SPECTRUM

Technology Highlights and R&D Activities at FEV

Issue 22, February 2003

Demonstration Vehicle with Continuously Variable Compression Ratio (VCR)

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Downsizing is a well known and significant technology to achieve beneficial fuel consumption characteristics and has been a fundamental reason for the success of the Diesel engine in passenger car propulsion.

SUMMARY

The higher mean load, associated with downsizing concepts, yields reduced heat and frictional losses and, for an SI engine, reduced pumping losses. For this reason, downsizing will also shape the future of SI engines. A smaller engine must operate over a larger load range, however, and this calls for reduced compression ratio, less favorable part load fuel consumption, and higher enrichment demand. Continuously variable compression ratio (VCR) offers an opportunity to make full use of the downsizing potential.

FEV's new VCR system is based upon the concept of an eccentric crankshaft bearing. Rotation of the eccentric bearing leads to a vertical position change of the crank train relative to the cylinder head and thus, a continuous change in the compression ratio. The principle is also applicable for V-engines where a small bank offset can be compensated by spark timing adaptation. The eccentricity of the crankshaft relative to the gearbox input shaft and the FEAD is balanced by special, packaging-neutral variable offset

PREFACE

Dear Readers,

It is clear that many sometimes-competing factors are influencing the global automotive and heavy-duty engine market.

The high level of global competition, combined with an unsteady economic environment, is causing engine developers throughout the world to balance a much larger set of customer, regulatory and market-driven attributes. A decreasing number of engines and transmissions are being developed for multiple markets and vehicle platforms, resulting in a need for highly engineered powertrains that meet differing fuel consumption, emissions, cost, reliability and NVH targets.

The level of technology required to integrate and optimize such a diverse group of requirements is daunting. However, in this issue of Spectrum, FEV presents clear, tangible examples of advanced technology and development capabilities that are directly applied to ensure that our customers' needs are met.

At FEV, we continue to invest in emerging innovations that can be effectively leveraged to add value to our customers' products. We believe that this can only be possible if we provide the highest possible value in the engineering services and instrumentation systems that we offer.

As we begin 2003, it is our goal to be the world leader in this regard.

Yours sincerly

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

Continued from Page 1

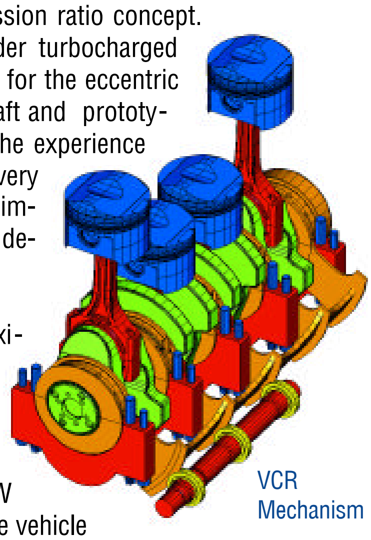
couplings. The flywheel unit can be designed as two-mass flywheel and/or as an integrated starter/ alternator device.

Compression ratio adjustment between 8 and 16 is accomplished by an electric motor that permits adjustment times of 0.1 s (CR decreasing) and 0.5 s (CR increasing). The system design allows integrated manufacturing using existing production lines. The total cost of the system is expected to be approximately 140 Euro.

The mechanical testing of the variable offset coupling was conducted on component test rigs. A prototype engine was durability testing over more than 400 hours. Compared to conventional production engines, the engine friction of FEV's variable compression ratio concept is neutral. Combustion as well as engine mechanics were evaluated as acoustically inconspicuous.

Thermodynamic benefits appear throughout the engine map since the compression ratio is optimized for maximum efficiency. Additionally, very smooth engine idle and full load operation are achieved combined with high EGR-capability and additional freedom to calibrate catalyst warm-up. Moreover, the VCR concept can be applied to both current and future flexible fuel vehicles.

FEV has developed a demonstration vehicle that features the variable compression ratio concept. A highly boosted, 4-cylinder turbocharged SI engine was re-designed for the eccentric positioning of the crankshaft and prototypes were manufactured. The experience that was achieved with the very first engine prototype was implemented in the current demonstration concept.



