SPECTRUM

Technology Highlights and R&D Activities at FEV

Issue 25, February 2004

The New General Electric GEVO-Engine for Tier2-Locomotive Application

The new EPA Tier2 exhaust emission levels for locomotives in the United States present significant challenges to reduce NO_X levels, particulate emissions and fuel consumption. Rather than compromise fuel consumption, reliability, durability and other important customer requirements, General Electric decided to develop a new engine platform that would provide the foundation to meet locomotive emission requirements for EPA Tier2 and beyond. The first engine of the GEVO family will be introduced in the Evolution Series locomotive in 2005. FEV (working closely together with GE) was responsible for the design, analysis and mechanical validation throughout the development of this new product.

The engine was developed in 12 and 16-cylinder versions with a 250 mm bore and 320 mm stroke. This allowed 3,360 kW (4500 bhp) to be generated with 12 cylinders rather than the 16 cylinder used on the 228 mm bore current GE production engines. The basic dimensions of the V12 version are illustrated in Table 1. One major design feature, which enables a very compact design, is the location of the intake and exhaust manifold between the cylinder banks. The unique design allows accessibility to all of the maintenance items from the outboard side of the engine. The cylinder head, water jacket, liner and connecting rod are all grouped into one assembly, known as the power unit. The power unit can be easily removed from the engine as one assembly. This helps

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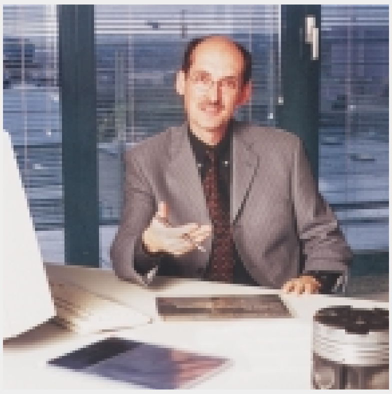
Preface: Globalization to the FEV



Dear Readers,

The world has become smaller – including for companies like FEV. In previous years, manufacturing and development capacities of our customers have followed the markets; the automotive industry is carrying the flag. Based on our customer's requests, we at FEV have reacted to this trend by offering a concept that combines excellent local accessibility with the high quality engineering services that we offer in Aachen and Detroit. A primary boundary condition of this concept is to maintain FEV's high level of flexibility, which ensures short reaction times and swift problem solutions.

In 2003, we successfully established new FEV subsidiaries in Krakow, Poland, Seoul, Korea and FEV Test Systems in Detroit. The subsidiaries have teams of highly experienced experts that are at your disposal in existing and emerging markets.

However, there is no time to rest. FEV is currently preparing new subsidiaries for the engine development, electronics, and measurement and testing technology sectors. In 2004, new subsidiaries will see the light of the world for the first time – to the benefit of our customers.

Yours sincerly

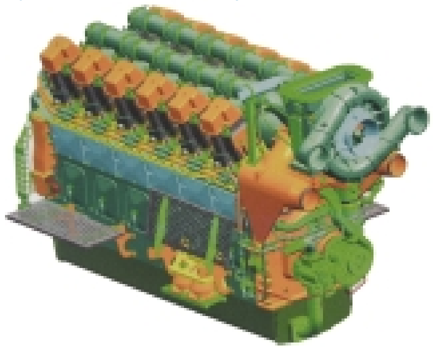
Dr.-Ing. Ernst Scheid
Executive Vice President

V12 Specification Sheet

Model	GEVO V12
Bore	250 mm
Stroke	320 mm
V12 Displacement	188,5 liters
Speed	1.050 rpm
Power	3.360 kW
Number Cylinders	12
Bank Angle	45°
Height	2.683 mm
Width	1.598 mm
Length	4.196 mm
Weight	19,500 kg

to minimize the service time for the locomotive. The turbocharger is mounted to an integrated front end, which also serves as a vibration damper housing and a support for the oil and water pump. The gear train for the camshaft drive on the flywheel side is mounted to an integral housing in the crankcase. The alternator for locomotive traction is directly mounted to the crankshaft and the crankcase. The CAD model of the V12 engine is shown in Figure 1.

