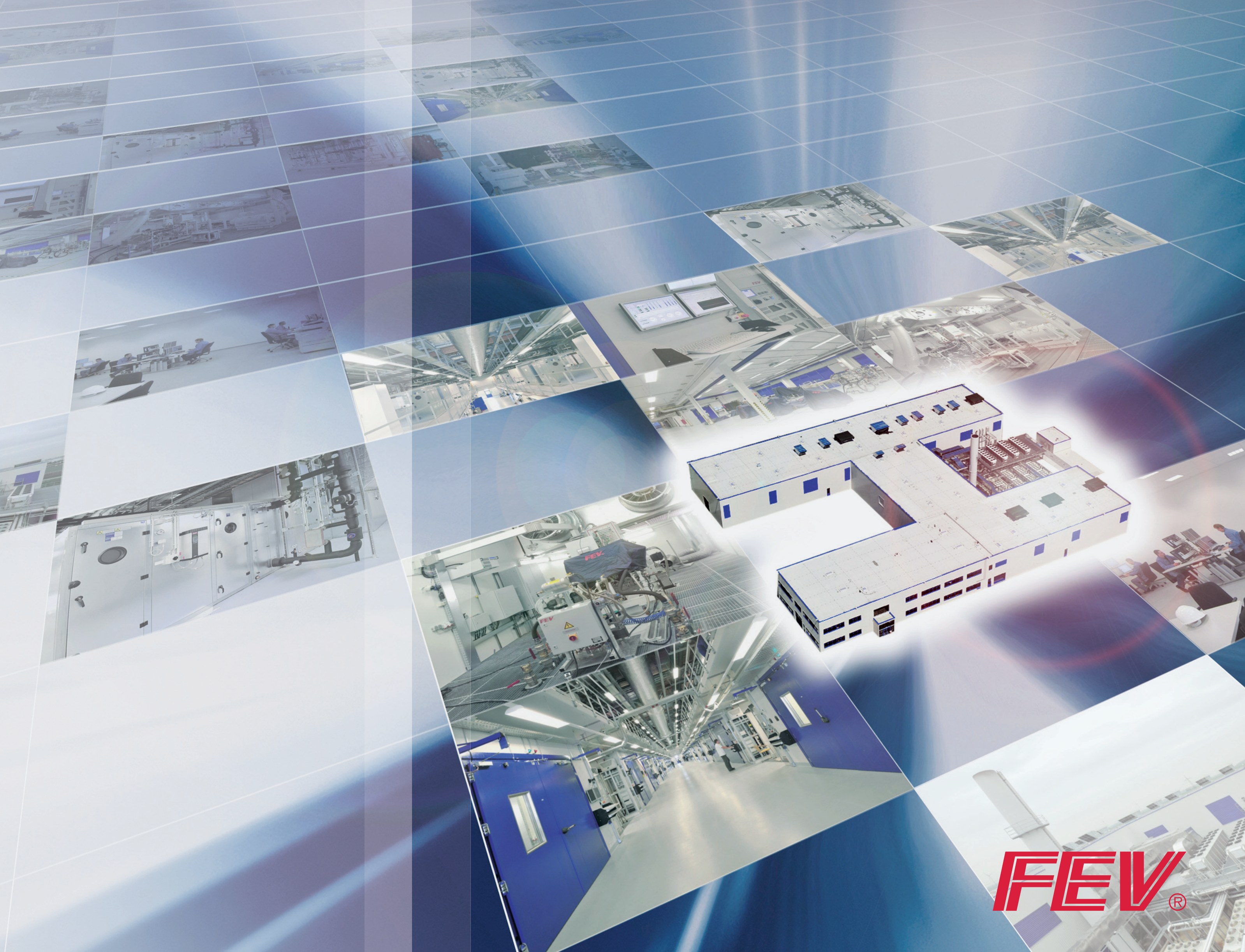
The new FEV Durability Test Center

in Brehna near Leipzig



FEV®

March 2009

The New FEV Durability Test Center
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In February 2007, FEV founded a subsidiary in Brehna in Saxony-Anhalt, the FEV Dauerlaufprüfzentrum GmbH, and created a new test facility for engines and complete power trains.
FEV has invested 45 million Euros in the technical infrastructure of the center and therefore has access to one of the most modern and efficient test facilities for the testing of engines and power trains.

INTERVIEW

CATEGORIES

Foreword

The new FEV Dauerlaufprüfzentrum in Brehna near Leipzig has started operations with 31 engine and power train test benches. The testing of future engine generations on the test bench outside the vehicle under boundary conditions similar to the later deployment requires considerable technical efforts. The task entailed new strategies and concepts which have been developed through intense cooperation between different disciplines at FEV.

The technical division "Mechanics, Simulation & Testing" defined the requirements for future tests together with key customers.
The wealth of experience from testing programs, process instructions and benchmark results led to optimized testing procedures which contribute to higher efficiency through time lapse effects. New methods were also pursued for the test setup: Auxiliary units, electrics, electronics and many components of the power train and the original exhaust gas assembly needed to be tested in parallel with the engine to evaluate stability.

The technical division "Production Planning" which is responsible for the design of engine plants provided extremely efficient organizational structures as well as operating schedules and work processes.
The technical division "Test Systems"-undertook the task of the planning of the durability test center at short notice, providing a turn-key construction and handing it over to FEV Dauerlaufprüfzentrum GmbH in Brehna. It realized the requirements through modification of the FEV products in the measuring and testing systems sector, expanded the product portfolio and adapted and optimized the software packages. Many functions were added to FEV TestCellManager (TCM). All customer-specific FEV internal test runs and measuring programs were integrated.

The result: A unique test center that sets new standards for dimensions, technical possibilities, organization and availability of the test facility. These are some of the extraordinary properties and innovations:
1. The control of the test center and the equipment under test takes place from a central control room where all information from test planning, employed testing technology, equipment under test, test run, central technical facilities and test evaluation and documentation converge.
2. The clients can also be granted access to the control room for their test runs (while confidentiality is fully maintained). The access is given through a so-called virtual control room.
3. The equipment under test is set up with all relevant components including auxiliary units with loading simulation, gearbox, drive shaft, sensor and actuator technology as well as the original intake and exhaust system. The test bench dimensions accommodate these boundary conditions.
4. All current, but also future fuels can be used.
5. The processes are continuously and consistently controlled by ERP systems. A 24 hour and 365 days shift system guarantees continuous operations.
6. All test benches are equipped with asynchronous dynamometers and allow dynamic testing programs.
7. The FEV exhaust gas analysis system "FEVER" yields a comprehensive evaluation of the state of the equipment under test which goes beyond mere mechanics.
8. Hybrid power trains and electric drives can also be tested.
9. Engines are tested under extreme temperatures in climate test cells.

The results are evaluated by a capable and experienced team in cooperation with the engine designers and electronics engineers at FEV whose competence goes far beyond the mere appraisal of the equipment under test. The DLP has set a new benchmark for power train durability testing.

Prof. Dr.-Ing. Stefan Pischinger
Chairman of the Management Board of FEV Motorentechnik GmbH

Dr.-Ing. Markus Schwaderlapp, Gary Rogers, Rainer Paulsen, Dr.-Ing. Ernst Scheid
Executive Vice Presidents

Prof. Dr.-Ing. Stefan Pischinger
Chairman of the Management Board
of FEV Motorentechnik GmbH

In 2008 FEV Motorentechnik celebrated its 30th anniversary and can therefore look back on a long tradition of engineering services. MTZextra talked to Professor Dr. Stefan Pischinger, Managing Director of FEV, about the special features of the new test center und how the clients of the Durability Test Center benefit from knowhow of the company.

"Durability testing is high tech business"

MTZextra The site has room for an expansion of the capacity. When will you expand the center?
Pischinger Currently less than half of the 60,000 m^2 area has been built upon. From the start, we have planned a long term development concept with the possibility to expand the durability test center (Dauerlaufprüfzentrum, DLP) to 100 test benches. We haven't decided on a specific time line yet.
However, we will establish four additional durability test benches in the existing buildings in the short term. We already have many client requests and if this trend grows, we will realize the respective development phases of the test center.

"Our center sets new standards in many aspects"

MTZextra You have made a conscious choice for the location Germany. What were your reasons for this decision?
Pischinger We evaluated the possible locations globally regarding personnel qualifications and cost, fuel cost, logistics and quality. The location Germany was the clear favorite.
We have found outstanding conditions in Brehna in Saxony-Anhalt regarding infrastructure, cooperation with government agencies as well as personnel recruiting. Together with investment incentives this spoke for Brehna as the preferred location.

MTZextra Does the choice of the location Germany limit your client base to Germany?
Pischinger No, there are no restrictions involved with the location Germany. The central location of Brehna near Leipzig and the excellent infrastructure allow to ship engines from anywhere in Europe to us within a day, so that our location doesn't restrict us at all in this respect.

MTZextra Does FEV have similar plans for other regions of the world?
Pischinger Our center sets new standards in many aspects, e.g. regarding the durability testing methodology. It is not only the most modern center of its kind within our company, but probably also globally.
We can also perform durability testing at our sites in the US and in India, but currently cannot offer the size and the service spectrum of the Brehna site there.

MTZextra How will the utilization be distributed between long term bookings and available short term capacity?

Pischinger We estimate about 70 percent long term bookings, and the remaining capacity will be filled with short term requests.
Naturally we aim for a long term utilization planning with all our clients. This will allow us a careful planning of the expansion phases of the center.

MTZextra How do the test center clients benefit from the overall competence of FEV?
Pischinger Durability tests are nowadays a high tech business. It is important for our clients, to also receive our competence regarding engine commissioning, trouble shooting appraisal, data evaluation and engineering. Our expertise in these areas is the reason for many clients to contract their durability testing with us.

MTZextra What specifically do your clients appreciate about the new test center in your opinion?

"We have planned many aspects of the business organization according to plant processes"

Pischinger Our center sets new standards for test benches, facilities and logistics. We have planned many aspects of the business organization according to plant processes, for example, we manage all resources of the DLP consistently with only one central software tool. The test rigs themselves can be precisely conditioned, e.g. with an exact representation of very low temperatures. Further, we are the first company on the market that has the facilities to test engines with the complete, unmodified exhaust gas system. All test benches are equipped with asynchronous dynamometers and therefore allow dynamic testing programs.
We have the technical equipment and the legal permission to use all special fuels.

MTZextra Your clients can access the important state parameters of their equipment under test online, but cannot actively influence their control. Why not?
Pischinger Our clients are granted direct access to their monitoring data so they can start the evaluation of the results immediately. Of course a remote control of the test benches would be technically possible. However, we cannot allow this for safety reasons and to maintain a clear distribution of responsibilities in the testing operations.

MTZextra How is the damage management dealt with should a defect occur at the engine during the durability testing?
Pischinger This is usually negotiated according to the individual requirements of our clients. Of course we offer a comprehensive package including appraisal, documentation and also exchange of parts, but in the end it is up to the client to decide on the scope of our services.

MTZextra The automotive manufacturers currently focus intensely on hybrid and electric vehicles as well as the relevant battery technology. What can you offer regarding these systems?
Pischinger The test center has four power train test benches which are also very well suited for the testing of hybrid power trains. To test a hybrid drive on a test bench, a battery emulator is needed to simulate the charging and discharging cycles of the battery. FEV has very comprehensive experience in this field, and we are happy to apply this knowledge in our new test center.
In addition, we are currently building two special test benches for batteries of electric or hybrid vehicles at our site in Aachen.

MTZextra Thank you very much for this interview, Professor Pischinger.

Interview by Richard Backhaus

Prof. Dr-Ing. Stefan Pischinger

graduated in August 1985 from the Technical University Aachen (mechanical engineering). From 1985 to 1989 he worked as a research assistant at the Sloan Automotive Laboratory at M.I.T. He completed his dissertation on „Effects of Spark Plug Design Parameters on Ignition and Flame Development in an SI engine" in 1989. From 1989 to 1997 he served in various positions in the field of diesel as well as SI engines at Daimler-Benz (today: Daimler). He has been director of the Institute of Thermodynamics at RWTH Aachen and has held the chair for combustion engines since 1997.
Professor Stefan Pischinger has simultaneously been appointed into the management of the FEV Motorentechnik GmbH in 1997. He has held the position of the chairman of the management board since 2003.

Introduction

In February 2007, FEV founded a subsidiary in Brehna in Saxony-Anhalt near Leipzig/Halle, the FEV Dauerlaufprüfzentrum GmbH (short: DLP) and established a new test facility for engines and complete power trains. FEV has invested approximately 45 million Euros in the development of the technical infrastructure of the test facility. FEV has therefore access to one of the most modern and efficient test facilities for the testing of engines and power trains.

1 Background

Value-oriented management is at the core of a company's task to secure its success and its future. The control indicator for value-oriented management is the added value (AV). It is calculated from the achieved return on capital, the capital cost and the capital employed in the operations (capital employed) (**Figure 1**). The added value of a company can be increased (apart from the development of profitable new fields of activity) through operative efficiency combined with optimized capital employment in the already established activities of the company. The withdrawal from activities that do not generate the capital costs as well as the targeted release of means through reduction of the already employed capital at constant company profit are driving factors for the increasing outsourcing of capital intensive development tasks.
In contrast to the OEMs the broad client spectrum of the development partner, the existing variety of development objects and markets offers the possibility of an efficient and profitable utilization of the tied up capital. It was also for this reason that the FEV group has been contracted increasingly in the past with development tasks in the field of the highly capital intensive testing of engines and power train components.
This high demand for testing capacity as well as a strategic and comprehensive cooperation with a well-known German automotive manufacturer in the field of durability testing led to a significant expansion of the test bench capacity of FEV Motorentechnik. Therefore a subsidiary was founded in Brehna in Saxony-Anhalt near Leipzig/Halle in February 2007, the FEV Dauerlaufprüfzentrum GmbH (short: DLP), and a new test facility for components, engines and complete power trains was established.
FEV has invested approximately 45 million Euros in the development of the technical infrastructure of this test facility.

2 Strategic Positioning of the DLP

In the course of the test facility design, conflicts had to be resolved which resulted on the one hand from the desire to cover a very comprehensive spectrum of clients and tasks (long term, variable usage) and on the other hand from the targeted focus on the execution of one testing task. The testing task at hand – the durability testing of engines and power trains – has to be performed with optimal capital expenditure. **Figure 2** characterizes the different test bench concepts regarding their design and assigns them to their typical application.

