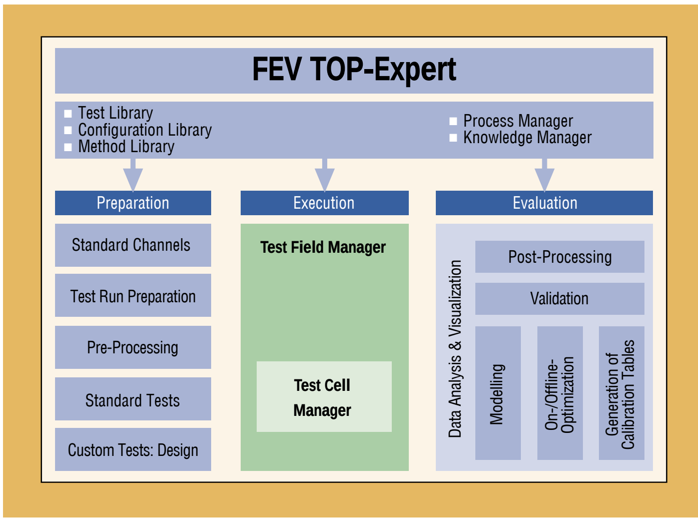
and emphasis on new features. The result of FEV's direction is a global development methodology, which will enable us to assist our customers in meeting the future engine design challenges.

The first step in powertrain development chronology is construction, which is achieved by virtual prototype (i.e. a validation before the first mechanical prototype). The methodology for virtual prototyping was developed in the nineties and tested in development reality. Great advancements have made during the last few years in the area of combustion and emission simulation through the use of measured data or special measuring technology.

Mechanical development also benefits from virtual prototyping. Efficient solutions to problems may be found much quicker by using a virtual prototype, than random testing. Moreover, optimizing the endurance run procedures can be gained by the extended knowledge, will lead to shorter experiment times.

Process development and calibration of a powertrain, using the methodology described previously, will lead to a rapidly increasing number of parameters. The development of an efficient method for optimizing these parameters on the powertrain test stand and in the vehicle is a precondition for controlling the complex calibration process. The diagram for this system is shown in Figure 1.

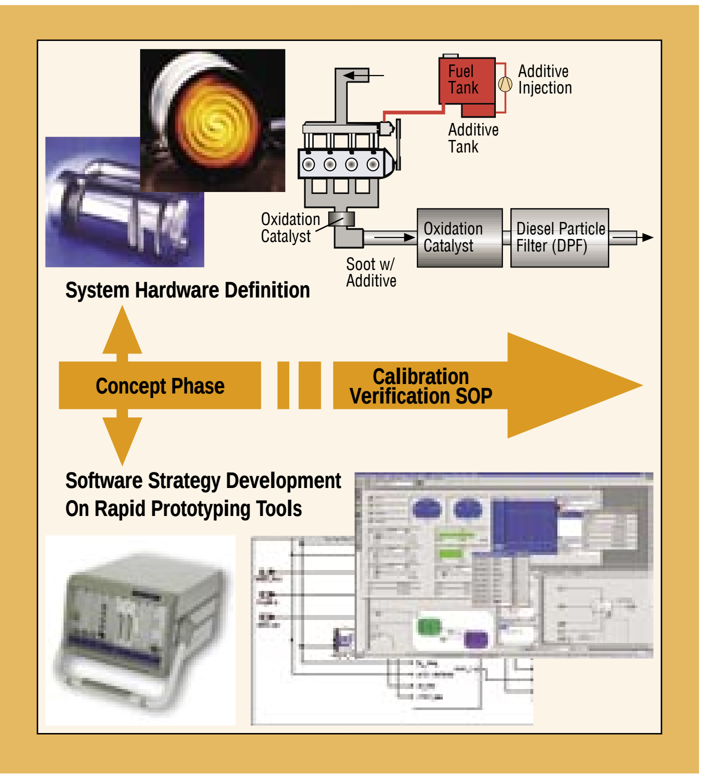
*FEV-Test Optimization Process*




The FEV TOP-Expert tool illustrated in the figure allows for continuous support of the user throughout the entire process. The main emphasis is put on the knowledge-based configuration and coordination of pre-confi-gured modules. The modules start with the utilization of existing application knowledge (i.e. determined by which design or model was already successfully used for a certain task) and end with the computation of the performance characteristics for setting the parameters of the engine control unit. The modules are based on the context related storage of individual fragments of knowledge such as, design, modeling and optima in databases. The knowledge gained from practice is provided and retained as a benchmark in order to increase the efficiency of the application work that is being supported. The combinations of the partial processes of modelling/test planning and modelling/optimization are tightly interwoven with each other. The selection of the model that is required, will determine the test planning process that is utilized. Creation of different models with one design (e.g. polynomials to a certain degree or neural networks) should be possible. Therefore, this must be taken into consideration in test planning.