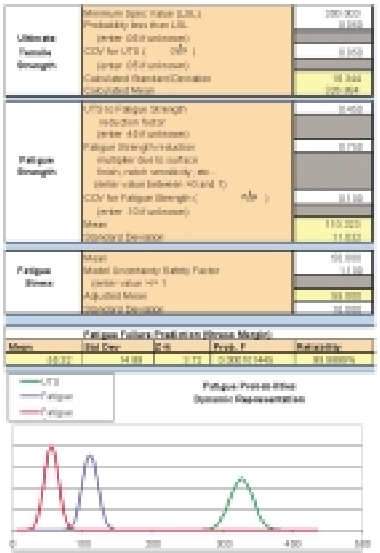
3D Unigraphics Model of V12 Engine



During the course of the project, FEV (again working closely with GE) was also responsible for the complete mechanical development. A comprehensive set of test procedures, considering the special locomotive boundary conditions, have been developed and documented within test specifications. The robustness of critical components was confirmed by performing destructive rig tests. High levels of design margin allowed aggressive testing of the engine to demonstrate its reliability. Multi-cylinder engine tests were run in the customer's test cells, while single cylinder and component testing was performed at the customer site as well as at FEV facilities.

In accordance with GE requirements, Design for Six Sigma concepts were used throughout the design and development process. The critical design features were statistically evaluated against the performance and reliability requirements to assure a high degree of robustness against failure (Figure 2). Statistical tools were also used for the tolerancing of all CTQ's and assessment of actual manufacturing process capabilities. This approach allows the definition of the required part tolerances along with a failure probability prediction based on given process capabilities.

Fatigue Probability Calculator



The most advanced design tools and stringent testing were key to the timely delivery of locomotives with the new GEVO V12 engine for field use to a railroad customer in early 2003 (Figure 3). Locomotive testing and field trials have shown the engine to exceed expectations in terms of power, acceleration, operation and reliability.

First Tier2-Locomotive

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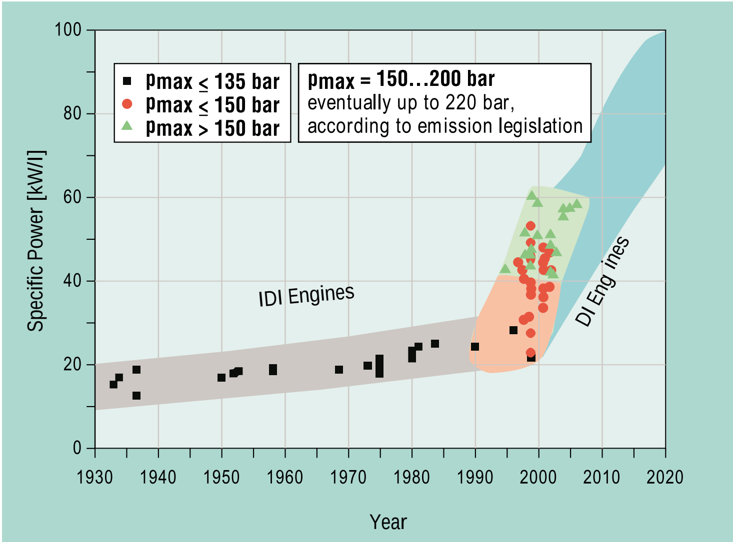
Diesel Engine Design for 200 bar Peak Pressure

The development of modern passenger car diesel engines requires a great deal of attention to the design in order to increase the specific output and peak combustion pressure (see Figure 1).