VCR Mechanism

The engine provides a maximum torque of 300 Nm (221 lb*ft) and a maximum BMEP of 21 bar which at 2300 rpm. The maximum power is 160 kW (218 bhp) at 5500 rpm. The vehicle calibration was performed for EU IV emission standards. The engine calibration on the test stand was conducted using a Design of Experiment approach (DoE). The corresponding requirements regarding the continuously variable compression ratio were defined as additional functionalities via an ASCET interface to the engine management system. The communication to the actuator is bi-directional for actuation as well as position feedback.

VCR-Engine
In-Vehicle Installation

Continuous adjustment of the compression ratio during vehicle operation is not perceptible, since it is executed in a torque-neutral manner. The actual comression ratio is shown in a bar diagram display which is located in the vehicle's center console.

Meanwhile, the vehicle has undergone several thousand kilometers of test driving and customer demonstrations. Throughout this process, neither damage nor unusual wear were detected. More than 100 customers have experienced the high quality realization, excellent driveability, and suitability of the variable compression ratio system. Throughout the demonstration process, the subjective acoustical assessment was positive. No adverse effects of the compression ratio can be detected, nor are there any significant drawbacks compared to the conventional 6-cylinder baseline engine.

As a result of careful combustion system tuning, the compression ratio can be adjusted to its maximum/ retaining position. Even during continuous driving at 140 km/h (87 mph), the compression ratio can remain at a relatively high value of 14. Use of the complete adjustment range is only required for full load accelerations with full boost pressure.

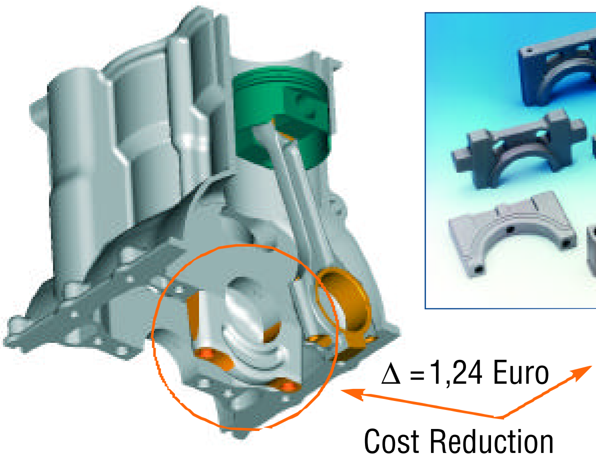
Dr.-Ing. Knut Habermann

Cost Optimized, Simultaneous Development of Powertrain and Production Technology

Future powertrain development efforts will increasingly require a complete and simultaneous integration of the product and production development efforts. Within PEDCO (Production Engineering based Design and Cost Optimization), a partnership between FEV and PLATOS, the competence that is required to achieve this is being offered to the automotive industry and its suppliers. By establishing project teams with experienced design engineers and experts in the area of production planning and cost engineering, significant cost reduction potential can be identified in a SE (Simultaneous Engineering) process.

The combined knowledge of powertrain development and production technology has been leveraged with great success in customer projects, as well as in our own development efforts, for:

- Evaluation of production engines and development of cost reduction measures,
- New developments or upgrades of engines and powertrains using DFMA (Design For Manufacturing and Assembly) and cost optimization,
- Industrialization of new technologies,
- Development of new engines, including production strategies and planning.



Material Alternatives for Main Bearing Caps

The fundamental production engine cost optimization process includes:

- Brainstorming,
- Assessment of functional aspects and characteristics,
- Cost evaluation,
- Realization into production.