While test benches for quality assurance and end of line tests with automatic feeding and automatic media connection are highly specific in their design, however, the focal point of use is on the accumulation of test bench running hours.
Also highly specific in their design are test benches for the statistical examination during production (COP) or for certification or high altitude application.
These applications require very small tolerances and an increasing conditioning of the physical properties (for example also the humidity) of the individual media (e.g. intake air, cooling water, fuel, environment), sometimes to the tenth of

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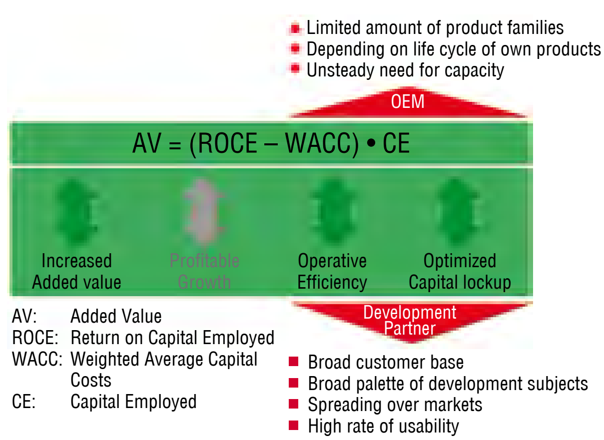


Figure 1: Value oriented company management and steering parameters

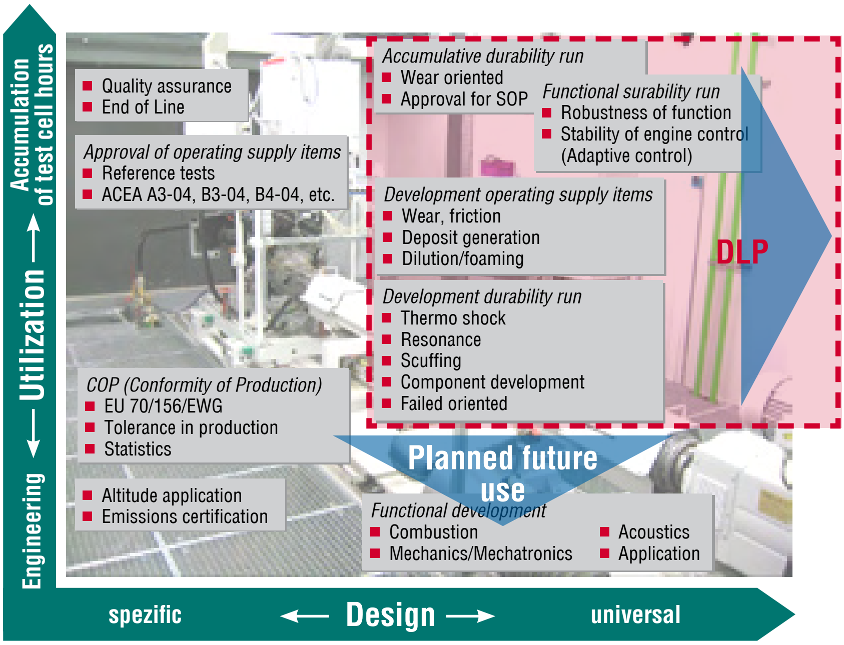


Figure 2: Strategic positioning of the durability test center

a unit. Furthermore, precise CVS exhaust gas measuring technology is necessary.
The proportion of engineering during the tests, i.e. the supervision by qualified staff, such increases considerably. Test benches for functional development, i.e. the investigation and further development in the early developmental phase are characterized by the broadest design spectrum. While acoustics test benches are rather specific due to the permanently installed sound absorbing paneling, test benches for the development of mechanics,combustion or for application are rather universally built. However, they are equipped with removable very specific measuring technology, e.g. for the measuring of exhaust gas components and internal cylinder pressures or with special software and methodology for online data input of engine maps.

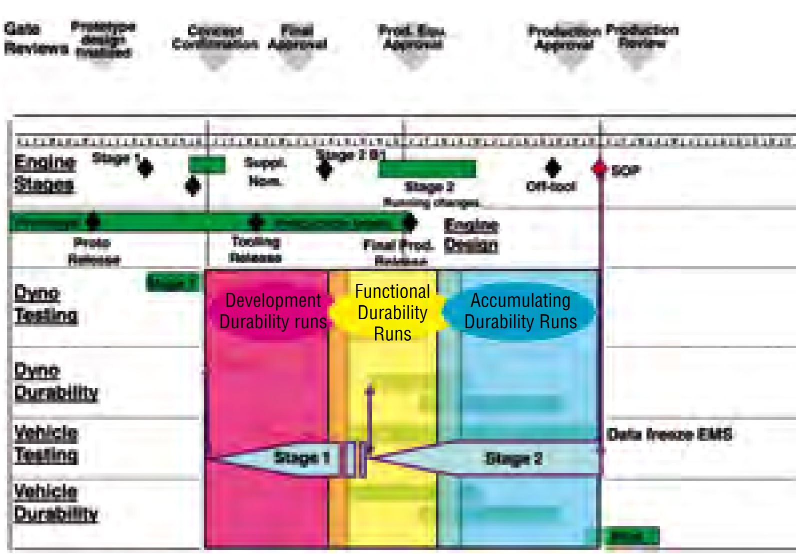


Figure 3: Development timeline and phases of durability testing

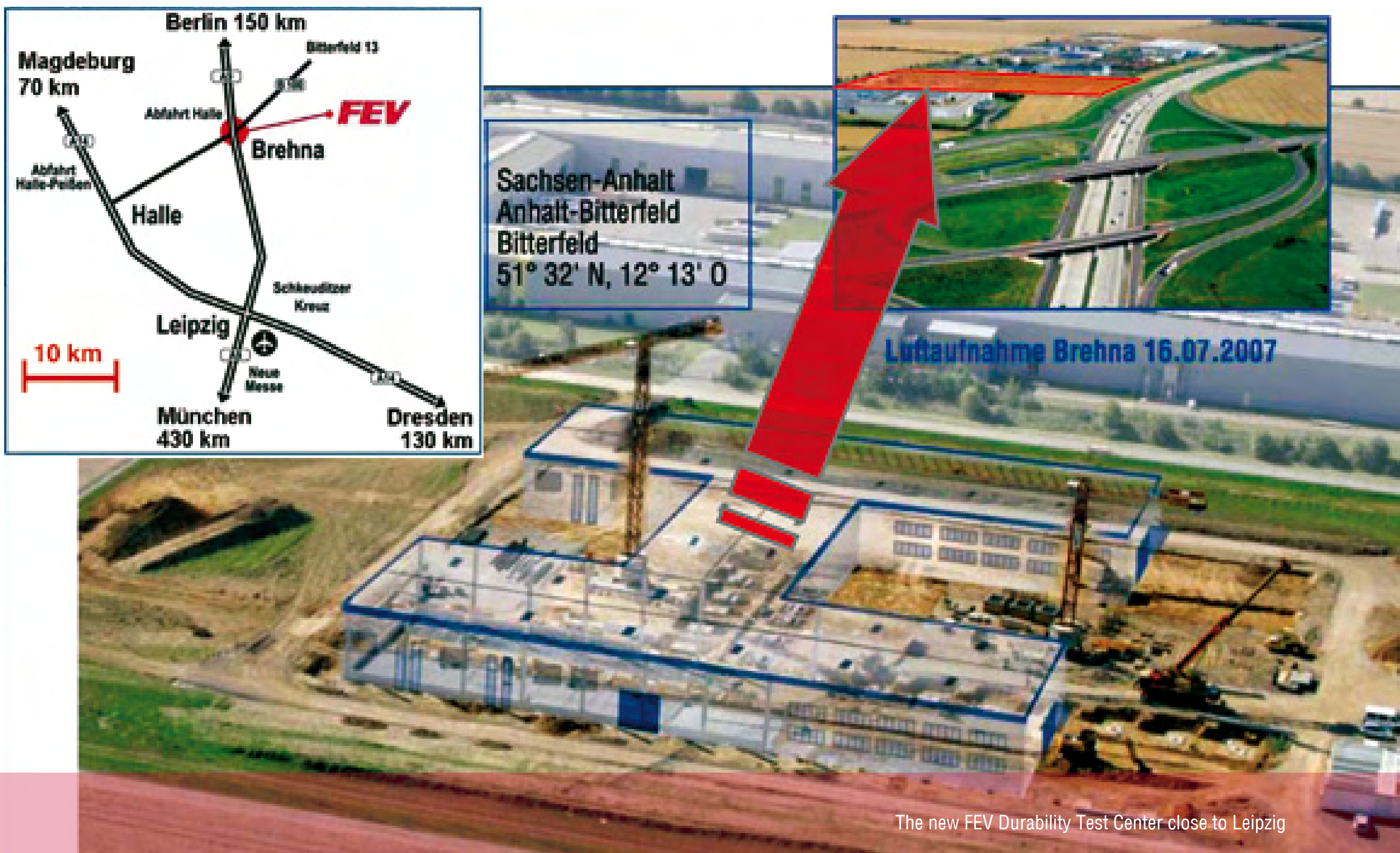
In contrast to the described test bench types, the durability test bench can be defined as rather universal with a focus on the accumulation of running hours. The FEV distinguishes between three different durability phases (**Figure 3**). In the phase up to approximately ten months before SOP (accumulated durability test), mainly wear-oriented test runs and release runs are performed. In the previous phase, the functional durability test (approx. eight months), mainly the robustness of the engine functions and the stability of adaptive controls are verified. From about 16 to 24 months before SOP (development durability test) failure-oriented investigations like thermal shock tests, resonance durability tests and tests with a focus on individual components are carried out. For the permanent equipment of a test bench, higher tolerances of media conditioning in the single-digit degree range are permissible.

Regarding the positioning of its new test facility at the Brehna site, FEV has focused on covering these phases of durability testing in terms of optimized capital expenditure and efficient test contract performance. However, comprehensive development testing is also possible at the Brehna site with the corresponding measuring technology, e.g. for exhaust gas concentrations (five components) or pressure indication in the cylinder, to accommodate for the requirement of long term and variable usage.

Equally future trends in the testing of power train components have been considered in the choice of the relevant testing technology and its adequate dimensioning:

– dynamic test cycles with simulation of gear changes, increasingly modeled on road tests
– setup of vehicle-oriented exhaust systems including after treatment
– integrated testing of engine-gear-power train assemblies.

FEV therefore has access to one of the most modern and efficient test facilities for engine and power train testing, and emphasizes its competence for the performance of comprehensive durability testing programs under client contracts on its own responsibility as a reliable volume production development partner. ■



The new FEV Durability Test Center close to Leipzig

Choice of Location

Brehna in Saxony-Anhalt in the region Leipzig/Halle was chosen as the location for the new durability test center of the FEV group.

1 Operational Criteria

Before the location was chosen, FEV performed a variety of investigations. To achieve a regional localization, the main criteria for various domestic and foreign locations were examined first, **Figure**:

- cost
  - personnel (current levels and future salary trends)
  - knowhow accumulation and safeguarding
  - operating and incidental costs
  - investment
  - site related residual value of the property after useful life
- quality of project execution
  - employee qualification
  - educational qualifications/proximity to universities
  - availability of resources and consumables
- logistics
  - accessibility (travel time) from the FEV headquarters in Aachen as well as to the client's sites
- air connection times/frequency
- highway connection and quality
- entrepreneurial risk
  - stability of legal conditions
  - compliance with time schedule
  - employee recruitment, availability.

Due to the high importance of the logistics the decision for the location Germany or the neighboring countries was apparent. It also became clear, that the theoretical costs of countries with low labor costs regarding personnel are balanced by a constant and high investment for the infrastructure. If one considers additional efforts for the ramp up of the facilities, the knowhow accumulation and its safeguarding at the location as well as the logistics, a location in the new German states is highly attractive. With the goal of a high facility availability and a highly efficienttesting process for durability testing of power train components, the latitudes regarding organizational layout have specific significance when it comes to the construction at a new location.

Further benefits as e.g. the stability of legal conditions and finally also investment incentives resulted in the decision for a location in the region Leipzig/Halle.

2 Criteria for Suitable Industrial Areas

The search for suitable industrial areas requires the evaluation of further criteria:

– layout and size for later capacity expansions
– transport connections
– approval guidelines, practical approach of the local government agencies as well as time and personnel investment to approval (local building authority, water authority, environmental agency, commercial regulatory authority, wastewater cooperative)
– connection capacities for supply and disposal (fresh water/waster water, electricity, gas, telecommunications, waste disposal, recycling)
– quality and type of soil.

A suitable area was found in the industrial area Carlsfeld of the city of Brehna near Leipzig (**Title Image**).

In particular the approving authorities of the chosen district demonstrated excellent cooperation and speedy processing with the aid of the "authority conference". Hence the approval period was reduced to in total approximately five weeks after submission of the application papers, an extremely short period in comparison with other German districts. The airport Leipzig/Halle is the main hub for renowned logistics companies apart from having an excellent location relative to the site, and offers the possibility of night flights for goods transport. ■

The Autor

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Analysis of different locations:

- German (south, west, east)
- Eastern Europe (Poland, Czech Republic)

Selection criteria:

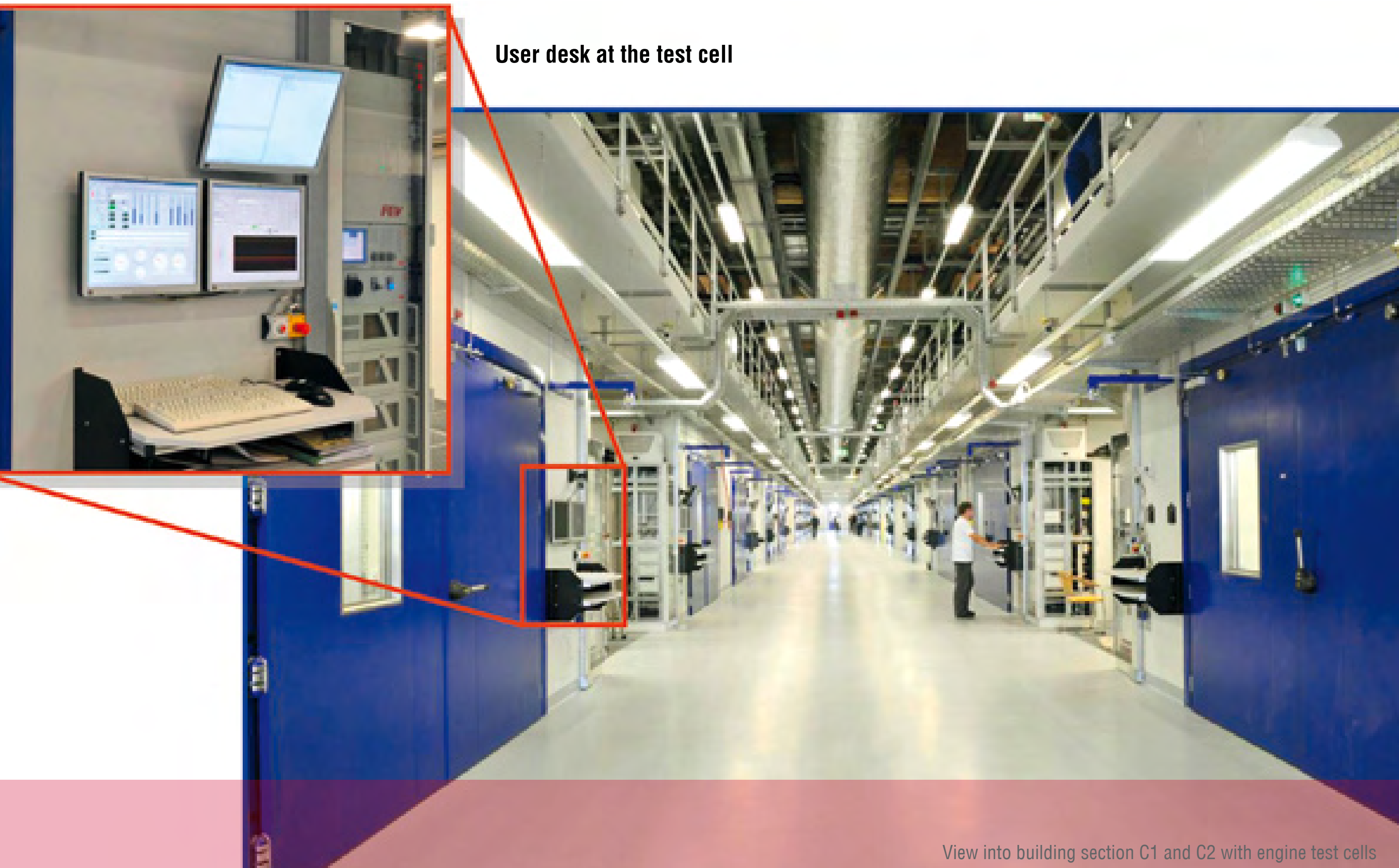
	Theor. Potential for costs*	Quality*	Logistics	Risk
G-South	–	+	+	+
G-West	O	++**	+	+
G-NEFS***	+	+	+	+
East. Eur.	+++	–	O	–

* also operating supply items (fuel)
** On Demand Access tof FEV-Facilities/AC
*** NEFS: New Eastern Federal States

1) incl. costs for development and securing of know-How

	Personnel costs	Investment/ Amortization	Overall costs 1)	Additional costs for Ramp-Up
G-South	110	100	104	O
G-West	100	100	100	O
G-NEFS***	85	100	92	O
East. Eur.	50	100	88	–

Figure: Main criteria for location decision and rating matrix



User desk at the test cell

View into building section C1 and C2 with engine test cells

Facility Design

A total of 31 test benches of various categories and services were installed in the new FEV Durability Test Center to cover the continuous, average order work load. The various test rig types are explained in the following chapters.

1 Capacity Planning

To determine the test facility capacities the yearly testing program collective of classical testing of fired engines, motored tests and complete power train tests was drawn upon, which has to be covered by the first construction phase (**Figure 1**).
Through the addition of details for the test bench preparation, the actual testing time plus the necessary secondary times for running in, acceptance measurements, regular measurements, equipment under test service and so on, the maintenance requirements for the testing technology as well as the estimated additional efforts for the trouble shooting of equipment under test in early development phases, a gross test bench utilization time can be calculated for every test run type.
Multiplication with the number of equipment under test to be examined per year yields the total test bench utilization time per test run type.