Specific Power and Peak Firing Pressure



Two issues require examination when establishing the boundary conditions for new diesel engine designs, the thermodynamic parameters and finding a solution for the problem of the

Comparison of Design Variants GJV-GJL-AL 4-Cyl. 2,0 L

4-Cyl. 2,0 L 400.000 per Year	GJV	GJL	AL
Nom. Wall Thickness	3.5 mm	3.5 mm	4.5 mm
Concept	■ Short-Skirt Ladderframe ■ Sheet Metal Oil Pan ■ Cracked Main Bearing Wall	■ Short-Skirt Ladderframe ■ Sheet Metal Oil Pan	■ Short-Skirt Ladderframe ■ Sheet Metal Oil Pan ■ Insert Design/ CI Liner
Total Block Weight	ca. 90%	100%	80% - 70%
Max. Peak Pressure	200 bar	200 bar	200 bar
Space between Liner	8 mm	8 mm	10 mm
Manufacturing Costs	138%	100%	162%

thermomechanical loading capacity. Premium applications of the next generation of diesel engines anticipate increased power densities with peak pressures of up to 200 bar.

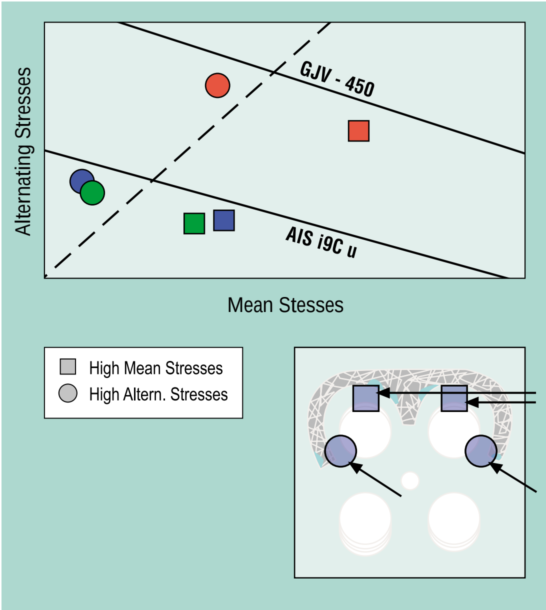
Light cylinder blocks constructed of aluminium-iron hybrides or as compacted graphite iron (GJV) castings (see Figure 2) show potential for high load conditions. The known problem areas for these concepts (bulkhead, thermal expansion of the main bearing, bolt threads, etc.) can be solved satisfactorily for the more difficult operating conditions.

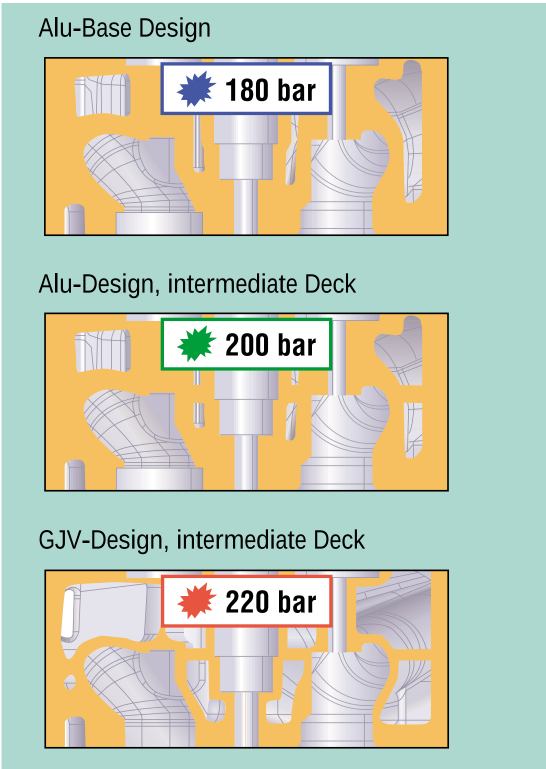
Structural optimisation is necessary for the cylinder head before a change in material should be made. Comparisons of potential materials are shown in Figure 3. The □-symbols mark the significant areas of thermal stress in the area below the exhaust ports. The O-symbols, on the other hand, illustrate the cylinder pressure dominated regions in the general area of the ports at the flame deck.