A stationary preoptimization or basic parameter setting is achieved by the previously described process, which can later be enhanced on the highly dynamic test stand and in the vehicle. Offline tools become very important at this stage. It is during this stage that calibration data are read out, functional frameworks are simulated, modifications are optimized offline and improved parameter settings are supplied back to the ECU. The process to develop a particle filter application using combined arithmetic and experimental tools is shown in Figure 2.

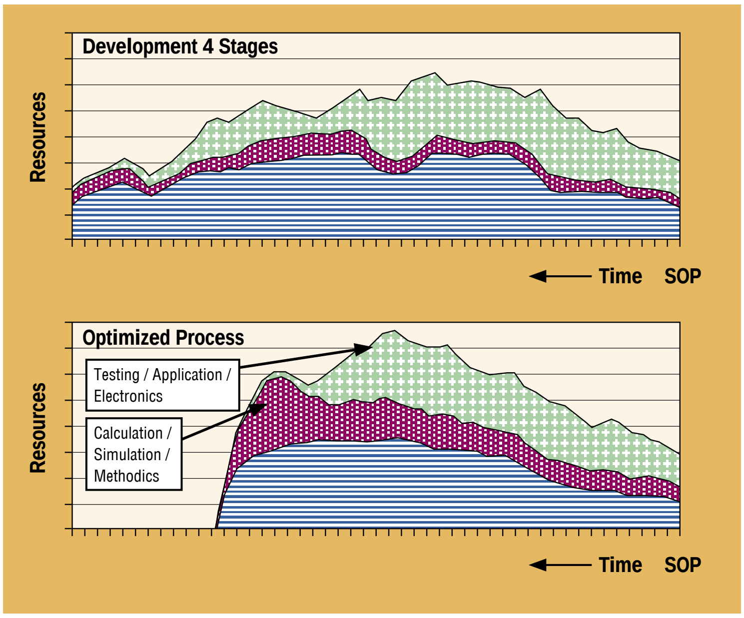
*Development of DPF-Systems*
*(Parallel Hard-/Software Definition)*




The system definition and software functional development takes place offline with rapid prototyping tools. The functions are then verified on the test bench and a basic parameter setting is established. Work done on the vehicle then serves as a fine adjustment and supplement to the data setting, which results from the dynamic driving conditions.

The methods provide the preconditions in calibration and vehicle integration for time saving downstream in the development process, if the CAE methodology with virtual validation allows the omission of a prototype stage upstream. That would provide a clear reduction in development time (Figure 3). The capacities for development shift in the direction of CAE and the method of application.

*Comparison of Engineering Capacities*




This methodology for development of powertrain applications could only be explained by a detailed review of the scope and requirements for the project. The use of it together with assistance from our partners has proven its suitability in practical applications. We would like to discuss the potential of <u>your</u> programs with you.

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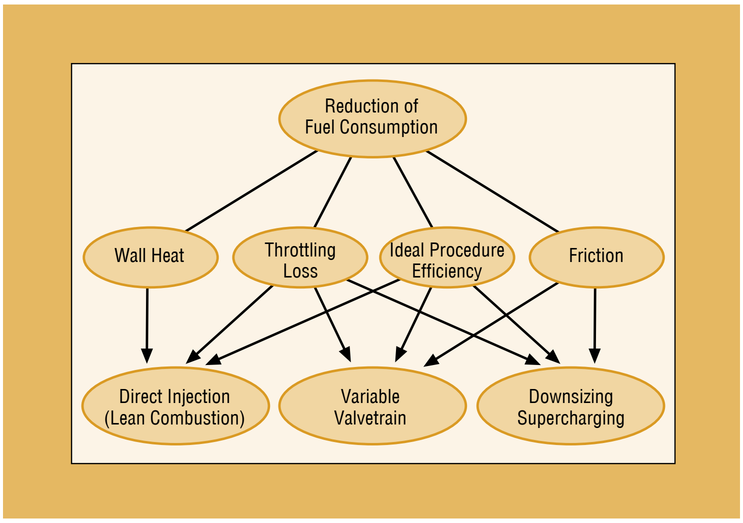
# Acoustic Behavior of New Gasoline Engine Concepts