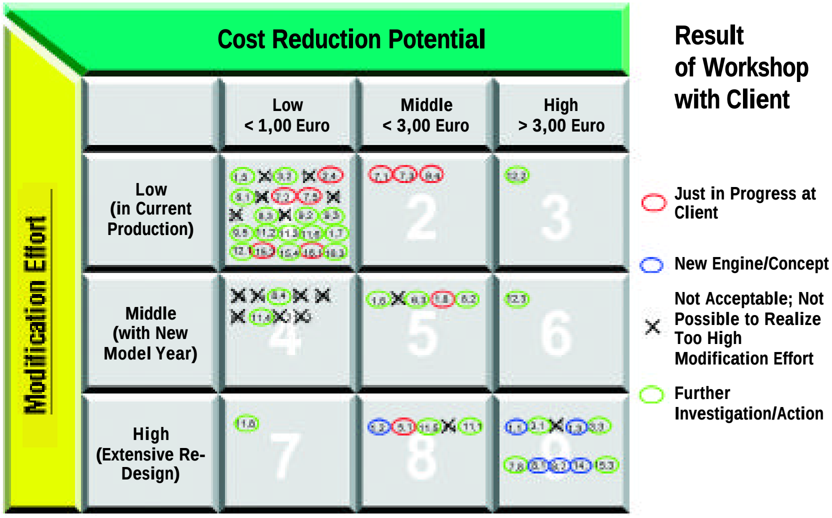
Typically, a systematic assessment of a number of cost reduction suggestions is jointly discussed with our OEM customers. Description of potential design alternatives and the cost comparison for manufacturing – machining and assembly – as well as the purchased parts are an integral part of the cost engineering process.

This process also applies to all components and delivered parts so that the supply chain is included in the detailed evaluation and identification of cost reduction potential including alternative manufacturing technologies.

The integration of process planning and cost engineering is of critical importance to powertrain development. Engine development efforts and the development of new technologies use Simultaneous Engineering (SE) processes that consider manufacturability, assembly DFMA, supplier qualification and cost effectiveness. This ensures continuous control of the product and production costs and results in an efficient engine production process.

Early in the process of planning and designing new engines, the strategies and requirements for future engine plant concepts are determined as well as the necessary measures to achieve them. For production planning, the demand-tailored manufacturing and the large number of engine versions necessitate increased flexibility –Production on Demand–. An engine development program with simultaneous concept development for a flexible and scalable plant that can be adapted for a variety of engine versions requires a number of key attributes to achieve optimum results:

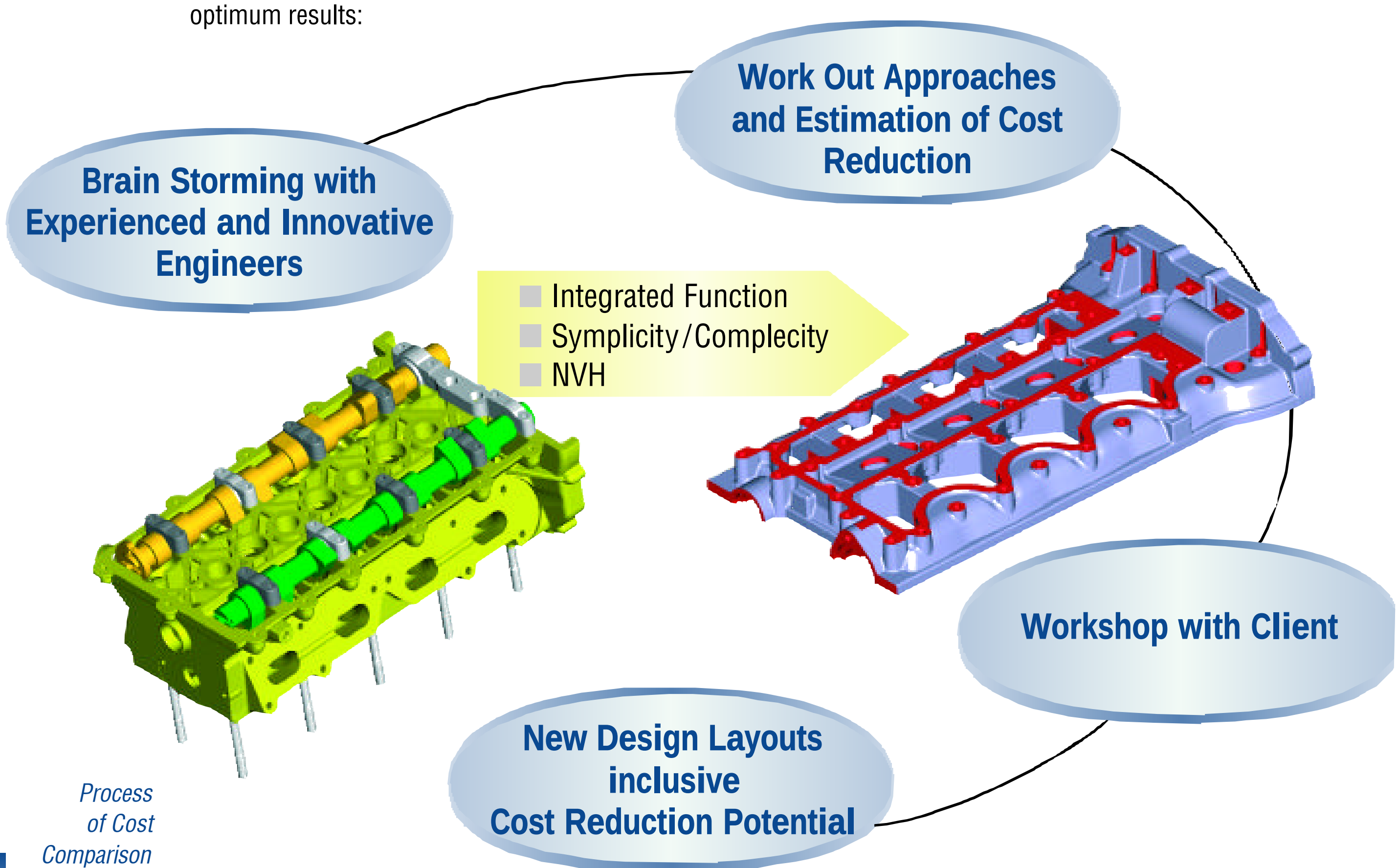
Design Study for Cost Reduction of Actual Production Engines



- Tailored flexibility and low piece-cost through demand-driven production systems,
- Avoidance of capacity losses and effort for modifications for version changes,
- Smooth production start of all planned engine versions,
- Strategic planning for capacity changes/increases using mobile production systems and the potential of flexible resource allocation.

PEDCO utilizes the experience from a number of successful projects, including the development of complete new engine families and their corresponding production facilities, to provide cost-optimized simultaneous development of powertrain and production technology.

Dr.-Ing. Ernst Fahl



Process of Cost Comparison

Solutions for Fulfilling US 2007 Heavy Duty Emission Legislation

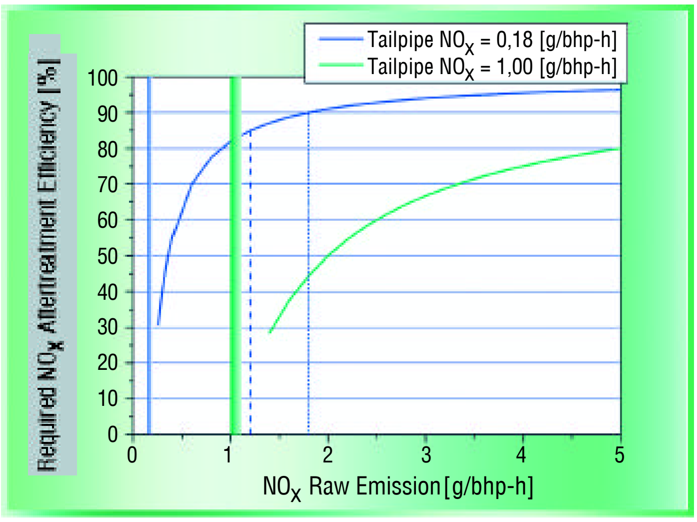
Both the U.S. and Europe have seen a dramatic increase in the number of heavy-duty Diesel vehicles over the past 15 years. Legislative measures have been introduced to reduce on-road transportation-borne emissions, particularly NO_X and Particulates. Although the accumulated annual mileage is expected to increase over the next few years, these measures are likely to result in a reduction in the total emissions by 2015, approaching the levels observed in the 1970's.