Comparing the basic design of cast aluminium (blue) with the intermediate deck variant (green), it is found that with the insertion of an intermediate deck the permissible ignition pressure can be increased by approximately 20 bar. For a GJV-variant (red) with an intermediate deck higher absolute stresses occur as expected. However, because of the significantly greater rigidity of the material, despite a 20 bar increase in gas force compared to the AlSi-alloy, this does not represent a disadvantage for the GJV-variant. The maximum temperature of the flame deck increases by more than 100°C, because of the low thermal conductivity of GJV.

The target values for the next generation engines can be represented by material-suitable block and head concepts. The performance limits for pure cast aluminium concepts for contemporary alloys will probably be reached soon. In order to reach the maximum potential of aluminum, aluminium foundaries are required to provide technical and cost-attractive solutions. GJV concepts are showing great potential for more stringent operating conditions. Iron concepts are at a clear weight disadvantage compared to contemporary aluminium parts.

Potential of Design Variants shown up in the Haigh Diagramm





However, it is conceivable to utilize iron in consistent thin-walled castings. In this situation, iron foundaries would be required to prove the feasibility for mass production. The final solution will be the material that provides best compromise between cost and weight.

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FEV Turbo-DISI - Driving with Improved Fuel Conomy

Turbocharging the gasoline engine is one of the most efficient measures to reduce passenger car fuel consumption in order to meet the stringent Association des Constructeurs Europeens d'Automobiles (ACEA) targets in 2008. Today's boosted engines, particularly in the European market, appear to have better New European Driving Cycle (NEDC) fuel economy compared to naturally aspirated engines with similar power. The advantage is the result of the downsizing effect. The main issue for these engines, up to this point, is the drive-away behavior.

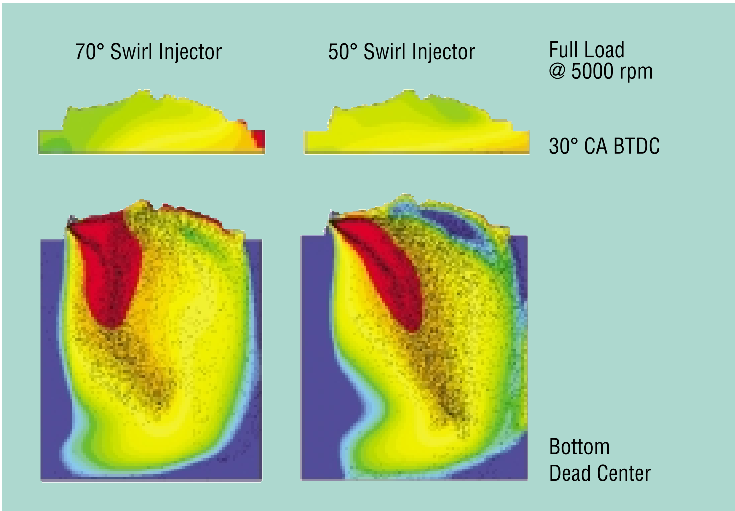
A significant contribution to solving this problem can be found in the combination of charging technologies and gasoline direct injection. FEV has optimized a 1.8 L gasoline engine with Port Fuel Injection (PFI) in stages, towards operation in a homogeneous direct injection mode.