New technologies, such as direct injection and mechanical fully variable valvetrains are state-of-the-art in gasoline engines. Additional concepts currently under development include the use of variable compression, high-pressure supercharging and electro-mechanical valvetrains. The paramount goal of all these new developments is a reduction in fuel consumption.

One of the papers FEV will introduce at the 25. Vienna Motor Symposium 2004 details how these new concepts affect noise excitation. In addition, it evaluates the concepts, with vehicle interior noise being the main criterion. Measures that can be taken to optimize these designs are also discussed.

Customer expectations regarding passenger cars mainly concern performance, fuel consumption, purchase price and noise. Depending on the vehicle classification, the individual criterion needs to be weighted differently. Moreover, reducing fuel consumption is currently the main development target, due to the need to compensate for the fuel consumption disadvantage gasoline engines have, compared to diesel engines. A second requirement is to improve fleet fuel consumption.

*Gasoline Engine Concepts for the Reduction of Fuel Consumption*




Gasoline engine concepts that can be utilized for the reduction of fuel consumption are illustrated in Figure 1. Direct injection with lean combustion causes minimal wall heat losses. Partial and fully variable valvetrains reduce pumping losses through dethrottling. Freely selectable timing helps to optimize the efficiency of the procedure. Turbocharging or mechanical supercharging an engine, when combined with variable compression or high-speed design for downsizing reduces pumping losses and engine friction.

The potential to reduce fuel consumption is about 20%. However, disadvantages may exist in the form of higher production costs as well as increased HC and CO emissions. Noise and vibration issues need to be considered as well, especially with regard to interior noise. This includes combustion excitation (e.g. controlled self-ignition), actuators and pressure wave clearance at the orifices (e.g. if a fully variable valvetrain is used) as well as vibrations (e.g. cylinder deactivation).

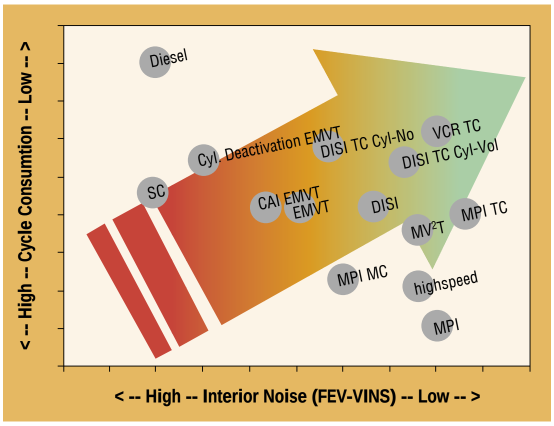
FEV has developed a simulation method called FEV VINS (Vehicle Interior Noise Simulation), to evaluate the impacts on interior noise and vibration behavior. The evaluation is based on data obtained by predictions using FEV's CSL (Combustion Sound Level) method as well as noise measurements on the engine test bench. The following concepts have been examined:

- Conventional Gasoline Engine (Multi-Point Injection) (MPI)
- Direct Injection Spark Ignition (DISI)
- Direct Injection with Turbocharging (Downsizing Cylinder Number) (DISI TC Cyl. No.)
- Direct Injection with Turbocharging (Downsizing Cylinder Volume) (DISI TC Cyl. Vol.)
- Mechanical Fully Variable Valvetrain ($MV^2T$)
- Turbo (Turbocharged) (MPI TC)
- Mechanical Roots Supercharger (MPI MC)
- Turbo with Mechanical Supplementary Charging (Roots Supercharger) (SC)
- Electro-Mechanical Valvetrain (Intake Side) (EMVT)
- Electro-Mechanical Valvetrain with Cylinder Deactivation (Cyl. Deactivation EMVT)
- Controlled Auto-Ignition with EMVT (CAI EMVT)
- Variable Compression Ratio with Turbocharging (VCR TC)
- High-Speed Engine (Highspeed)

Criteria considered in the evaluation are interior noise, fuel consumption and cost. The target value is situated in the upper right corner of Figure 2. The corner points that show a positive score mark the conventional gasoline engine (excellent interior noise) and the diesel engine (low consumption).