The US 2007 emission standards will be introduced in two steps, beginning with a phase-in period from 2007 to 2009. The final standards will become obligatory in 2010. Particulate levels will be reduced to 0.01 g/bhp-hr, beginning in 2007. This value is well below EURO 5 standards. The new legislation requires a 50% NO_X emissions reduction during the phase-in period, based on the 2002 / 2004 levels, and a final reduction exceeding 90% for 2010.

The engine-out emissions that are necessary to meet the standard will be defined by the efficiency of the available NO_X aftertreatment technologies. The figure indicates the necessary engine-out emissions for both NO_X target values: 0.2 g/bhp-hr (2010, blue bar) and 1.1 g/bhp-hr (2007, green bar). These estimates include a 10% safety margin offset from the respective NO_X limits.

The current U.S. 2002 / 2004 emissions limits are attainable without the necessity of advanced aftertreatment devices. The 2007 emission standards are likely to be met with a combination of new combustion systems and a diesel particulate filter (DPF). However, achieving the U.S. 2010 standards will require addition NO_X aftertreatment devices that have not yet been fully developed.

In order to demonstrate raw NO_X emission levels in the range of 1 g/bhp-hr, high rates of cooled EGR in combination with high-pressure turbocharging will be required. Further injection pressure increases will be necessary to compensate for the drawbacks of EGR related to particulate emissions. Two-stage turbocharging not only offers the required high boost pressure level, but also allows for two-stage intercooling. To keep soot emissions constant, while EGR-rates are increased significantly, the cylinder charge mixture preparation must be optimized. This will be accomplished by adapting a smaller hydraulic nozzle hole diameter, optimizing nozzle hole shape and increasing injection pressures. It is not useful to consider use of the CRT©-effect as the primary particulate filter regeneration method, since the high C/NO_2 ratio renders it ineffecte. Therefore, the regeneration process needs to rely on thermal regeneration that is initialized by increases in the exhaust temperature. For the most part, this process is controlled by exhaust temperature but e.g. oxygen concentration also plays a role.



Engine-Out NO_X Emissions Required to Fulfill US 2007/2010 Limits as a Function on Efficiency of Aftertreatment System Efficiency

NO_X aftertreatment for 2010 will require an improvement in reduction efficiency to values of about 90%. Such reduction rates can be achieved with a NO_X adsorber system, which stores nitrogen oxide during lean diesel operation and is regenerated during rich operation. However, the actual regeneration strategies have to be improved to cope with highly transient engine operation and the significant fluctuations in the exhaust mass flow rates that result. Since adsorber catalysts are very sensitive to the presence of sulfur, the anticipated lifetime of these units does not currently fulfill the requirements for heavy-duty engines. A potential configuration, presented by the U.S. Environmental Protection Agency (USEPA), featuring a combined DPF and Adsorber was demonstrated in “SAE 2001-01-1351”.

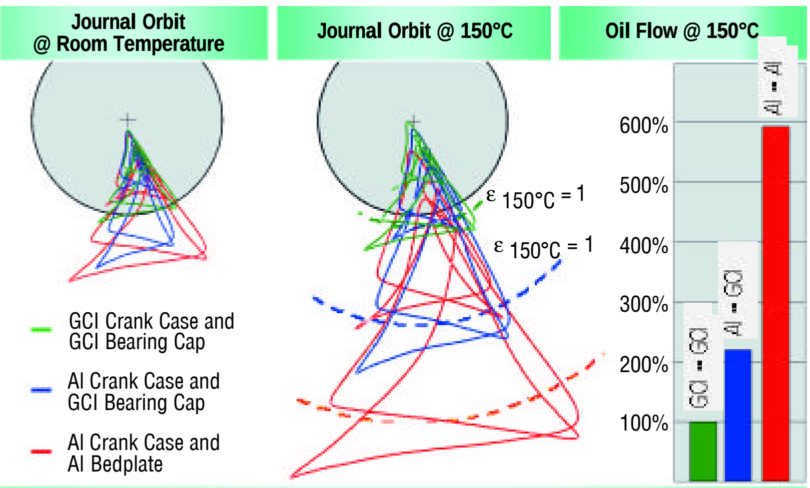
The ammonia based continuous SCR system is also an alternative for NO_X reduction. A fast NO_X sensor and a predictive NO_X emission calculation will dramatically improve control. It also allows provision of ammonia quantities much closer to the slip limits. Assuming an end-of-lifetime NO_X aftertreatment efficiency of 85%, the NO_X emission standards for 2010 can be met with a combination of a $DeNO_X$ device and an engine with NO_X engine-out emissions conforming to the 2007 regulations.