For optimally tied up capital the test benches normally should be graded according to their measurement performance. Therefore the total test bench utilization time per test run type has to be distributed on different object types. The object types can be defined by for example the engine range to be tested, or in case of a complete power train the vehicle range.

With the help of this capacity planning a total of 31 test benches of various categories and performance were defined for the new FEV Durability Test Center to cover the continuous average contract work load. The various test bench types will be explained in the following.

2 Basic Data and Building Concept

The new facility has been built on a plot with an area of 60,000 m².
During the first construction phase a building with approx. 9,000 m² floor space and 31 engine and power train test benches (Hall A1 first floor/second floor, A2, M first floor/second floor, C1 and C2) has been erected (**Figure 2**).

The layout as well as the orientation of the first construction phase have been optimized for a later gradual expansion. With the available free area, capacity for more than 100 test benches can be created by adding several wings or a completely separate new development (DLP II). The technical area for the media supply including the bypass road for service and delivery vehicles could then be commonly used as a central technical area. The offices

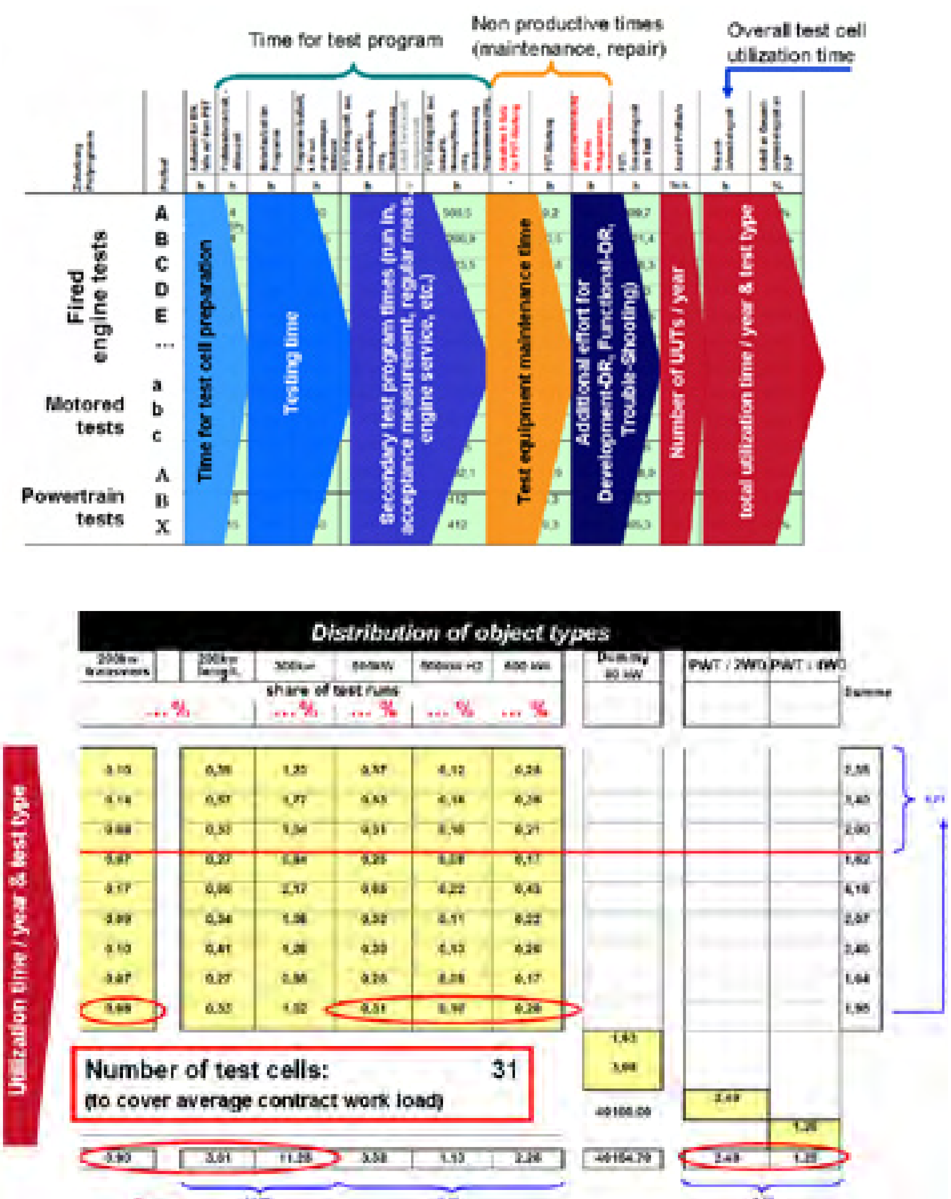
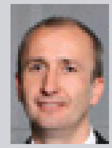


Figure 1: Capacity planning based on testing demand, test types and test objects

The Authors



Dr.-Ing. Stefan Trampert
is Senior Project Manager at FEV Motorentechnik GmbH in Aachen and Managing Director of FEV Dauerlaufprüfzentrum GmbH in Brehna and had overall responsibility for the ready-to-use erection of the DLP.

Philipp Kley
is General Manager Project & Procurement of the technical division Test Systems at FEV Motorentechnik GmbH in Aachen and was responsible for the turnkey erection of the technical infrastructure of the DLP.

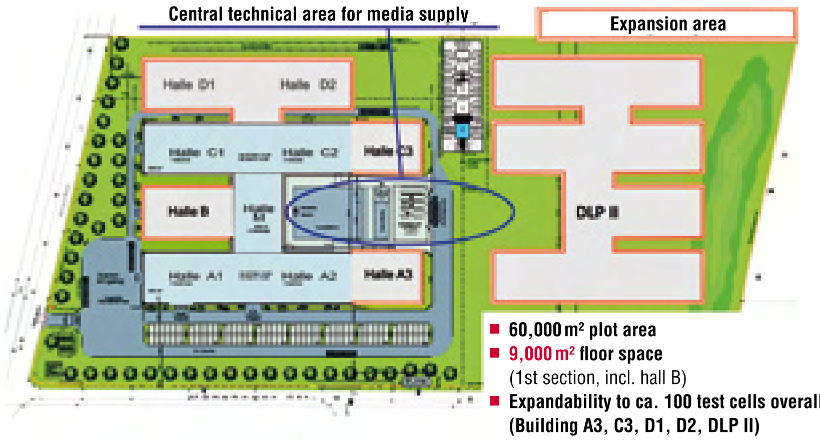


Figure 2: Plan of site and expansion area

and conference rooms are situated in hall A1 on the upper floor and are easily and directly accessible from the entrance of the premises.

The internal layout of the test facility is shown in the functional diagram in **Figure 3**. In building parts C1 and C2 (Figure 3 above), 22 engine test benches with a shaft and measuring performance of 200 kW to 600 kW have been accommodated. Amongst them are special test benches for climate (green) and thermal shock tests (yellow). Between the engine test benches, which are mostly arranged in pairs, there are so-called multifunctional technical rooms for the automation, the exhaust gas measuring equipment, the connections for the central media supply and additional conditioning units (**Figure 4**).If necessary, it will be possible to position complete vehicles in the technical rooms for the supply of the equipment under test to mate with real bus topologies.

In building part A2 there are four power train test benches and five motored test benches. All test benches will exclusively be supplied from the center aisle, the feed corridor. Due to the positioning as durability test facility as well as for optimally tied up capital, the installation of an operating corridor was explicitly omitted. In case of a continuous and test bench-oriented supervision the multifunctional technical room serves as a test bench-oriented operating corridor.

All rooms for preparation and support of the test runs, e.g. reception/shipping of goods, mechanical and electrical workshops, measuring laboratory, storage rooms for pallets and exhaust gas systems, a room for engine disassembly and analysis and the open engine setup area with pre-test area (**Figure 5**) as well as central technical and lunch rooms, are situated in the so-called service area in building part A1.

Apart from generous storage areas for set-up and ready to test, tested or temporarily stored equipment under test, the building part M contains an oil and fuel storage, an additional mechanical and electrical workshop for shift operation as well as the control room, which is the core of the complete facility. The concept of the control room as well as the complete operations flow are described in chapter 4 in more detail.

3 Test Benches

The consideration of future trends of the power train testing influences the test bench design. Therefore, apart from the asynchronous dynos in the total power train test rigs, the DLP concept exclusively uses asynchronous dynos as loading units.

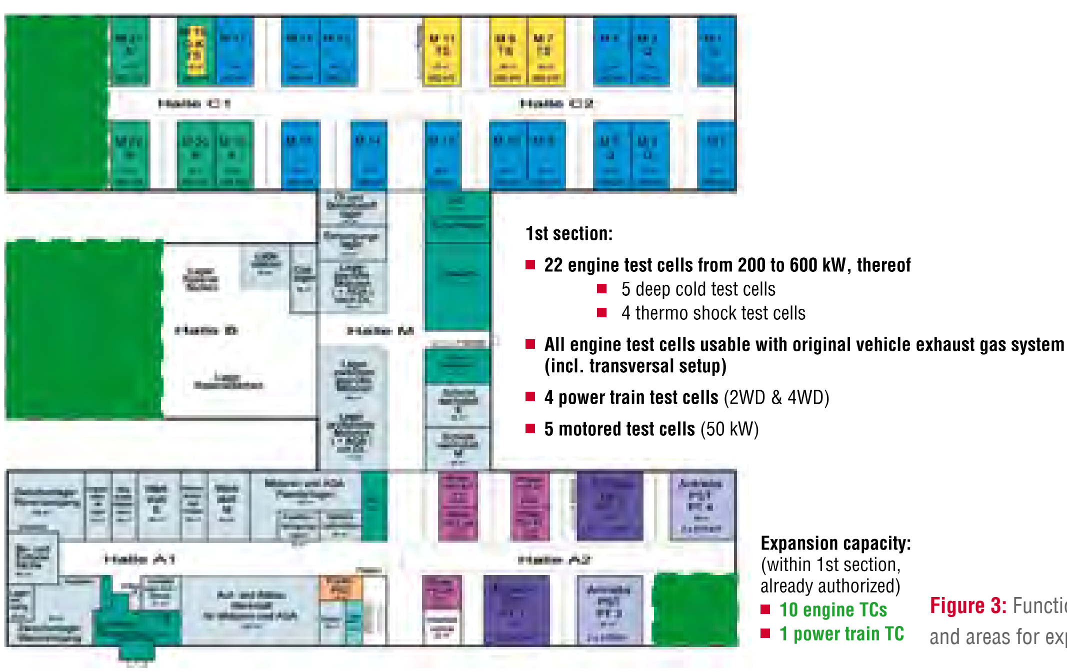


Figure 3: Functional plan of ground floor area and areas for expansions within 1st section

Figure 4: Multi functional technical area between each two test cells – here shown with mobile systems for coolant conditioning and thermo shock

Figure 5: Openly arranged engine preparation area with test cell for pre testing

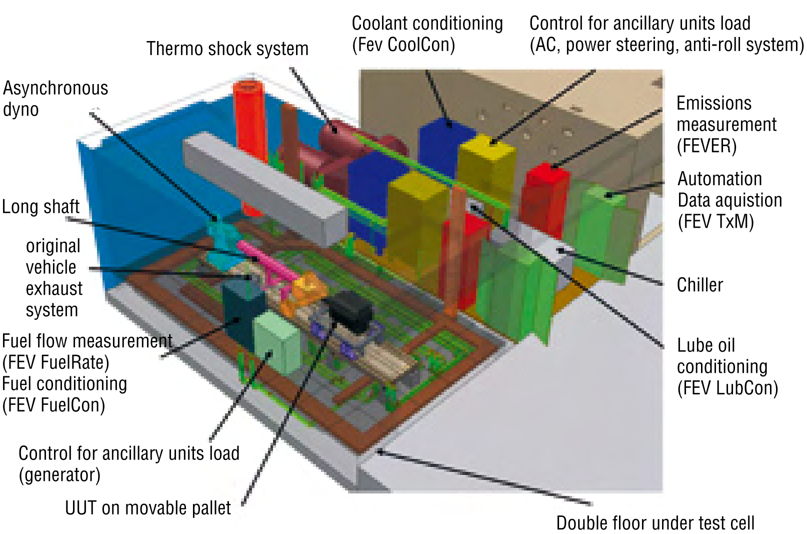


Figure 6: Test cell setup with theoretical maximum equipment

The increasing complexity of power trains and test cycles requires increasingly sophisticated measurement, load and conditioning units which have to be positioned according to demand and close to the equipment under test. Further, sufficient space has to be designated for the setup of the original and unmodified vehicle exhaust system (**Figure 6**).

The engine test cells in the DLP therefore have generous dimensions of 5x9m. The test cell for engine, power train (9x9m) and motored test rigs (5x4.5m) have been built with ready-mix concrete modules in filigree construction (**Figure 7**). This guarantees expeditious erection on the one hand, and on the other hand the soundproof setup of the test cell through additional filling of the spaces with liquid concrete. This results in an extremely moderate sound level in the test bench hall.

For the provision of the installation space for the unmodified vehicle exhaust system an alternative positioning of the asynchronous machine is required. After thorough examination of several concepts based mostly on the usage of gears with various configuration and principles, FEV decided explicitly to employ the concept of a long test bench shaft with simultaneous positioning of the asynchronous dyno at the opposite face of the cell (Figure 4). The advantage of the long shaft is the unlimited dynamic capacity due to the play free design. Further, with respective dimensioning the design is virtually maintenance and supply-free. Dynamic simulations were performed for various combinations of combustion engine, test bench shaft, measuring flanges and asynchronous rotor to achieve a sufficient shaft life time (**Figure 8**). The simulation results were used for the dimensioning of the shaft, its homocinetic joints as well as the dimensioning of the highly rotation flexible decoupled element regarding stiffness and necessary damping as well as damping performance. The latter ensures an operation beyond critical eigenfrequencies in the operating speed range for all possible combinations. Two different shaft types as well as three different decoupling elements are used in the DLP due to the performance spread of the test benches. Figure 6 shows the basic dynamic simulation model as well as the low rotary oscillation amplitudes at the shaft input and damping performances over 600/min as an example. The total shaft train including the connection to the dyno rotor can be used up to speeds of 8,500/min (depending on the combination).

Permanent test equipment to cover standard test runs, which is installed at each test bench, includes (apart from the shaft system and the additional mechanical and electrical installations) the fuel conditioning close to the engine and the fuel measuring device (FuelCon and FuelRate), a cooling module close to the engine to supply the equipment under test with cooled engine coolant, an intake air temperature control in form of cooled air ventilation as well as a generator loading device. The proximity to the equipment under test in the case of the cooling module provides boundary conditions that are similar to a vehicle as well as a short control path for the fuel conditioning for precise control.

The test bench automation is situated in the technical room directly at the test bench. The test bench can be operated from a compact operator panel next to the feed door e. g. for commissioning of the equipment under test or problem solving, **title image**, whereas the primary control and the monitoring of the test bench are performed in a test facility control room.

Additional requirements regarding the further media conditioning as e. g. active and rapid heating/cooling, provision of media (coolant, oil) with low temperature (also < 0 °C), intake air heating, further auxiliary unit loads etc. are covered by mobile systems at the respective existing und uniformly designed media interfaces in the test bench or in the multifunctional technical rooms between the test benches.

The **table** lists the test rig types realized in the first building phase. **Figure 9** shows an engine test bench in longitudinal and transversal setup with the permanently installed test bench devices.