Engines that use electro-mechanical valvetrains with cylinder deactivation as well as high-speed mechanical engines with additional charging have a less than favorable acoustic behavior. Variable compression, when combined with turbocharging, appears to be a good compromise. Downsizing the engine with a smaller cylinder volume results in good acoustic behavior and decreasing the number of cylinders reduces fuel consumption.

*Noise/Cycle Consumption*




Based on an evaluation of interior noise levels and production costs, conventional gasoline engines are most efficient. Modern diesel engines with common rail injection are the most expensive. All gasoline engine concepts prove to be less cost intensive.

An evaluation of the different gasoline engine concepts does not produce a clear winner. Variable compression or electro-mechanical fully variable valvetrains as well as certain direct injection concepts are relatively expensive. However, they offer a high potential for fuel consumption reduction. Variable compression turbocharged engines as well as direct injection turbocharged engines with reduced cylinder volume result in good acoustic behavior with low fuel consumption.

Engines that utilize the gasoline pumping loss and combustion procedure concepts that have been described are bound to appear on the market in the near future. Depending on the manufacturer and the line of production, the engine's cost, fuel consumption and acoustic behavior aspects need to be weighted differently.

Our attempt at evaluating cost, fuel consumption and noise and vibration behavior of new gasoline engines concepts is based on a quick review of several, specific examples. A more thorough evaluation of each concept may produce considerably better or worse results.

We hope that this article will encourage further in-depth discussions and we would be pleased to hear your opinion on this matter.

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# Truck Engine Design

## Yuchai F-6113 Engine Upgrade with a New Cylinder Liner Concept for HD Diesel Engines

The Yuchai F-6113 is an inline 6-cylinder heavy-duty diesel engine and is mainly utilized for truck applications. The engine has a displacement of 8.4 L and a rated power of 258 kW. It was derived from the F-6108 model that has a displacement of 7.3 L. The engine was designed and developed in a joint effort by YMC (Yuchai Machinery Co., China) and FEV. The concept design and layout, using various simulation tools, was performed by FEV. YMC was responsible for the detail design. YMC and FEV agreed to divide work regarding procurement, prototyping and testing.

*The YMC F-6113 with UPS*

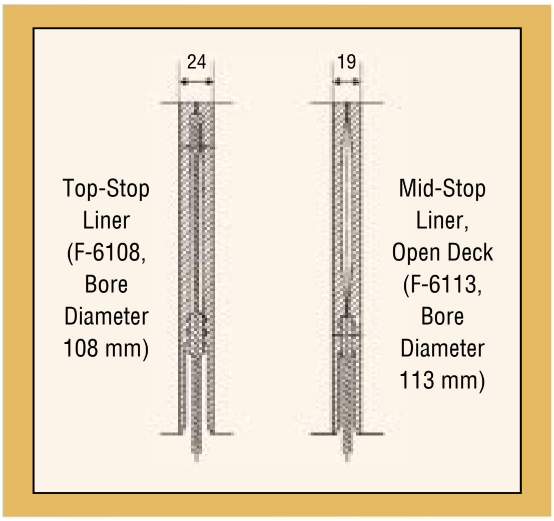
A major target was to carry over as many features as possible from the F6108, in order to minimize the investment required for production facilities. The existing machining line for the crankcase defined the bore spacing for the new engine.

The new design features electronically controlled unit injection pumps. The pumps are mounted in a separate housing, with the potential alternative of using an inline injection pump. The two 2-valve cylinder heads, covering three (3) cylinders each, were replaced by a 4-valve one-piece cylinder head. The engine structure was laid out based on the high specific output and the peak cylinder pressure requirements for compliance with Euro III standards. The engine was placed among the top performers of state-of-the-art European and North American truck engines, with a specific power of 30.6 kW/L and a maximum BMEP of 20.9 bar.

**Unique Cylinder Liner Concept for Heavy-Duty Truck Engines**

The ambitious performance target values could be achieved only with a substantial increase in displacement. The increase in displacement was realized with an increase in both bore diameter and stroke. The displacement increase was possible with the switch from a conventional top stop liner to a mid stop liner with open deck, due to the engine's fixed bore pitch of 132 mm. In addition to the advantage of minimum bore spacing, the open deck facilitates an optimum cooling of the liner top end at TDC of the first piston ring.