Dr.-techn. Andreas Pfeifer;
Dipl.-Ing. Ulrich Grütering

Lightweight Crankcase Design Solutions for Weight, Friction and NVH

The demand for fuel-efficient vehicles is leading to rigorous performance specifications for power unit weight. In many cases, the use of cast aluminum alloys is the technical answer to these requirements. However, in addition to weight reduction, the performance of the crankcase with regard to noise, vibration, and harshness must also be taken into account and various potential design solutions have to be evaluated:

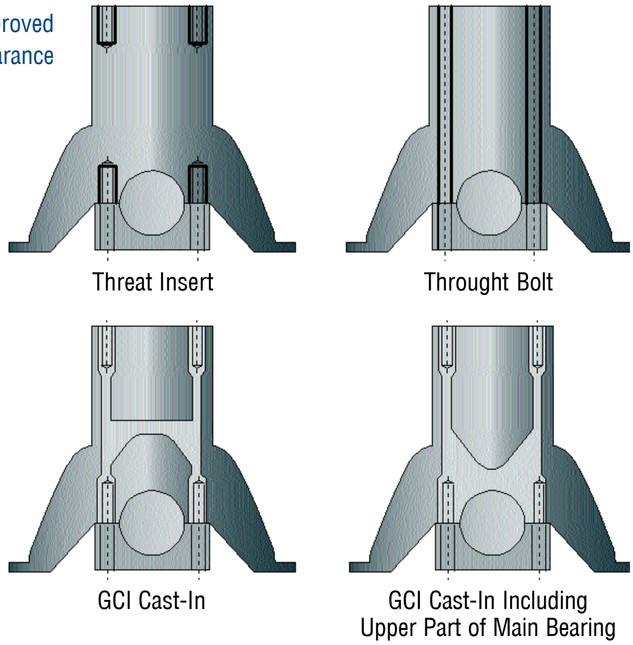
The cylinder liner walls must demonstrate wear-resistance and low deformation. The gray cast iron liner is still the standard solution from an economic standpoint. The potential alternatives are expensive (monolithic crankcases made from hypereutectic aluminum) or bound to a certain manufacturing process (pressure diecasting with aluminum liners, squeeze casting with fiber material performs), but they yield weight advantages and (partially) better friction characteristics. Plasma-coating could become an interesting alternative if manufacturing expenses can be reduced.



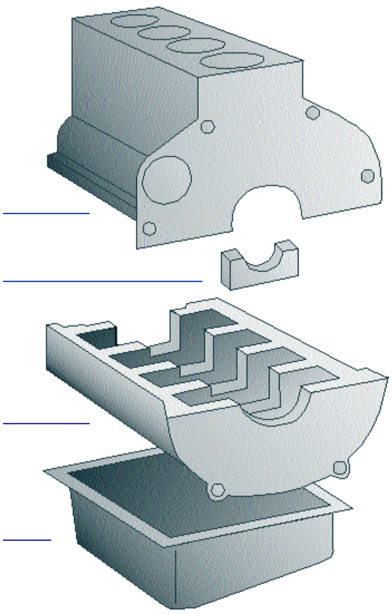
Thermal Bearing Expansion and Oil Flow

The higher expansion coefficient of aluminum (compared to that of steel or gray cast iron), leads to more pronounced bearing expansion and dramatically increased oil flow rate with an all-aluminum engine. In addition, the larger bearing clearance has a significant influence on the acoustic excitation of the engine by the crankshaft. Force flow and bearing expansion can be accommodated by the use of iron materials in the main bearing region. For the normally stressed engine, a main bearing cap made from iron is a sufficient solution, whereas for the high performance diesel engine additional cast-in parts are developed on the block side to ensure the force flow.