Figure 10 yields an insight in one of the climate test cells that are used tosimulate the engine operation under winterly conditions. These test benches

Figure 7: Test cell construction with concrete modules

Simulation model

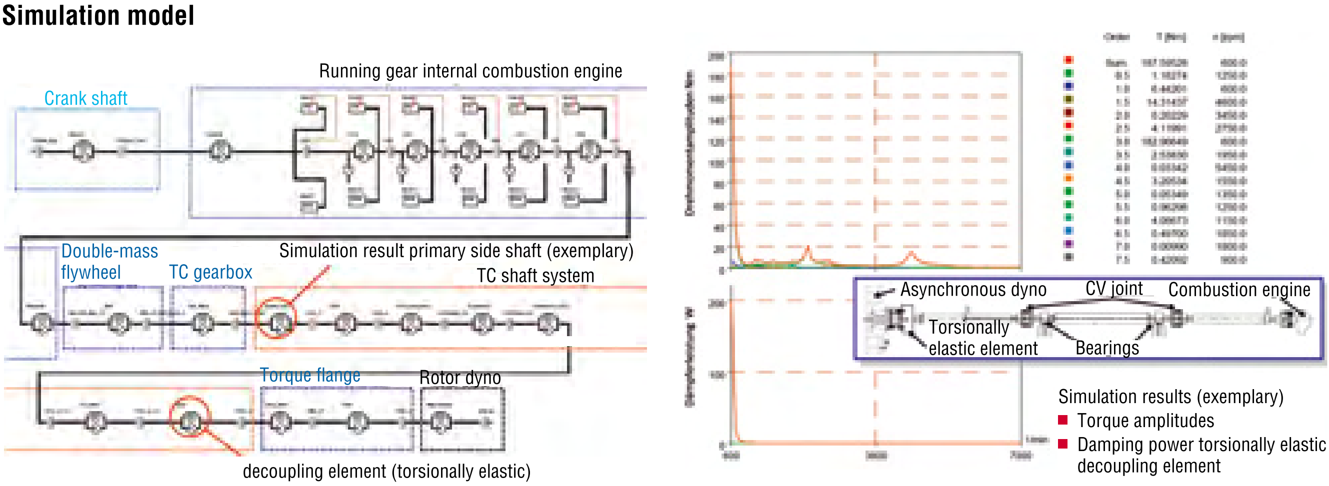


Figure 8: Dynamic simulation for dimensioning of long TC shaft

Table: Overview of test cell functions and power

Type	Test cell description	Dimension of TC	Functions	Nominal cell power	Dyno power	Amount
		m		kW	kW	
A	Durability TC	9 x 9	Transversal setup; thermo shock, deep cold	200	200	1
B			Longitud. setup, deep cold	300	300	2
C			Longitud. setup, deep cold	600	600	2
D			Longitud. setup, deep cold	300	300	2
E			Transversal setup	200	200	2
F			Transversal setup	200	200	2
G			Longitudinal setup	300	300	2
H			Longitudinal setup	300	300	5
I			Longitudinal setup	500	500	2
J			Longitudinal setup; thermo shock	800	800	1
K			Longitudinal setup	600	600	1
L	Motored TC	5 x 4.5		0	50	5
M	Power train TC (2WD)	9 x 9		800	2 x 315	2
N	Power train TC (4WD)			800	4 x 315	2
	Sum			10100	11730	31

TC = test cell

are typically used to run low load profiles at constant temperatures considerably less than 0 °C in the close environment of the equipment under test. On these test benches special conditioning and measurement units that are suited for these environmental conditions and an insulation shell that is heated from the rear are employed.

Figure 11 shows the building area A2 with the motored test benches. These test benches are used to test mechatronical engine components as for example variable oil pumps, valve and control gears as well as auxiliary unit drives regarding their function and durability. Due to the partially oil contaminated environment of the equipment under test, these test rigs require also a special test bench ventilation.

Figure 12 and **Figure 13** each show one of the four total power train test benches. In addition to the standard pallet setup, support racks for the rear axle support with rear axle gear on the vehicle side are used which can be complimented by shift and clutch robotics if required. The selection of an automatic gear via CAN communication is alsoguaranteed. FEV's four machine control provides a precise and dynamic dyno control.

4 Test Facility Control Room

ZA fully continuous operating mode is indispensable for the intensive use of the test facility capacities, in particular when a moderate portion of engineering during trial is targeted. Only this way the investments can be allocated to high utilization times and result in low hourly rates. The DLP has realized a fully continuous operating mode of 24 h per day on 365 days a year from the beginning.

A fully continuous operation also means that the individual test runs must be attended to without exceptions by the changing personnel working in shift operation. A lean business organization in the complex environment of an engine and power train test facility therefore must rely on clearly laid-out and unambiguous leadership and information management. An efficient test operation requires:

- a fast regular information exchange on the status of the equipment under test
- a fast decision making should problems occur
- a continuous information flow through the shift changes
- a high flexibility regarding the case work of the individual test runs
- an efficient handover at shift change.

To safeguard an efficient test operation, the DLP is equipped with a test facility control room for the centralization of control and supervision functions of the test facility. The test facility control room also serves as the communication and information center of the durability operation of the DLP It includes several operator's stands as well as a control station (**Figure 14**).

The information systems of the control station in the control room are the decision basis for the diverse activities in the test facility. The control station is used for the basic supervision and the drive of all central functions of the test facility as the technical media supply, ventilation and air conditioning (HVAC), the fire alarm and extinguisher system as well as the test benches themselves (**Figure 15**).

The operating concept requires that the responsible control room operator acknowledges the error messages of the HVAC arriving at the WinCC operator station and reports them to the respective facility manager for correction. The control station also allows active intervention in the HVAC control.

The control station operator is also supplied with an overview over the test benches. The most important information on test benches, equipment under test and test run are shown on the

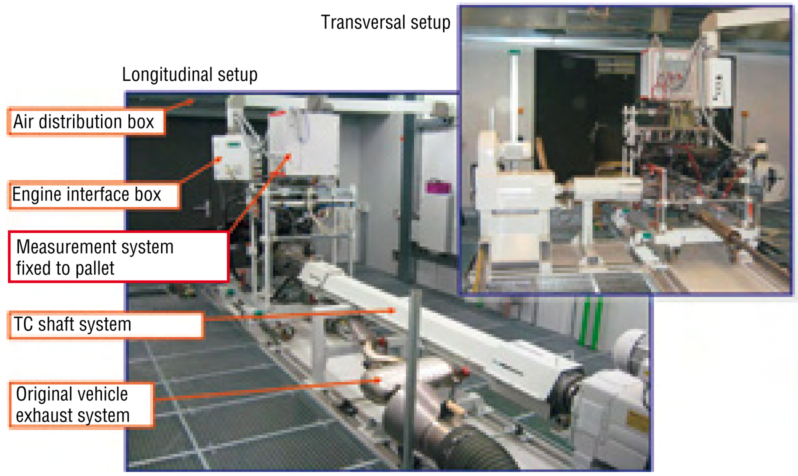


Figure 9: View into test cell with longitudinal and transversal setup

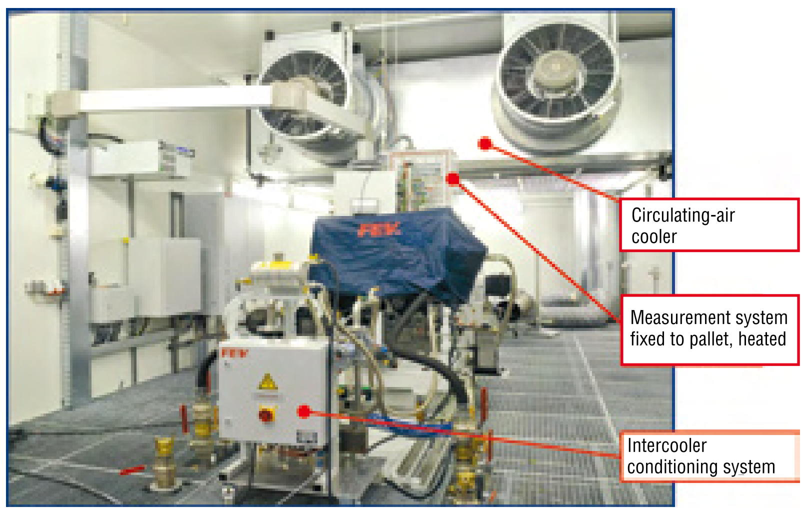


Figure 10: View into deep cold test cell for the simulation of low load driving profiles at winter weather conditions

Figure 11: Motored engine test cell area in building section A2

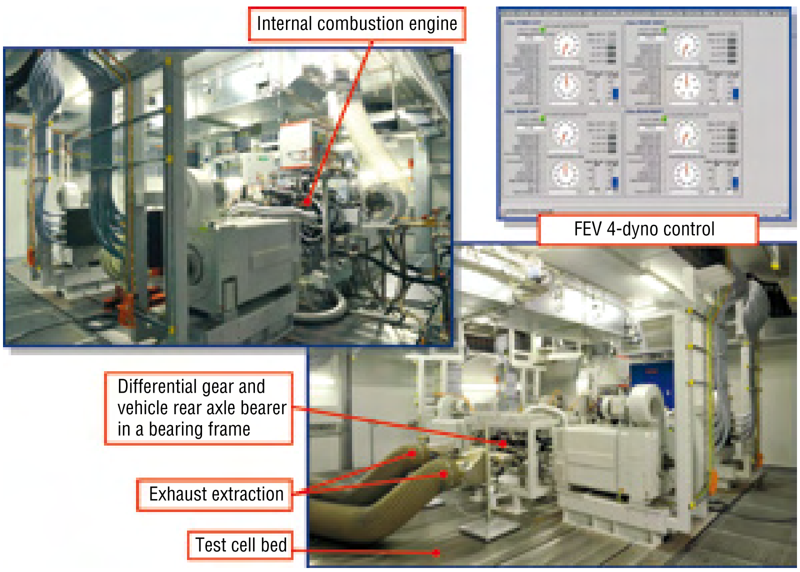


Figure 12: Power train test cell with transmission system components of a four-wheel-drive vehicle

Figure 13: Power train test cell – here with transmission system components of a two-wheel-drive vehicle

screens of the FEV TestFieldManagers (TFM) and monitored. The control station operator forwards incoming error messages, e. g. exceeding of alarm limits or emergency stops to the test bench engineer at the adjacent operator's stand. The test bench engineer then can make further decisions about the test run and its parameterization (case work) based on the analysis of the information on test bench automation, measurementdata collection, the data from theengine control module as well as video and audio transmission (Figure 9). The aforementioned flexibility is achieved through accessing each test bench of the DLP on each operator's stand. The operator's stand allows full access to FEV TestCellManager (TCM), TestObjectManager (TOM) and TestEnvironmentManager (TEM).
The operating concept requires that the test bench engineers with their team of test bench technicians and mechanics only visit the test bench for commissioning of durability tests or trouble shooting.
The control station operator can shut off the test benches in emergencies. However, he is intentionally relieved from the control and the detailed analysis of the individual test runs as well as the reporting. The acknowledgement of the incoming messages at the control station as well as each further action requires the personal login of the responsible control station operator of the respective shift. This leads to the required transparency regarding decision paths and reasons.

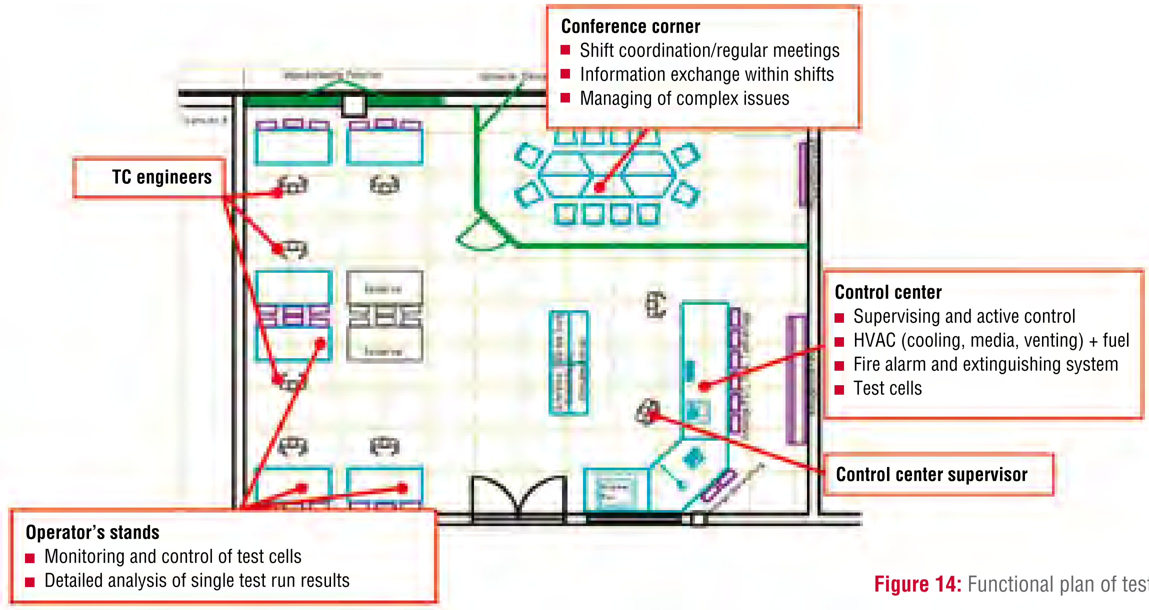


Figure 14: Functional plan of test facility control room

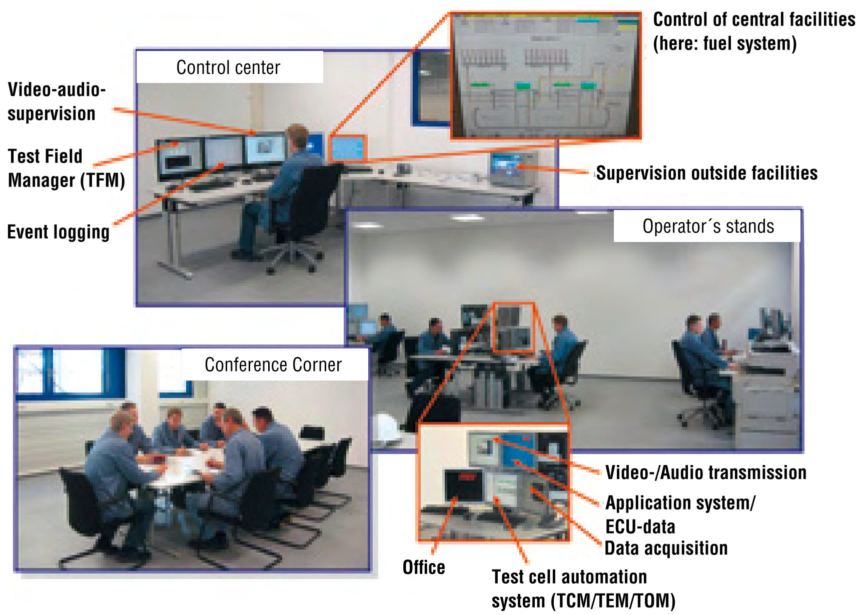


Figure 15: Test facility control room with control center and operator's stands plus communication area

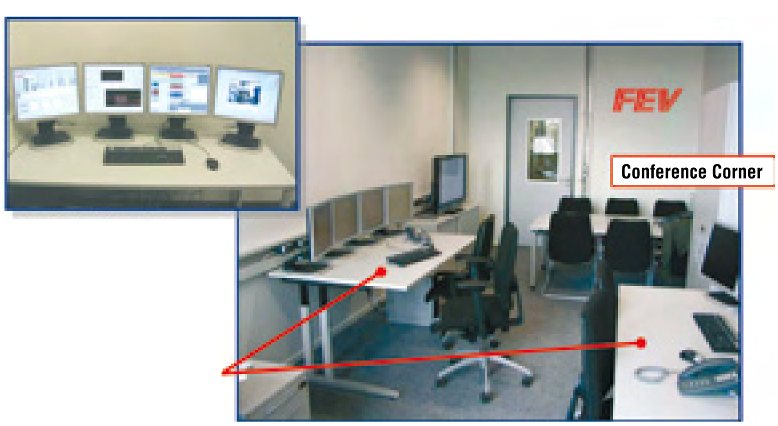


Figure 16: Virtual control center at a FEV customer's site respectively at FEV in Aachen to follow up test runs after electronic granting of access

If required, FEV offers the setup of a so-called virtual control room at the development site of the client, so that the client is granted insight into the ongoing operation of his test bench. The setup of the virtual control room corresponds to that of an individual operator's stand (**Figure 16**). This allows tracking of the control and measurement data as well as the audio and video data and provides optimized information and communication mechanisms at the interface to FEV's client.