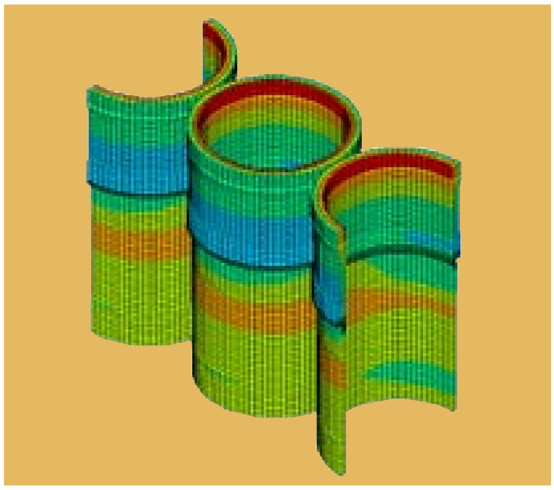
*Schematic Comparison of Liner Concepts for a Bore Pitch of 132 mm*




The depth of the liner support, measured from the top deck, was defined at approximately 85 mm, based on extensive FEA investigations of temperature distribution in the liner and the supporting crankcase structure. Despite the rather short water jacket, the surface temperature below the liner support is significantly lower than the maximum temperature in the water cooled area.

The cylinder head gasket is a Multi-Layer Steel (MLS) design. It consists of two (2) inner functional layers that incorporate the beads for combustion sealing and sealing of the oil and coolant passages and the two (2) outer flat layers. The beads for combustion sealing are fully compressed between the cylinder liner and the cylinder head, due to the protrusion of the liner. In order to secure the function of the cylinder head gasket, the allowable tolerance of the liner protrusion was restricted to a very small value. The solution to stay within this narrow tolerance band utilizes three (3) different thickness classes of washers between liner and crankcase.

*Temperature Distribution at the Cylinder Liners*



**Conclusion**

With the development of the F-6113, YMC obtains an engine for the increasing demand in China of high output Diesel engines for HD trucks. Extensive testing, which has successfully been carried out, has confirmed the feasibility of the engine concept. Especially, the liner concept proved to be reliable in this application. This concept has the potential of maximizing the displacement on existing engines or minimizing engine length and weight on new engines.

In a first step a Euro II version of the engine with a mechanically controlled inline injection pump, delivering the same power and max. torque as the UPS version will be brought into the market. The series production of this engine starts in the beginning of 2004. Also a Euro III version with inline pump has already been certified.

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# Piston Temperature Measurements with Telemetric Data Transfer

Knowledge of piston temperatures during fired engine operation represents important information for the development of modern internal combustion engines. Fields of engineering that benefit significantly from the availability of reliable piston temperature values include mechanical engine development, layout and optimization of cooling and lubrication systems and development of thermal management strategies. Development of the combustion process can be supported by these measurements, since they allow a direct investigation of parameter variation (e.g. ignition timing or injection timing and strategies on the piston combustion chamber wall and temperatures).

FEV developed the technology to obtain online piston temperature measurements.

The primary constraints for developing this new system are:

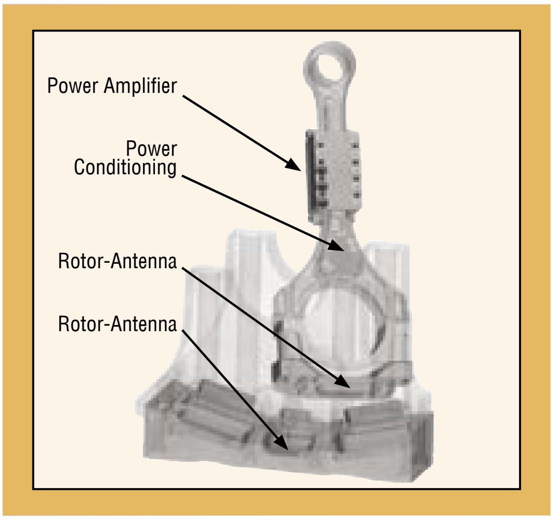
- Adapting the components to the engine has to be possible with only minor part machining and only slight changes can be made to the effected engine part geometries
- Operating capability of the system has to be within the entire engine speed range (mechanically and electronically)
- Allowing stationary measurements of different parameter changes with the resulting long measurement times.