Main features of the turbocharged Direct Injection Spark Ignition (DISI) engine are:

- Turbocharging with charge-air-cooling
- Adapted charge motion for reduced knocking sensitivity
- Optimized compression ratio for improved partial load fuel consumption
- Intake and exhaust camshaft phaser

In order to realize a smoke-free combustion system, extensive Computational Fluid Dynamics (CFD) calculations have been performed early in the development phase. The calculations are performed to investigate the spray propagation and mixture formation with different injectors. It is important that for turbocharged engines with high fuel injection rates at full load, that the fuel spray does not impinge on the cylinder walls in order to avoid increased smoke and Hydrocarbon (HC) emissions as well as the risk of oil dilution. For example, figure 1 shows a comparison of the behavior of injectors with 55° and 70° spray cone angles. At bottom dead center, the 70° injector inclination clearly indicates wall contact with a spray of fuel in the area of the exhaust valves. A stronger stratification in the combustion chamber also results during the compression phase, so that zones remain that containe a rich mixture, even at the end of the compression stroke. Wall wetting can be significantly reduced using the 55° injector. The rich zones at the end of the compression stroke (shown in figure 1) are diminished, so that the formation of black smoke at full load can be reduced. In addition, with the actual combustion system, multi-hole injectors have the advantage of offering a large degree of freedom concerning the number and arrangement of the individual holes. In the layout of the spray pattern the collision of the spray with the intake valves must be avoided (if applicable, boundary conditions concerning the high pressure stratified start-up should be taken into account).

CFD-Simulation Mixture Formation

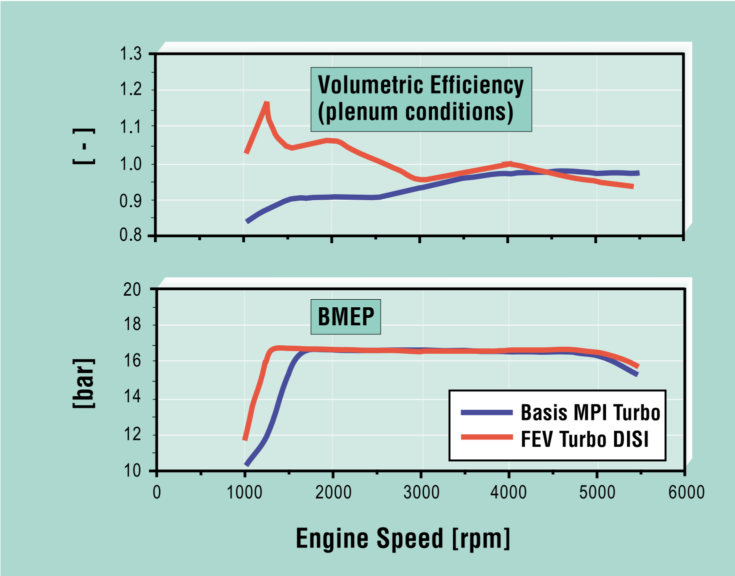


The gas exchange layout and the adaptation of the turbocharging system show outstanding advantages when compared to today's turbocharged engines (see Figure 2). In particular, the systematic optimization of the intake and exhaust camshaft phaser at low engine speeds, with positive scavenging pressure ratio, leads to improved residual gas contents in the cylinder. Additionally, the internal cooling effect yields reduced knocking sensitivity. The volumetric efficiency relative to the boosted state can be enhanced to values of up to 120%, which otherwise could only be possible through application of costly impulse charging systems. The energy available at the turbine and the boost pressure level are improved through higher mass flow as well as a 100°C higher exhaust temperature level.

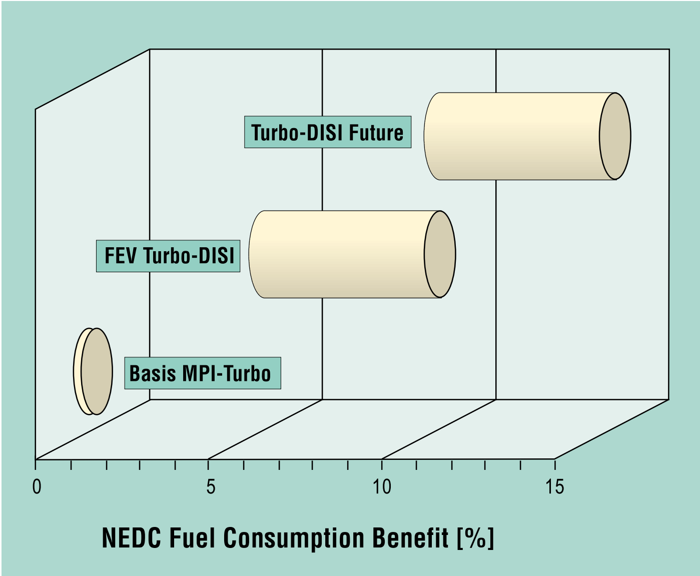
Overall, the steady-state torque at low engine speeds is increased up to 50%. Investigations concerning the transient behavior confirm this positive effect and it will permit the enlargement of the vehicle's final drive ratio with a positive effect of an operation point shift. Driving dynamics that will even beat modern diesel engines may be expected, because of improved drive-away torque and a broad usable engine speed range. The benefit of this concept is not only reflected in vehicle performance, but also in terms of vehicle fuel consumption.