For safety reasons remote control of the test bench is not permissible. It is understood that the exchange over the virtual control room is only activated after the electronic clearing of the respective test bench and according to the strict rules of the information security management systems (ISMS) to honor confidentiality agreements. ■

The Project and its Management

The continuous application of the mentioned project control methods allowed the realization of "project DLP" meeting main and intermediate deadlines including commissioning and ramp-up according to schedule. The total infrastructure of the DLP war erected with a cost deviation of less than 2%.

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1 Introduction

The construction of the infrastructure of the new durability test center with 31 test benches as well as the organizational, process-oriented concept of the new subsidiary has strategic importance for FEV in many regards.
The control of a project of this scope and its multitude of extremely complex interface relations required a correspondingly careful selection und structuring of the planning team. In August 2006 the project center DLP was founded which under the direct supervision and support of the management team of the FEV Motorentechnik as well as the total project management of the DLP in the subprojects infrastructure construction, process development, durability test operation and personnel ramp-up (**Figure 1**) was tasked with the formation of the new "business DLP".

A total of approximately 70 employees of FEV and external supporting planners were involved with the concept and planning of the DLP. The sole planning of the infrastructure required the contribution of 50 employees. The project success war secured by consistent application of process management methods and instruments. This included defined information pathways and communication laws. The project management activities comprehended the essential project control tools for the time schedule, cost and performance evaluation as well as the quality management and the risk evaluation.
The reporting of the project status for example was supported by FEV's normal project evaluation sheets, which account for the periodic rating of technical criteria as well as time schedule and financial status regarding contracted work groups. Measures

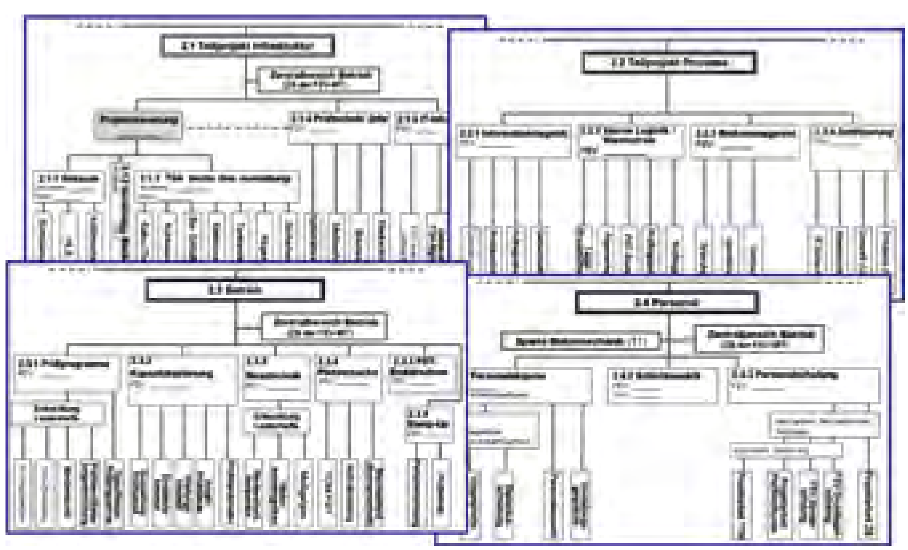

Figure 1: Macro-structure of the DLP planning team with sub-projects for the formation of the enterprise

for correction or alternative plans were created and realized under critical evaluation.

A consulting team consisting of the technical divisions and central functions of FEV Motorentechnik was assigned to almost all subprojects. Hence these groups contributed with their comprehensive experience from test facility operations and product development.

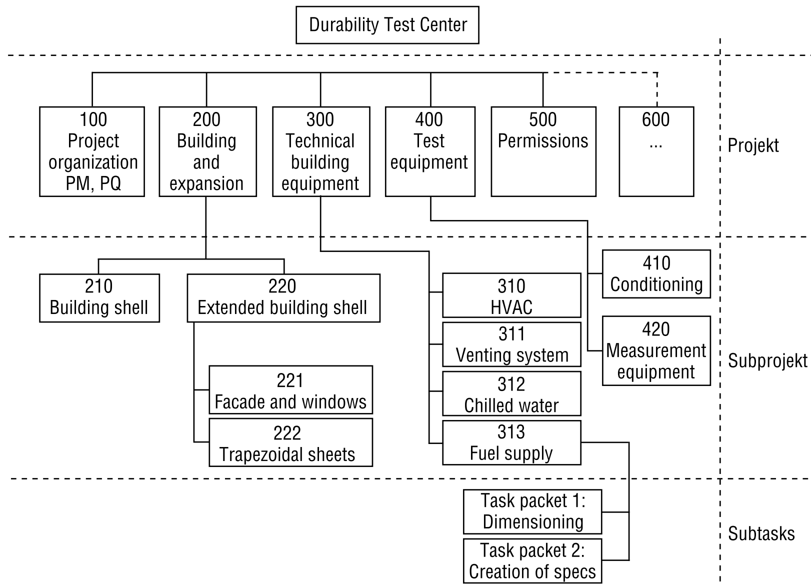

Figure 2: Selection of the project structure plan for the sub-project "Infrastructure"

2 The Subproject Infrastructure

The project organization was built upon a structural project plan. The structural project plan yields a high transparency of the individual processes. A breakdown according to DIN 276, which is used for cost control, guarantees a uniform structure and nomenclature. Therefore the subproject infrastructure was divided into further subprojects. These subprojects were again split into subtasks. From these subtasks the work packages can be derived which are assigned to the individual work groups of the project team. **Figure 2** shows an example representation of the principal layout of the structural project plan.

The structural project plan serves further as an input parameter for the time schedule and resource planning, for identification of critical work packages, for the interface and risk analysis.

3 Cost Control

A continuous cost monitoring and cost control is indispensable for projects of this size. The cost control known from building construction according to DIN 276 can be well used in modified form for test bench projects. It is helpful, to define individual groups according to the different contracted work packages to be given out. The distribution chosen in this project is exemplarily shown in **Figure 3**. A cost estimate is established for each cost type at the start of the project. This estimate is calculated based on empirical values or contract awards from past projects. In consideration of the planned contract award packages and the resulting necessary reposting a budget estimate is calculated for each cost type. A first correction of these budget estimates is performed with the award of the respective contracted work package and will be continuously modified during the project duration.

4 Time Scheduling

The project execution was completed in the extremely short period from October 1, 2006, to December 31, 2008. In a first sub-breakdown the blocks planning, realization and commissioning were chosen. The individual blocks were divided according to the necessary individual steps and assigned their respective time frames. It became quickly clear that a sequential execution of the individual points in a period of two years was not possible. In particular in the planning phase the work packages that allowed a parallel execution had to be identified and prioritized. To find the correct prioritization, they were differentiated by technical and practical aspects as well as the availability and delivery time of the individual components.

The deadlines were defined in reverse order to identify the available time periods. A first approach determined which contracted work package had to be available when ready for use. From this final deadline the periods for commissioning and installation were subtracted.

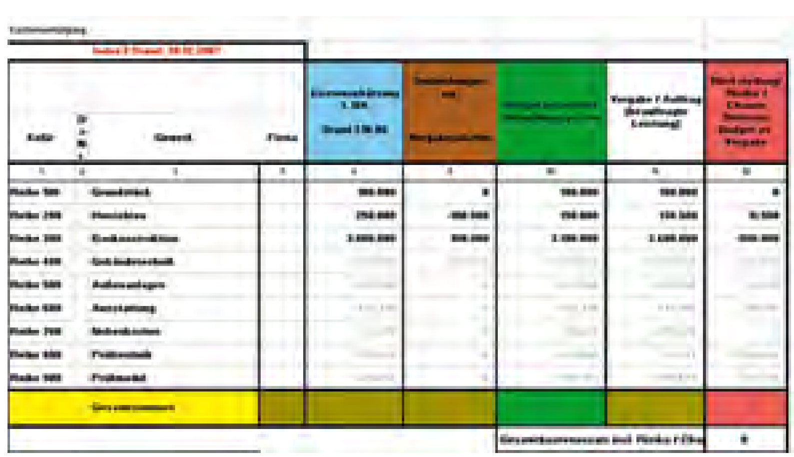

Figure 3: Cost control during the construction of the DLP infrastructure, following DIN 276

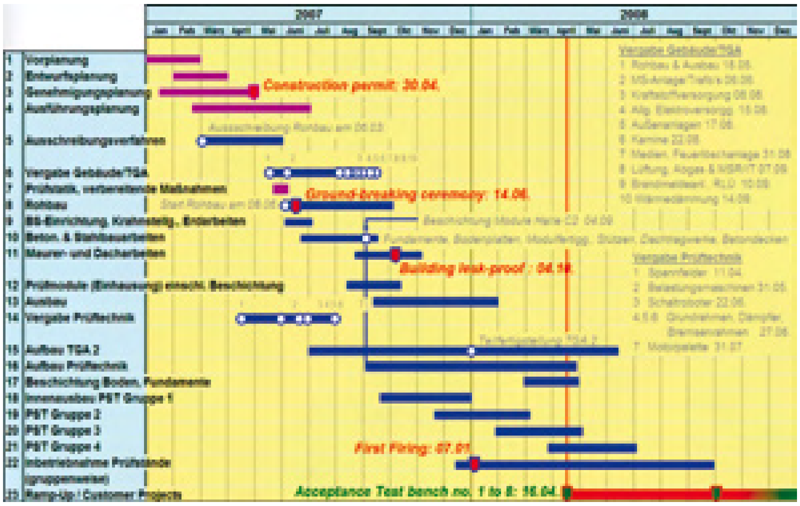

Figure 4: Macro timetable for the planning and ready-for-use construction of the DLP infrastructure

The deadline for the start of the work at the construction site can now be derived and must be considered when determining the deadline for the contract award (**Figure 4**).

For the contract award it was mandatory to have comparable offers from various companies. To receive comparable offers, specifications had to be created for the requirements of the individual contracted work packages determined during the planning phase. Specifications are the list of the deliverables under a contract to determine the contract scope and the required quality. It has proven helpful to specify a structure for the submission of tenders. This structure allows the systematic comparison of individual tenders. Usually ten tenders were solicited and analyzed in detail.

The successive award negotiations were usually led with three to four companies.

The basic procedure for the award of the individual contracted work packages can be summarized as follows:

- planning
- creation of specifications
- invitation to tender according to specifi cations on the market
- tender evaluation
- contract award.

From the necessary durations of the individual contracted work packages and their subsections a comprehensive project schedule was created, from which the necessary and possible parallelization of the steps can be concluded. E. g. the planning of the electricity supply from the medium voltage station to the low voltage main distribution in the building had to be started immediately. This was caused by a delivery time of more than six months for transformers.

5 Risk Management

For a successful execution of the project an active risk management is indispensable. If risk is seen as an unwanted event, which occurs with a certain probability und causes a damage of a certain scope, a risk analysis has to be performed with the subsequent risk control. The analysis itself is divided into the risk identification and its evaluation. The risk identification is performed on the basis of the structural project plan.

For each subproject and its subtasks difficulties with high risk and their potential causes are identified. The evaluation of the recognized risks follows from a monetary approach. Therefore, the costs are weighed by the occurrence probability. From these procedures, a ranking list of the evaluated risks can be established.

The possible measures for risk minimization are categorized into preventive and corrective measures. Preventive measures are best addressed in form of an active supplier management. Corrective measures have to be applied during the course of the project.

6 Supplier Management

Supplier management is mandatory for the adherence to the given time schedule and the available project budget. This starts with the choice of the contacted companies and contains the evaluation of the performance capacity as well as the support of the contractors. During a first step, an evaluation matrix was established for all companies that had bid for the individual contracted work packages. Criteria as e.g. turnover, number of employees, delivery spectrum, adherence to delivery dates, references and tender price were evaluated. At contract award it was contractually agreed that the supplier had to prepare a detailed schedule with verifiable intermediate deadlines and that FEV had the right to check the manufacturing progress at the supplier and their subcontractor's facilities. The goal was the establishing of a trusting partnership with the individual suppliers.This allows for the early recognition of arising problems and their cooperative solution.

The challenge of the project was the extremely tight timeline to 100% operational readiness and the accompanying clear overlapping of individual planning and erection phases. The strong overlapping demanded a strong interface management between all teams, suppliers and contracted work packages. With the aid of the consistent application of the mentioned project control methods the "project DLP" was realized on time regarding main and intermediate deadlines including commissioning and ramp-up. The total infrastructure of the DLP was erected with a cost deviation von less than 2%.

7 Commissioning

The main task of commissioning is to lead the facility to the contractually agreed durability test operation.

The following goals have to be achieved during commissioning:

- removal of errors and deficits from earlier phases
- optimization of the facility and control parameters
- verification of availability and functional capability
- verification of operational safety
- training and induction of the operational staff.

The successful and expeditious commissioning as the interface between construction and productive phase requires a corresponding coordination effort of the contracted work packages involved. It proceeds in several process-oriented phases (**Figure 5**) and according to the aspects of costs and time requirements. After the mechanical completion of the test bench and the technical media supply (phase 0) the systems are prepared and tested in phase for the initial operation (e.g. by flushing, cleaning, pressure and leak tests). In phase 2 functional tests of the mechanical, electrical and pneumatic systems (e.g. direction of rotation tests of the ventilation devices, the dyno engine, the actuator and valve drives) as well as I/O checks and plausibility tests of position feedback, measurement technology, monitoring and alarm systems. The communication with the test bench automation system and the master computer is tested.

In Phase 2 all interfaces between engine, engine pallet and the test bench are checked as well. This is the so-call "dry commissioning".

With completion of phase 2 ("dry functional qualification") all devices have been tested and approved with the help of the safety matrix. This safety matrix contains all necessary safety devices and their functions in the test bench. It describes the respective subsequent reactions in case of an alarm. Prerequisite for this safety matrix is a risk analysis with respective safety and risk investigations. Measurements according to the safety matrix e. g. for the detection of fires and hazardous substances:

- alerting personnel on site
- automatic closing of doors
- triggering of the automatic sprinkler
- increase of the ventilation rate
- shutoff of the test run and the fuel supply
- shutoff of the non-explosion-proof resources
- alerting the responsible station (fire brigade)

During the most complex phase 3, the first fired operation is performed on the test bench. Various dynamic test cycles are run and the loading device (asynchronous dyno, frequency converter, shaft system) as well as all conditioning units are tested regarding performance capacity and control quality and optimized through modification of the control parameters. The fuel dosage and conditioning unit as well as the functions according to the safety matrix are part of the tests. The last phase, the official acceptance serves as verification of the function according to the specifications and the capacity of the test technology.

Phase 3 began in Brehna with the first fired operation on January 7, 2008. During the first day several hours of full load and changing load could already be completed successfully. After completion of the acceptance runs the first group of eight test benches was ready for the productive phase (ramp-up). An area-wide separation of the central technology provided an a self-sufficient and largely independent operation of these test benches.

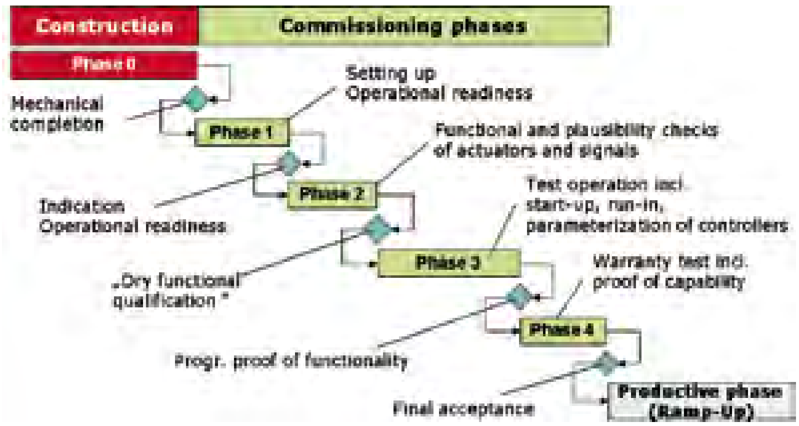

Figure 5: Commissioning phases as interface between construction and productive phase

8 Documentation

Apart from technical requirements, thorough documentation is essential to guarantee a high availability of the test facility. Parallel to the planning of the building a concept for the total documentation was established from the start (**Figure 6**).