A system was realized that avoids the introduction of two or three antenna systems for the data transfer from the cranktrain. The solution chosen offers a continuous long-distance data transfer combined with an interrupted power supply and a capacitor energy storage component.

A typical installation is depicted in Figure 1. The power amplifier is mounted to the connecting rod. In addition, a miniature power conditioning and storage system and the rotor antenna are adapted to the connecting rod. The stator antenna including the power supply and the signal antenna is mounted on the engine block. The wiring from the piston to the connecting rod is done with an optimized and very stable mechanical solution. A photo of a completely prepared connecting rod is shown in Figure 2.

This system can measure up to eight (8) piston temperatures under all operating conditions corresponding to engine speed and load, using an analog bandwidth of 10 Hz per channel. The positions of the thermocouples in the piston can generally be placed in any location, which can be reached by drilling.

*Telemetry components on the engine*




*Example System Application*

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# FEV ModuTainer - The Flexible, Modular Test Cell

FEV Test and Instrumentation Systems has established itself over the last few years as a competent and reliable business partner. It delivers planning and execution of complete engine test cells as well as individual components. In addition to conventional brick and mortar test cell installations, FEV supplies integrated, mobile, container-based testing solutions. The FEV **ModuTainer** is a unique concept for **modul**ar con**tainer**ized test cells, utilizing the vast experience gained over the last several years.

*ModuTainer-Facility under Nordic Environmental Conditions*

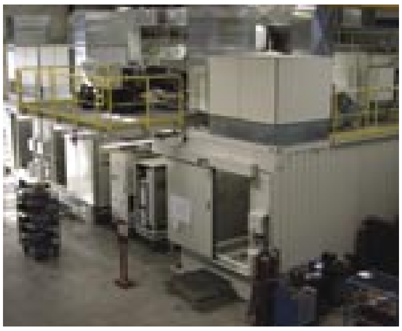
The current ModuTainer is no longer comparable with the modified transportation containers, used initially. Virtually any test cell parameter is definable by the customer. The available sizes range from compact single test cells to multiple cell facilities with integrated control room areas.

*Technical Data (Standard Layout)*

| | |
|---|---|
| For Engine Power (Standard) | up to 700 kW |
| Material | steel |
| Max. Length/Width/Heigtht (in m) | 10 / 4 / 4 |
| Wall Thickness | ca. 150 mm |
| Noise Insulation | > 30 dB(A) |
| Fire Resistance | up to IE 90 |
| Ambient Conditions | -25 ... +40 °C |

The optimized, selfsupporting steel structure includes a double floor for the piping, electrical installation and drain pan. A crane rail enables easy loading and unloading of equipment from the test cell. The ModuTainer is fire resistant as well as highly insulated from noise, to ensure industrial safety and protection of the personnel. Optimum working conditions are granted to the test cell staff by completely equipped, convenient and customer specific control rooms. In addition, the customer can define their system demands for media conditioning, exhaust analysis, general measurements, dynamometers and custom test instrumentation. FEV delivers a broad range of modular subsystems that when combined, fulfill the usual requirements and often even the unusual ones.

*ModuTainer during Setup at FEV*



ModuTainers are completely assembled and commissioned at the FEV site, including detailed tests that can be performed with customer engines. A flexible media interface provides easy connectivity to the local facilities at the customer's site and enables an almost immediate start of actual testing after delivery. Outdoor installation of a ModuTainer (e.g. under a canopy) is possible and provides a facility that is equal to the integration of a test cell into existing or newly constructed buildings.

A ModuTainer is mainly a separate unit. If necessary, it can be moved relatively easily from one location to another. A very economical alternative is renting or leasing a complete unit for a limited time.

The ModuTainer concept enables FEV to build test cells with almost any equipment combination. Special customer demands are perfectly attainable with this system and the ModuTainer is the most cost effective way to expand or improve your testing capabilities. Just add air, electricity, fuel, and water.

**ModuTainer advantages at a glance:**

- Transportable, self-supporting structure
- Excellent noise insulation
- High fire resistance
- Flexible adjustment to customer demands
- Short installation and commissioning at customer site
- Easy maintenance
- Modular media interface
- Outdoor installation possible

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