This engine concept is very attractive because the efforts required for the aftertreatment of lean burn engines (NO_X adsorber) are inapplicable. The application of a stratified, lean burn combustion system will permit additional fuel saving benefits for this concept. However, this additional fuel saving potential is lower compared to a naturally aspirated engine, since a portion of the measures (de-throttling) have already been applied through operation point shift.

Comparison PFI vs. Direct Injection



NEDC Fuel Consumption Benefit



At full load, especially at mid and higher engine speeds, specific fuel consumption can be reduced through improved combustion phasing and lower enrichment demand. The results can be particularly noticed during real on-road driving conditions. At partial load operation, both an increased compression ratio and the improved effects of residual gas control account for improved fuel economy. The NEDC driving cycle simulation shown in figure 3 confirms that a 5-10% fuel saving benefit can be realized compared to current turbocharged gasoline engines.

Additionally, a 5% fuel saving potential may be achieved with such measures as:

- Multiple injection
- Optimization of engine start and warm-up through high pressure stratified start-up and variable valve timings
- Future charging concepts [e.g. Variable Turbine Geometry (VTG) for gasoline engines]
- Optimization of the final drive ratio

It is expected that the combination of turbocharging and gasoline direct injection will become the standard in the future. High performance engine variants with a maximum Brake Mean Effective Pressure (BMEP) of more than 20 bar can be realized without major drawbacks in the usable speed range. The attraction of this concept will push turbocharging and direct injection towards even higher significance for passenger car gasoline engine applications.

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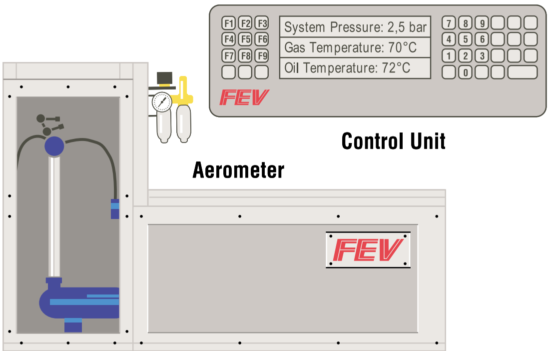
Gas Content Measuring Device for Oil

FEV-Aerometer



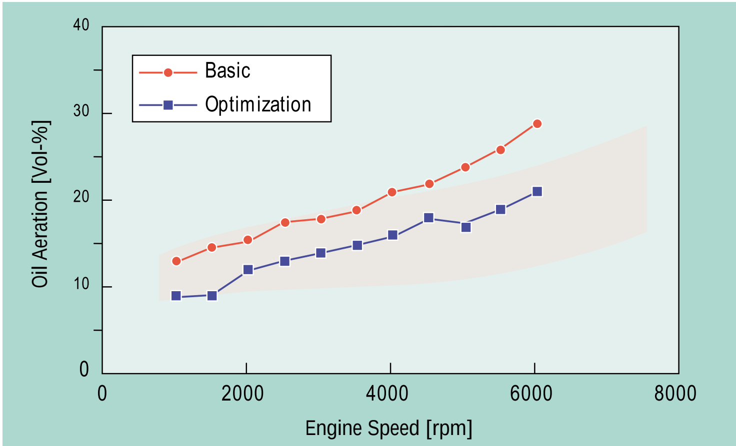
Lubricating oils are capable of dissolving gases (air). Oil containing dissolved air is not critical, because the properties of the oil are only marginally influenced. In contrast, undissolved air influences the compressibility of the oil that can lead to malfunctions of various engine components. In order to optimize the air entrainment in the oil, a secure and reproducible method of measurement is required. FEV has developed a discontinuous measuring technique, based on the principle of evacuating an oil sample from a running engine. Utilizing this technique, one can easily and effectively determine the gaseous content of the oil.