Goals of the documentation concept are:

- compilation of the documents from planning and realization
- contracted work package-wide requirements for the documentation of the construction, central technology and test technology
- uniform setup and structure for the individual contract work packages
- summary of all records relevant for approval
- to create the foundation and means for the quality management of the ongoing operations.

Based on this concept an overall structure of the documentation was established and defined as a binding requirement for the executing contractors.

Therefore, close to the productive test start a detailed documentation of the overall facility was available to support the operation of the test benches, the main-

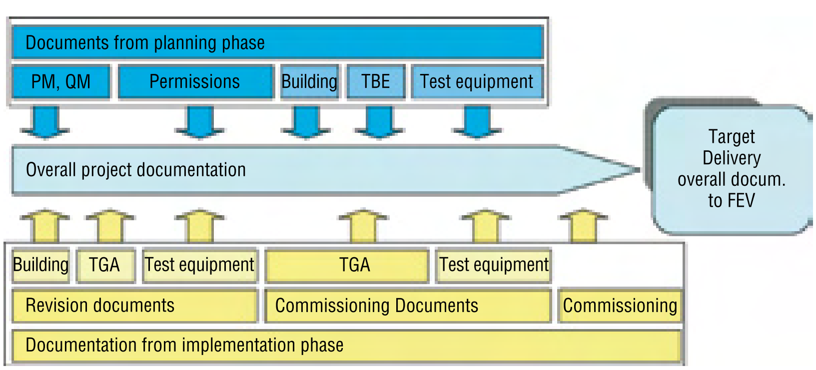

Figure 6: Concept for overall documentation of DLP

tenance and the repair teams. As an aid for the operations, the total documentation is available as HTML documents through the facility's intranet (**Figure 7**). Therefore it can be accessed online from each network socket and at almost every location inside the building. This guarantees efficient and quick information access in particular for questions arising on technical details during repair and maintenance of the facility, and supports the principle of autonomous repair implemented in the DLP. ■

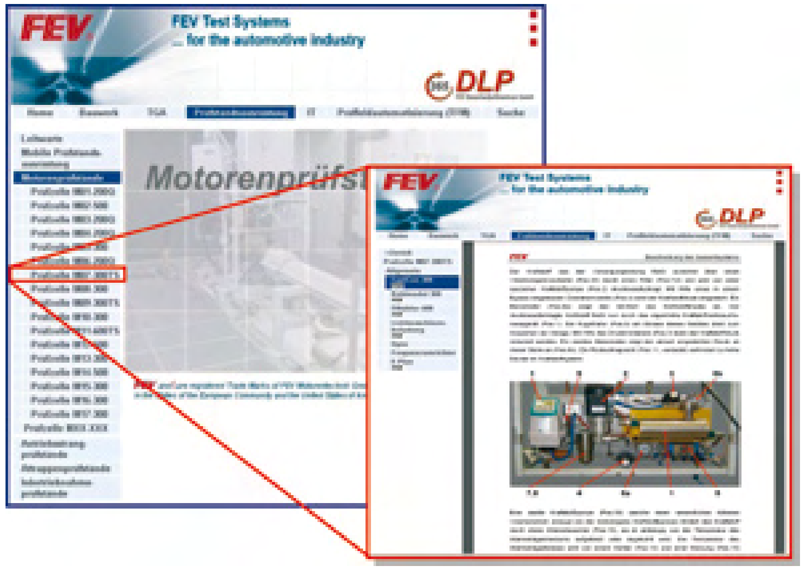

Figure 7: Overall documentation of building, technical equipment for building, and testing equipment in the DLP intranet – shown here for testing equipment/fuel conditioning

Development of Processes, Models and Tools for the DLP

Within the subproject "processes" and under the predominant guidance of the technical division Production Planning of FEV, the foundations for an efficient operating mode of the DLP were created by the planning and development of procedures.
This concerned not only the design of facilities for optimized goods logistics but also the information logistics.

1 Introduction

The active design and definition of processes in the DLP formed the basis for the certification of the durability test center according to DIN-ISO, which is planned for 2009. The DLP profited from the fortunate situation of freedom of planning at a new site to concentrate on a process-oriented design from the beginning.

The planning focused on the guarantee of a high customer satisfaction which shall be secured through the lean flow of the intermeshed processes.
Simultaneously, the process flow design and documentation focused on an integrated management system covering quality management, health, safety and environment. Another aspect of the process planning of the DLP that is very important for the profitability of the company is the cost-oriented focus of processes, which is well-known from various production management systems. The DLP defined all activities, that are not directly involved in value-adding, as non cost-oriented. Examples are wastages through transport and excessive stock keeping.
The preparation and definition of the individual processes were assigned to a team which addressed the process design during the complete planning, erection and commissioning period of the durability test center. The planning was performed from the top down with the focus on the client benefits.

In a first step of the flow design the business policy of the DLP was defined, which served as a consistent touchstone of the process steps subsequently

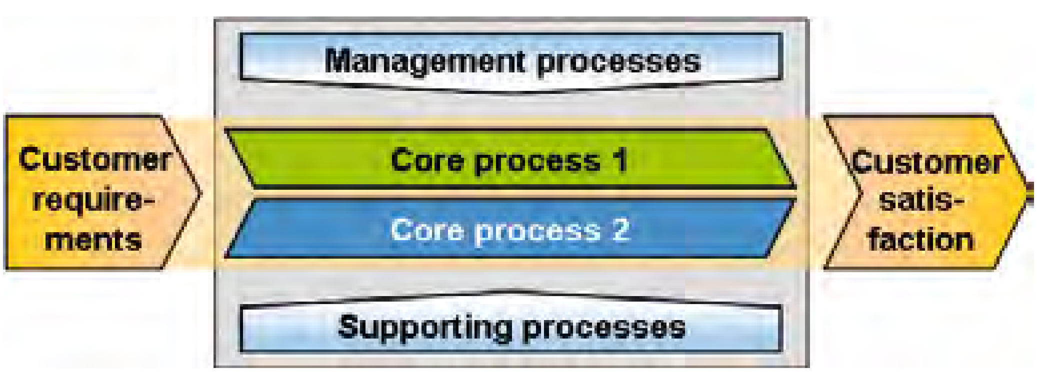

Figure 1: Structural model of enterprise processes

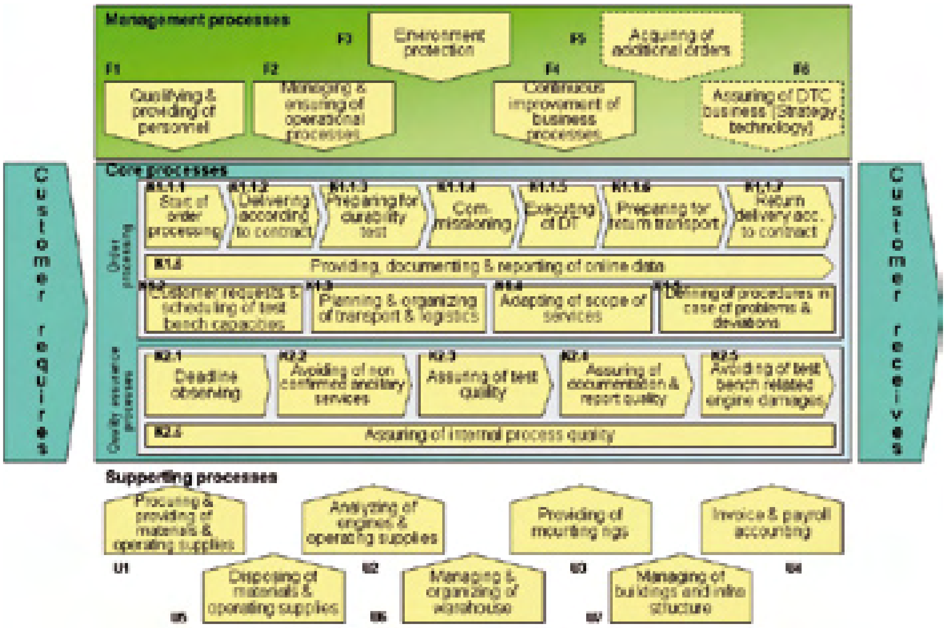

Figure 2: Enterprise process model of DLP

to be planned. The designed processes were questioned during several recursion loops regarding the business policy to achieve the optimal flow orientation for the start of the operations.

An excerpt from the definition of the DLP business policy:

- Outperformance of the client expectations
- Addressing of the individual needs and expectations of our clients
- Offering of economically attractive and technically innovative solutions
- Increasing the competitiveness of our clients
- Flexibility to adapt to changing markets.

2 General Layout and Structure of the Processes

In a second step of the planning phase a structural model of the super ordinate business processes was defined (**Figure 1**).

The processes were divided into three classical areas:

- management processes
- definition of business policy and goals
- supervision, guidance and controlling of the core and support processes
- core processes
- application of core competence and business-specific knowhow
- direct relation to the services of the company
- direct fulfillment of the client expectations
- support processes
- provision of resources for the execution of the core processes.

Apart from the core processes of the actual contract execution the quality assurance processes were also declared as core processes, since customer satisfaction is an important part of the processes of FEV (**Figure 2**). Another task was the detailed description of the individual processes. The input, the involved functional divisions, the functional steps and the associated information as well as the process output were considered. The process responsibilities were also defined. The complete knowhow of FEV regarding the delivery of services was utilized for the process description. Actual analyses within FEV Motorentechnik GmbH were performed, analyzed for weak points and an optimal flow was designed. This optimal flow was evaluated during several calibration rounds with process specialists from the automotive industry, and boundary and

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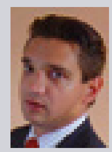

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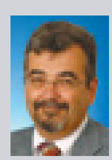

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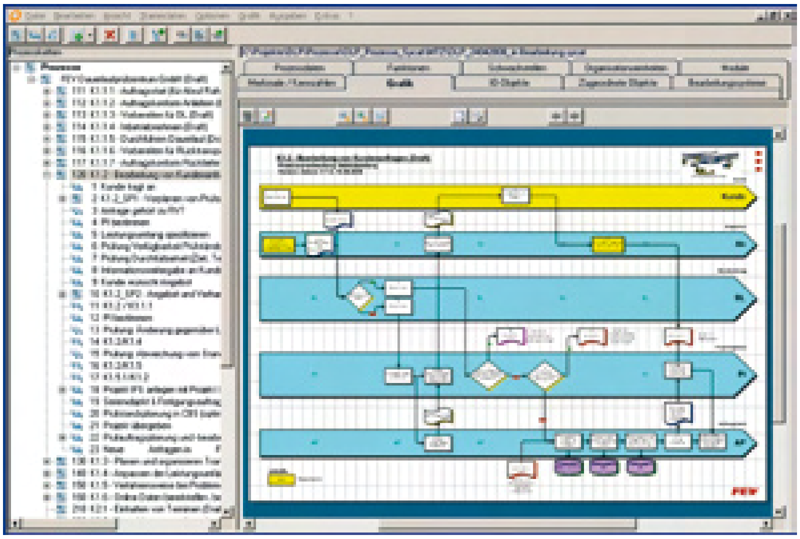

Figure 3: Process management tool of DLP, based on databases

secondary conditions were considered, and the resulting desired process was defined as the standard. The complete process model was such populated with contributions from all technical divisions of the FEV group as well as from additional specialists. It is now available to all DLP employees.

3 Technical Realization of the Process Model

The process description and documentation is created with a data bank based process management tool. This tool offers the possibility of a central documentation instead of diverse documentation on paper. Other essential benefits are also using a single system for quality management, health, safety and environment as well as simple change management. The tool maps the functional divisions involved as well as the individual functional steps, information and links graphically. During modeling it is also possible to save additional information as operations, specific performance figures, weaknesses, measures or documents for each process step or the total process chain (**Figure 3**).

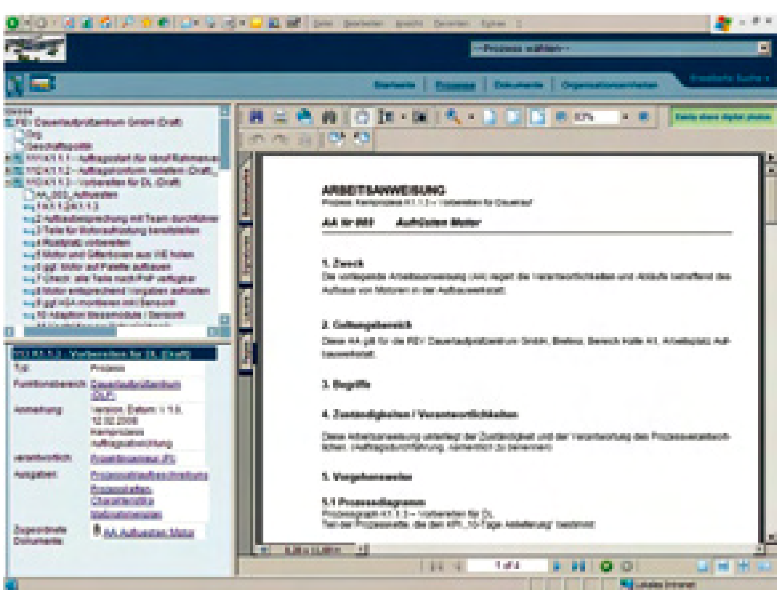

Figure 4: Example of a work instruction stored in the DLP intranet

4 Use of the Process Model

A special feature of this tool is the possibility to create an HTML output of the complete process landscape. This allows all DLP employees to navigate the process landscape through the intranet. This easy usability allows a very quick retrieval of all information from the system. **Figure 4** shows a work instruction as an example, which opens in the main window after being called.

5 Employee Training

All DLP employees have been trained in process management during the theoretical basic training. First, the theoretical foundations as e. g. process definition and structuring, process-oriented organization and the DLP process model were presented. The employees were then given the chance to familiarize themselves with the process documentation as well as their tool, in particular the HTML output. The training ended with an outlook on quality assurances processes and problem solving processes.

The process design of the DLP has also had strong influence on the building layout, the sourcing of the resources and process materials, the design of the ERP system as well as the on-the-job training of the DLP employees. Such the condition precedent for the ramp-up and the future operation was given, to provide the DLP employees with a reliable tool with work instructions to perform their daily tasks. The process system continues to be further developed in a constant CIP process to support the kaizen concept as a dynamic system and to make DLP the benchmark of the agreed targets. ■

Process-Oriented Project Handling in the DLP

The organization of the project handling in the DLP is modeled after the proven organizational structure of the parent company in Aachen. An ERP system specifically designed for test bench operation is used as the central electronic tool for holistic management and control of the projects.

1 Project Management via ERP Tool

One of the major challenges of the establishment of a durability test center is the combination of the benefits of a modern, production-oriented plant operation with the strengths and working methods of a flexible development service provider who responds quickly to the client's needs. The organization of the project handling in the DLP is modeled after the proven organizational structure of the parent company in Aachen. The project execution is secured through experienced project management engineers at the DLP with technical as well as commercial project responsibility. If needed, the DLP draws on the specialists of all the development divisions of FEV.

In addition, the DLP uses modern concepts that have been mixed with the progressive principles of lean management. An example is the introduction of an autonomous repair at the DLP, where to a certain degree the test bench operators perform maintenance and inspection work independently.
A further concept is the introduction of CIP work groups (CIP: continuous improvement process), where the employees analyze technical failures together with the technical divisions involved, and identify and implement improvement measures. Here, a practical approach is valued, where urgent problems are dealt with immediately and successes contribute more quickly to increasing of the plant's efficiency.