Design Variants for Improved Strength and Bearing Clearance



Design Concept for In-Line Engines



However, these solutions are neither cost nor weight neutral.

A target-oriented design concept for inline engines combines many of the examined solutions: A short skirt block with main bearing caps made from iron ensures acceptable bearing expansion with low casting costs. A nearly closed oil sump top section (ladder frame) made from aluminum creates a very stiff end section and a worthwhile gearbox connection. The block and the top part of the oil sump can be produced by die casting. The use of gray cast iron inserts in the main bearing areas, which is in any case rather delicate, can be dispensed with. In addition, greater freedom is won for the oil sump connection to ensure an adequate oil quantity. The sheet metal oil sump is a favorable solution in terms of noise radiation and expense. This design is quite lightweight (only a few ribs after an early noise optimization), and it meets the necessary requirements at reasonable cost.

Dipl.-Ing. Christof Tiemann

FuelCon / FuelRate

Today's engine control units are tasked with increasing demands on electronics to allow for much greater flexibility in the adjustment of control parameters. The increasingly stringent set of global exhaust emissions standards represents another force that is driving control system complexity.

FEV FuelCon with FEV FuelRate

Precise control of the fuel system is a major parameter in reducing emissions. As a result, many new fuel systems have been introduced for both diesel and gasoline engines.

Two major factors drive the need to condition fuel during the engine development effort. On one hand, reproducible measurement results can be only be guaranteed if the fuel feed to the engine is controlled within narrow temperature and pressure limits. On the other hand, such a conditioning system must have the flexibility to be quickly and inexpensively applied to different engines.

General System Description

FEV's conditioning units undergo a continuous development process. As part of this cycle, the well-known FEV **FuelCon** system has been fundamentally revised and improved. The FEV FuelCon defines a new standard for compactness, ease of maintenance, and modularity. The figure shows an external view of the new unit.

The functional set-up of the new FEV **FuelCon** is completely modular. The base version supplies a fuel-cooling module – most common for diesel engine testing. The base layout is suitable for engines in a power range up to approximately 700 kW.

The system can be extended with a fuel-heating module that can also be retrofit to existing base systems, allowing greater functionality and flexibility for engine testing.

The FEV **FuelCon** system functionality can also be enhanced with fuel pressure control to meet the needs of today's as well as future engine fuel systems.

Special attention was given to the integration of the unit into the return flow of the engine where an enormous variety in engine flow rates and pressure levels must be anticipated. In addition, the return flow from the fuel injection system can have a significant influence on the engine parameters.

Temperature Range:	... +80°C (Diesel) ... +45°C (Gasoline)
Accuracy:	+/- 1 K
Max. Flow Rate:	200 l/h
Supply Pressure:	0,1 - 4,5 bar
Cooling Capacity:	6 kW
Heating Capacity:	1,6 kW (Option f. Diesel)
Power Supply:	380 - 400 V; 50 Hz 380 - 480 V; 60 Hz
Applications:	Wall-mount/Stand-alone

Main Technical Data FEV FuelCon

Besides the engine integration optimization, the interface between the unit and the facility was also designed to ensure rapid, flexible and cost-effective integration into nearly any environment. Among other features, this includes the integration of several controllable valves and a steam bubble separator.

Maintenance

Beyond the fundamental functionality of the new generation of the FEV **FuelCon**, special emphasis was given to serviceability.

Both the side and front doors can be quickly disassembled. All relevant parts such as valves and controllers can be very easily maintained and, if necessary, replaced.