The gaseous content of the oil is determined by the FEV-Aerometer through the extraction of an oil sample (approximately 30 ml) from a bypass oil flow. The sample is analyzed by being automatically fed through an screen and occasional evacuation. During the evacuation, the dissolved gaseous components are separated according to the law of Henry-Dalton. The separation process is caused by the pressure decrease and takes place throughout the entire sample volume (similar to the opening of a bottle of carbonated water). The separated gas gathers together with any undissolved gas before the evacuation at the highest geodetic point of the measuring device. The sample can be volumetrically measured via a scale, after a quick and automatically controlled compression to atmospheric pressure level (standard pressure 1,013 mbar, which is then referenced to the sample volume. The ratio of oil to gas is displayed as a percentage of the total volume.

In order to compare and evaluate the results, the measured value is normalized to standard temperature and pressure conditions (p_0=1,013 mbar, T=293K).

The necessary start and end conditions are recorded by one pressure sensor and two temperature sensors. Based on this data, the thermal change in volume during the usually non-isothermal measuring procedure is arithmetically compensated.

Scatter Band Oil Aeration



Technical Data

Dimensions	1000 x 200 x 750
Voltage supply	230 V, 50 Hz
Compressed air supply	5 bar
Max. oil temperature	120°C
Max. oil pressure	8 bar
Accuracy	± 1 %
Noise level	< 70 dB (A)

The secure and reproducible approach of determining the gas content in oil with the FEV-Aerometer is recognized and is being used successfully in the development of modern engines by automobile and engine manufacturers as well as engineering service providers around the world. The FEV-Aerometer is manufactured according to the currently applicable European Union (EU) guidelines of the board for Consultants Europe (CE) certification and carries the CE compatibility mark.

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FEV Obtains Quality Certificates

Customer satisfaction is a primary operating principle for an engineering service provider. Attention to quality and customer satisfaction through process control are key factors in the success and performance of a company.

Recently, FEV Motorentechnik was certified to the ISO 14001 Environmetal Management System Standard. Re-certification to the ISO 9001:2000 Quality Management System Standard was obtained by FEV in the summer of 2003. These certifications were granted for FEV's total service and product spectrum (e.g. motor - powertrain, vehicle application, electronics - mechatronics and measurement - test systems). FEV now has an integrated quality and environmental management system.

Evidence of customer satisfaction has been demonstrated by the receipt of one of our customer's own certifications. In November, Ford of Europe updated FEV's Q1-2003 status for powertrain development. The Q1 requirements exceed those of the ISO-standards. The Q1 global standard is a highly esteemed quality mark that also stands for proof of FEV's systematic quality assurance.

The strategic determination of measurable quality metrics as well as the continuous pursuit of improvement measures are required for this standard.

FEV has established a QM-system in preparation for future quality requirements.

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News: New Addition to Executive Management

Effective February 1, 2004, Dr. Markus Schwaderlapp has joined FEV's executive management.

Dr. Schwaderlapp has been a member of FEV's staff for nearly 20 years and has held leading positions in various engine and powertrain development areas during his career. Dr. Schwaderlapp has also played a key role in the growth of FEV's global business.

In his new function, Dr. Schwaderlapp is available to respond to all engineering services.

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