An ERP (enterprise resource planning) system specifically designed for test bench operation is used as the central electronic tool for holistic management and control of the projects (independent of their size). The ERP system used at the DLP is the latest version IFS 7.0 of the IFS Deutschland GmbH & Co. KG, which is also employed at FEV Motorentechnik. This ERP system maps all projects with their deadlines, finances and resources. After the project release by the authorized employee a consequent monthly controlling is performed. **Figure 1** shows the functional structure of the ERP system wit the following functional divisions:
– test bench utilization planning
– project handling
– material management (sourcing, stock keeping, disposition, evaluation)

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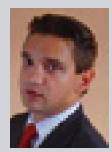

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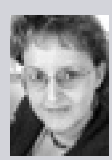

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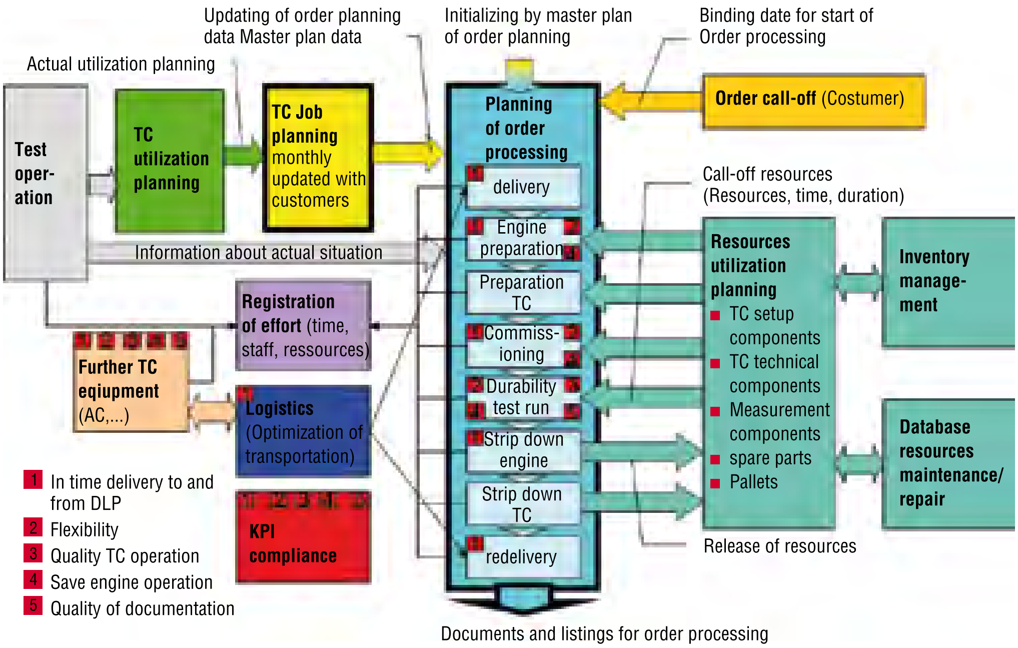


Figure 2: Functional structure of the ERP-System for integrated project processing

- resource management
- service and maintenance
- measurement and test equipment monitoring
- finances and accounting
- controlling.

A team of IT employees and users was created for the roll-out of the software. The start of the evaluation phase was November 1, 2007. The evaluation was already completed at the end of January 2008. The particularly ambitious goal to introduce such a comprehensive and specifically customized functional package ready to use was achieved in only four additional months. A few milestones of the system integration are described in the following.

2 Service and Maintenance

The extensive supply installations, the test equipment as well as the building structure have to be low-maintenance and need to allow easy repair. At the same time critical supply systems (bottlenecks) must be redundant, so that failures of small components will not cause the standstill of the test process.

The IFS maintenance module provides FEV DLP with a tool that is in direct contact with the business processes material management, purchasing and test job order planning. Hence, maintenance work relating directly to the test benches is imported into the IFS test bench planning tool CBS (Constraint Based Scheduling) and considered in the test bench utilization. Therefore no test bench scheduled for maintenance will be assigned an engine for testing during this time.

The event, calendar or running time dependent maintenance cycles meet the requirements of a powerful maintenance system. In case of an unscheduled technical defect this failure is entered in a so-called error report by employees of all technical divisions. Their systematic classification supports the continuous improvement process. These error reports are then processed by members of the maintenance team and the failure reasons are analyzed and documented. A periodic Pareto analyses reveals the main failure reasons and the activity focus of the preventative maintenance can be adapted and optimized accordingly.

3 Test Bench Utilization Planning

Every engine to be tested is entered as a job into the IFS system. The CBS system which is directly connected to the manufacturing module places every job immediately at the earliest date possible when all requested resources are available. Only the type of test bench has to be entered. The CBS system then searches automatically for the next available test bench of this type and assigns it (**Figure 2**).

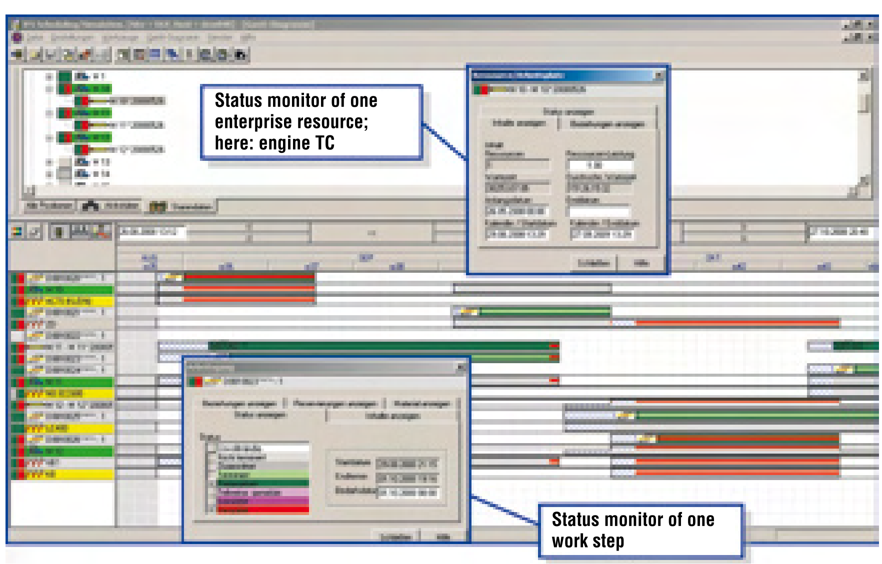


Figure 2: Test cell utilization planning within the ERP System

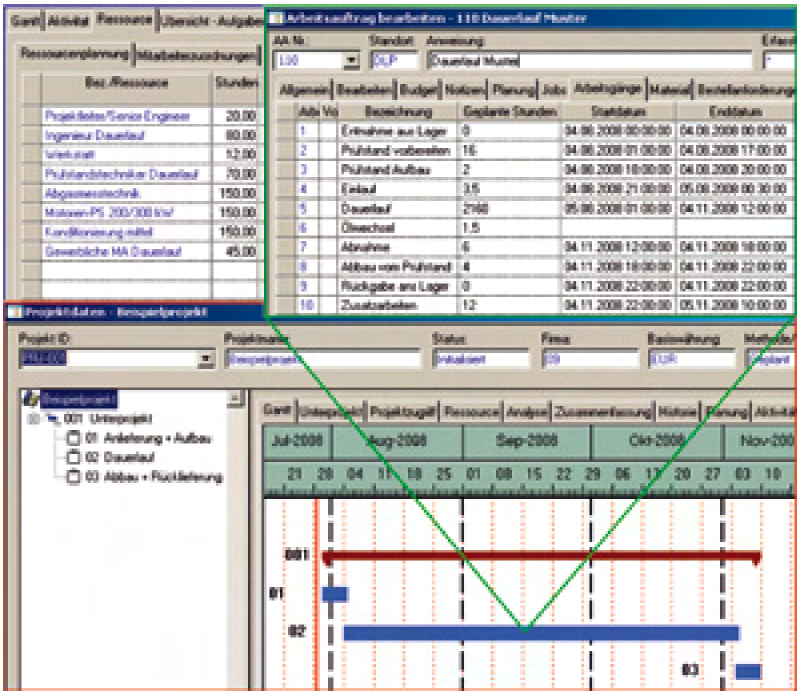


Figure 3: The project as the center of all information

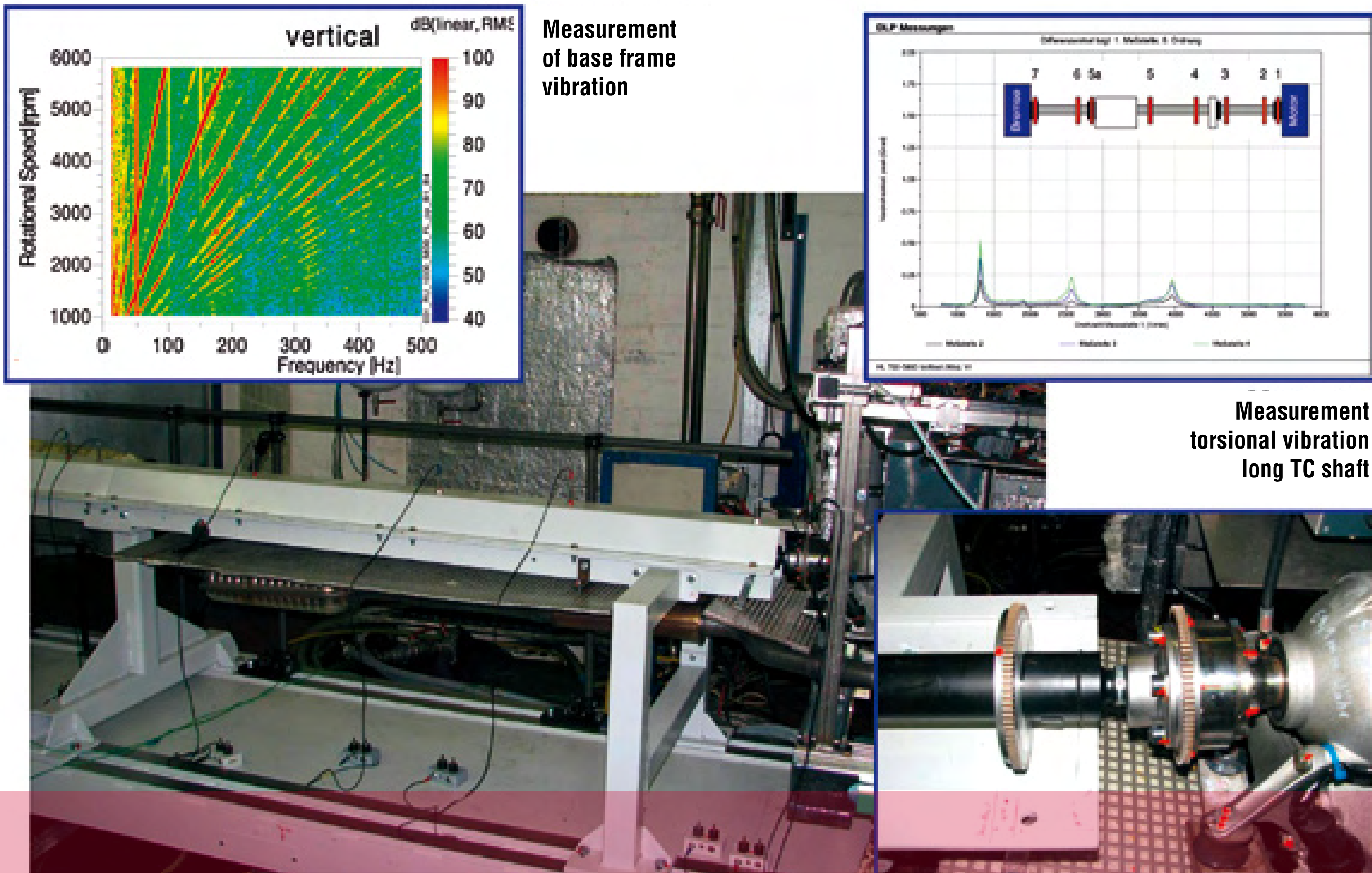
Therefore the project management knows early on which test benches are scheduled for the equipment under test during which time periods. Through the interaction of the maintenance work into the CBS the project management can rest assured that then all of the requested resources, e.g. a mobile thermal shock device or a mobile oil conditioning unit will be available and operational.

4 The Project in IFS as the Center of All Information

Apart from the classic cost control the project manager can also monitor the progress of the complete test job. The project in IFS links the test job to the DLP durability test operation with the work assignments for rigging and stripping down in the workshops of the DLP service area. The IFS provides a solid and consistent integration of all cost relevant data across the organizational units. Automated reports are made available to the management, the project and shift managers via IFS Event Server. They serve to highlight all circumstances which require intervention.

A Gantt chart shows the project management if deliveries are delayed, which jobs have been brought forward, and if all rigging and stripping assignments have been completed to schedule (**Figure 3**). Deviations from the defined times are reported by the system. Extraordinary interruptions at the test bench can be registered by the shift managers through the already mentioned error reports and their causes can be identified. The consequently resulting costs for material, labor and orders are directly assigned to the relevant cost center.

The modern test equipment installed in the test facility as well as the implemented control tools guarantee the optimal balance between production-oriented plant operation and a flexible customer-oriented development service. The basic concept of CIP plays an important role during the operational phase. A consequent shop floor management supports the employees in the realization of the optimization potentials. ■



Pilot runs at FEV Aachen to test new, DLP specific test technology

Staff Expansion and Durability Operation

With the development of a qualified permanent staff a prerequisite for the efficient execution of client projects in Brehna has been implemented. The FEV Dauerlaufprüfzentrum in Brehna currently has more than 80 engineers, technicians and industrial workers. Prior to the sourcing in Brehna, DLP specific components were tested in pilot runs in the test bench facilities in Aachen.

1 Staff Expansion

The development of the DLP permanent staff was conducted prior to the beginning of the DLP project as well as during the project duration through systematic advertising of the positions on well known online portals and in print media. PR campaigns on regional radio and TV supported the advertising of the DLP in the region. For example, regular reports on FEV and the progress of the construction were broadcasted. FEV used its own electronic portal for the sorting and automatic initial evaluation of the received applications based on a questionnaire.

After preselection according to the questionnaire and a short telephone interview, suitable candidates were invited for an assessment and a job interview. The assessment consisted of exercises and questions for the evaluation of the general technical understanding, the power of comprehension and the communicative abilities depending on the candidate's education. In addition, engine specific knowledge was tested.

From a pool of by now far more than 2000 applicants a considerable portion of the current DLP employees was chosen according to schedule. Beyond the necessary new hires experienced project management engineers and executives from the FEV parent company in Aachen have come to Brehna and are supported by additional FEV employees in Aachen if needed.

It should also be noted that the strong interest in a technology company like FEV in the new German states as well as the willingness of many young qualified applicants who today work as weekend commuters in all parts of Germany as well as abroad to return there proved an essential advantage of the location Brehna.

The new hires received a systematic nine month practical training at the test benches and in the workshops in Aachen (**Figure 1**). The training stations ranged from engine assembly, rigging workshop, commissioning of equipment under test and test bench teams to the technical divisions Mechanical Testing, SI Engines and Diesel Engines, the software calibration and the test technology. The new hires also underwent a two week activity related theoretical training. Contents of this theoretical training were the principles of engine technology, build and operation principle of modern engines, engine and test bench measurement technology as well as methods and processes of power train testing.