The black-colored element serves as an access panel for **FuelCon** information. Behind the panel, the user will find a short introduction into self-service and maintenance, together with contact numbers for FEV servicing. In the future this philosophy will be applied to all FEV conditioning units.
All of the mechanical and electrical components are

FEV FuelCon with FEV FuelRate

tightly integrated in to space-saving enclosure. The overall di-mensions of the **FuelCon** are only 90 x 90 cm with a depth of 45 cm.

Integration of Fuel Consumption Measurement Device

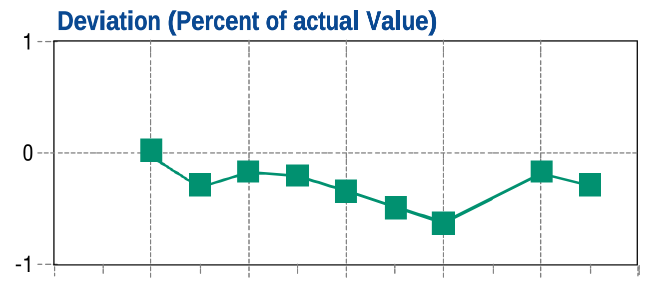
The figure shows the FEV **FuelCon**, coupled with the FEV **FuelRate** module, which measures fuel consumption using direct fuel mass flow measurements.

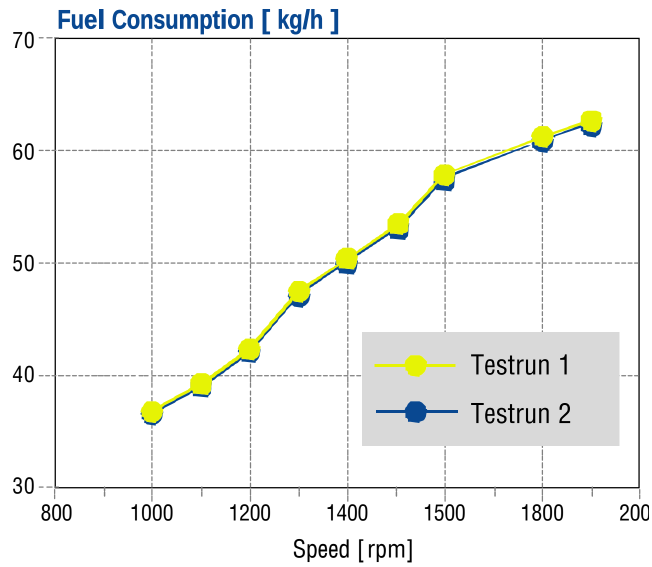
The measuring principle is based on the Coriolis force and is suitable both for steady-state and dynamic measurement. The measurement range of the standard system is sufficient up to 130 kg/h. Other measurement ranges are available upon request.

The FEV **FuelRate** has also been developed as a modular system. The base system includes the basic measurement technology. With the optional “pre-conditioning” expansion package, FEV **FuelRate** can be flexibly applied to nearly all potential engine test cell environments. This can be accomplished for many different signal interfaces, including not only analog but also fieldbus oriented interfaces.

Measuring of:	Mass Flow
Media:	Liquids, Gases
Measuring Principle:	Coriolis Force
Measurement Range: (3 bar Pressure)	0.5 - 130 kg/h 0.05 - 28 kg/h
Accuracy:	0.1 % FS
Temperature of Liquid:	... + 80°C
Outputs:	Frequency parameterizable Current; 4 - 20 mA
Comm. Protocols:	CAN-open, Profibus
Power Supply:	115 - 230 V AC 24 VAC/DC

The next figure shows diesel engine test results indicating the excellent reproducibility of the measurements in two selected test runs. The lower diagram displays the absolute values; the upper diagram shows the very low deviation in percent of the actual value. Results such as these can only be gained with an optimal combination of accurate fuel conditioning and measurement.





Catch a Glimpse at Your Advantages:

- High control accuracy
- Modular set-up
- Flexible applications
- Dynamic mass flow measurement
- Highest measurement accuracy - excellent reproducibility
- Wide application range (gasoline, diesel, alcohol, gases)
- Low-maintenance
- Excellent price-performance ratio

Dipl.-Ing. Bernhard H. Biermann

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