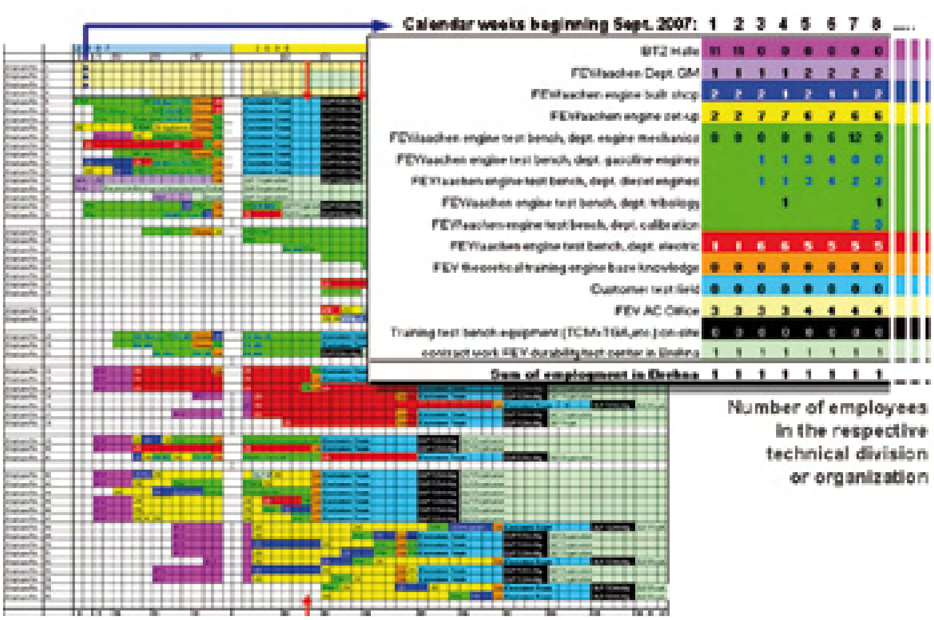
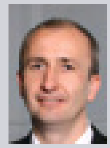


Figure 1: Training schedule for the function specific theoretical and practical education of DLP staff over several months

The Authors



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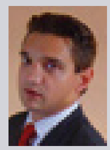

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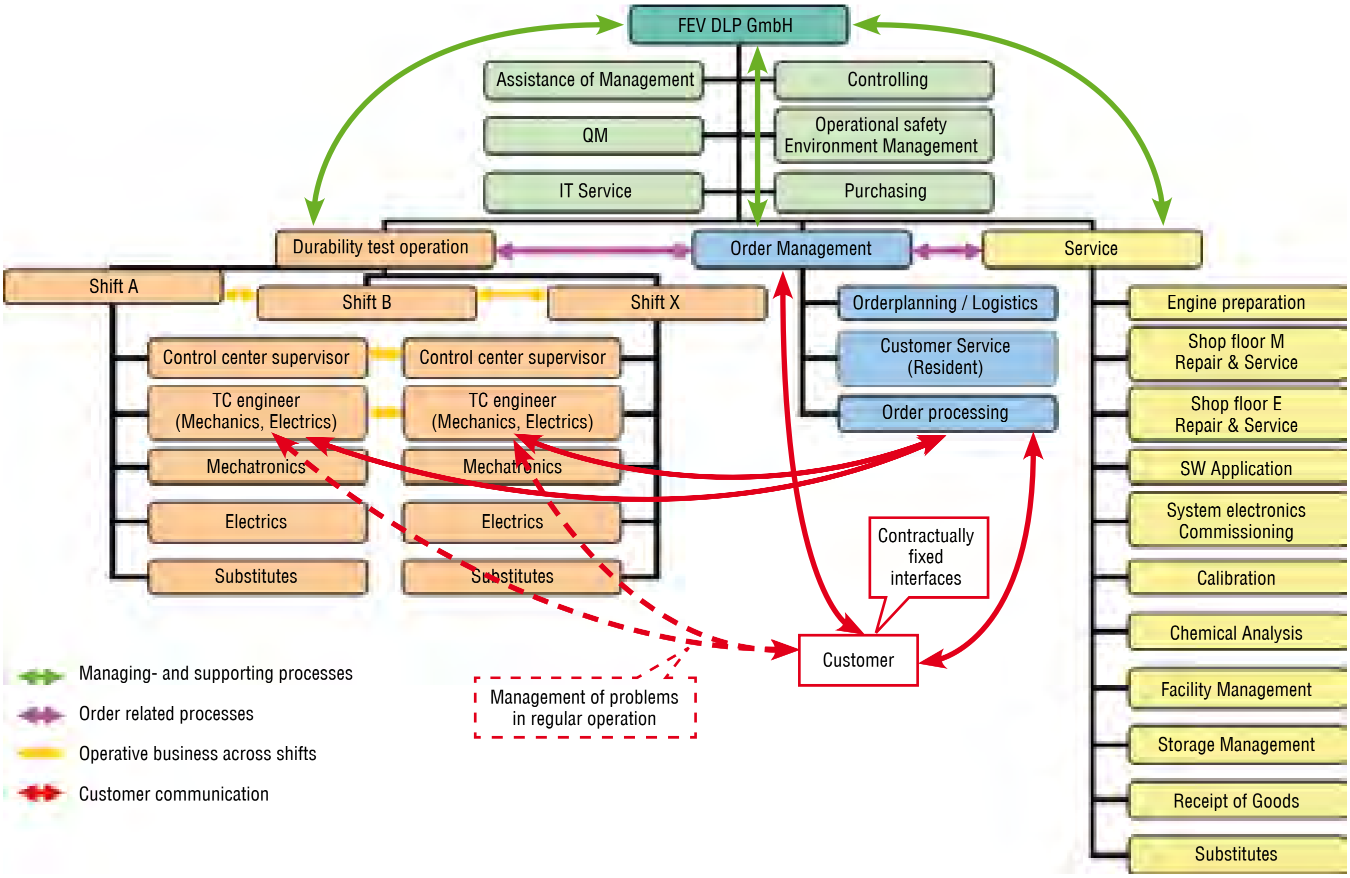
Figure 2: DLP structure for Organization and Communication



The DLP can now rely on carefully prepared and trained staff for the execution of test runs. The majority of the employees of the new durability test center has several years of experience with test bench projects. **Figure 2** shows the layout and the communication structure of the DLP with the communication guidelines defined during process development. The durability test center in Brehna currently has more than 85 engineers, technicians and industrial workers.

Apart from the technical design of the facility and the process development, a further prerequisite for the efficient execution of client projects in Brehna has been achieved with the establishment of a qualified permanent staff.

2 DLP Pilot Runs

Starting with the strategic positioning of the DLP the capacity planning as well as the technical boundary conditions of current and future test programs, the technical specifications of the measurement and test technology were developed within the frame work of the subproject “operation”. During the course of the project a variety of DLP specific components were tested within pilot runs in the test bench facilities in Aachen prior to the start of the comprehensive sourcing and the setup in Brehna. This included e. g. the measuring and testing of the mechanical test bench components (for example foundation, pallet, clamping, long test bench shaft or rigging parts) regarding deformation, vibrational behavior and durability.

The various conditioning units for the media were tested regarding their functionality at commissioning of the equipment under test (e. g. rapid automatic ventilation) and during operation (performance and control dynamics) together with the refined test bench automation owned by FEV (**Title Image**).

The approval of the test technology by predefined approval runs and quality criteria was conducted by the project team employees of FEV Motorentechnik and DLP.

3 Ramp-Up

The ramp-up and the start-up of the DLP were performed according to the customary system of the industry. First, several performance tests were conducted accompanied by observers. The observers’ task was to document difficulties which lead to problems with the execution of the test jobs. In a second step, this list of noticeable problems was analyzed and corrected through appropriate measures by a team representing all divisions of the DLP. ■

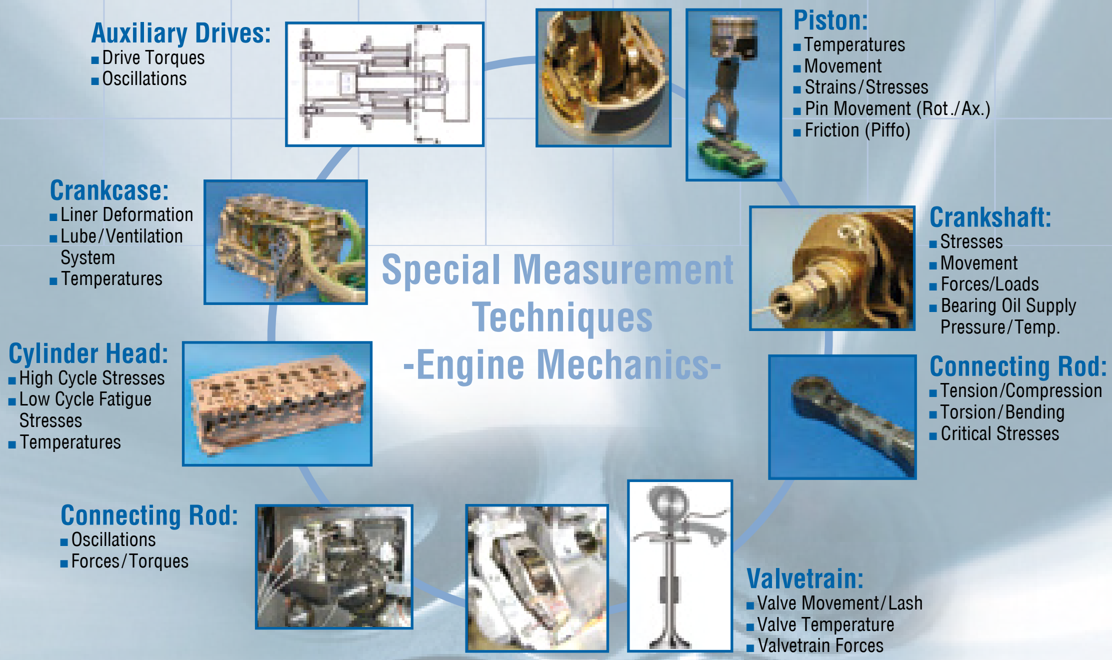


Fig. 1: Examples of Special Measurement Techniques

Special Measurement Techniques in the Area of Mechanical Development

The mechanical development and engine testing process focuses on the continuously increasing requirements for the development of production engines. Engineering trends, such as powertrain downsizing, frequent requirements to increase cylinder peak pressures and advancements in friction reduction in parallel with lightweight designs are examples of trends that increase engine component loading. However, these design features cannot be allowed to have a negative affect on the engine's lifetime or service intervals. This can only be achieved through the steady improvements in the methods and processes used in engine mechanical development. The basis for the discovery and understanding of loads as well as dynamic effects that, based on current requirements, lead to unknown problems and failures lies in advanced measurement techniques. A detailed technical analysis of these effects is necessary with complete consideration of the real operating conditions. Apart from its use for classical troubleshooting, which leads to individual concept improvements, the field of special measurement techniques simultaneously forms both a basis for development as well as a calibration tool for state-of-the-art simulation techniques. This, in turn, enables consideration of effects within the concept phase that are currently neglected. To support this complex theme, FEV offers a wide variety of special measurement techniques, which offer largely modular characteristics.

- On one hand, a large number of application methods exist for various sensors, all of which are optimized for use under the most adverse environmental conditions that are typically encountered in developmental engines. Many of the methods have been proven in engines at speeds approaching 20,000 rpm. This allows the carry-over of these methods into other drivetrain analysis fields.
- On the other hand, many different data transmission methods are available to support the measurement needs of practically all engine components, ensuring secure transfer of the data to data logging devices.

Depending upon the requirements, data transfer has shifted to a predominantly telemetric approach, but direct cable connections are still used, for example between the piston and engine block via a special high speed linkage device (to engine speeds well above 7000 rpm). Such special measurement systems can be designed and integrated as requested if the number of channels or the sensor type requires such solutions. From this modular toolbox, highly individual measurement requirements can be met in a short period of time. Examples of analyses conducted by FEV are shown in Figure 1. FEV looks forward to working with you to solve your special measurement needs.

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Planning and Design of the DLP Infrastructure

The technical division Test Systems of FEV was tasked with the planning and the creation of the test facility including the building and the complete technical infrastructure. The central technical facilities of the durability test center guarantee a high availability, because their systems are redundant and designed for fully continuous operation.

1 The Boundary Conditions

With the decision for the construction of the DLP the technical division Test Systems within FEV Motorentechnik was tasked with the planning and the creation of the test facility including the building and the complete technical infrastructure. This created a clear interface to the principal, the FEV DLP GmbH. The activities of the technical division Test Systems comprehended the following:

- planning
- process creation
- realization
  - test bench components
  - test benches
  - test facility
- project management
- maintenance and service.

The planning of test bench facilities differs from that of other buildings through its considerably more comprehensive requirement profile, the higher complexity and the extreme installation density of the technical media supply. The participating technical disciplines are closely linked to the planning process. The planning of the complete infrastructure formally contains the following planning disciplines:

- planning (buildings and functions), monitoring

– planning of the supporting framework (statics and construction)
– technical planning
– technical media supply (supply and disposal)
– test technology/test benches
– special areas, approval planning and coordination planning
– project control, project management.

In summary, the task of FEV Motorentechnik can be described as follows:
– planning and erection of 31 durability test benches according to capacity planning
– infrastructure for 100 employees including workshops and laboratories
– expansion possibility for another eleven test benches within the first phase of construction
– fulfillment of the predefined boundary conditions as
– braking power
– temperature ranges of media conditioning
– fuel types (ten different types)
– availability
– continuous operation, i.e. 365 days per year
– availability > 85 %
– minimization of life cycle cost of the facility
– project duration of 24 months including search for location and approval procedures.

2 Planning (Building, Basic Function), Planning of Supporting Framework

The following planning parameters served as input variables for the development of a functional test bench building regarding optimized utilization during operation (**Figure 1**):
– functional connection of subprocesses, including:
  – control desk ↔ test area (“does the test bench operator need to see the engine?”)
  – specialized test benches (climate test cells) ↔ mixed operation
  – test cell-oriented or task-oriented measurement technology
  – system redundancy
  – facility availability
– distances to be covered during the process cycle
  – control desk/test area ↔ local or central control room
  – workshop ↔ local or central
  – communication ↔ office assignment
– room connections, physical boundary conditions
  – performance range of the nominal baking power
  – simultaneity factor of the central systems and the test facility performance
  – dimensioning of the supporting frame work
  – required area for TBE
  – fire safety

Building layout designed for …

- Short distances for supervision, maintenance, and repair
- Clear information management (detection and information system)
- Transparency of performance indicators for DLP staff
- Easy access to all technical units and facilities
- Minimization of risk in case of an incident (e.g. fire)
- Strict separation of main flows (e.g. before and after durability test)
- Expandable step by step without major influence on operation
- Organizational separation between 24/7 test operation and service (work shop / normal shift)
- Simple building structures
- Clear arrangements, bright rooms
- Minimized operational costs (personnel, energy, maintenance)
- Residual value of property after facility life-span (possibility to convert type of usage)

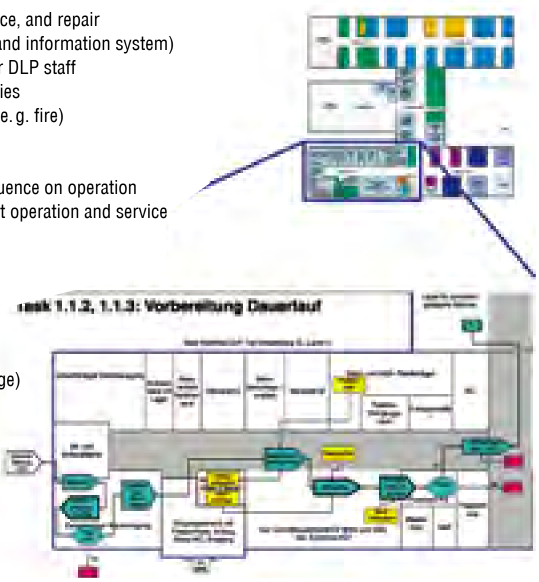

Figure 1: Process oriented design of building layout

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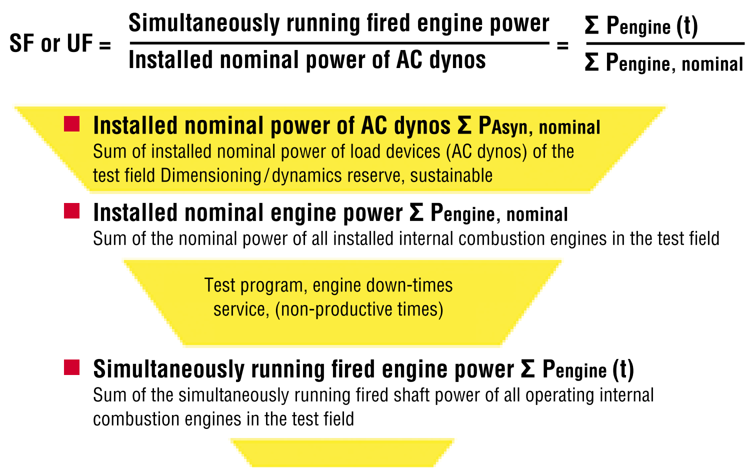


Figure 2: Definition of the utilization factor / simultaneity factor for the planning of the technical building equipment (TBE)

- laws and regulations
  - German laws regarding immissions air quality and noise (BImSchG, TA Luft, TA-Lärm)
  - vibration protection.

Figure 1 in the section on process development shows the core process in a test bench building. The main process line of the engine to be tested is embedded in an environment of various management and support processes with optimum conditions for a good communication of all areas.

The main path of the workflow starts with the order intake and the receiving inspection (contract conformity of delivery), followed by assembly and rigging of the equipment to be tested in a preparation workshop. Since the preparation of the test equipment is essential for the efficiency of a test bench system, this part of the process with the subfunctions logistics, adaptation of the equipment to be tested, component storage, rigging of measurement technology, calibration and pre-commissioning is of pivotal importance.

The actual testing of the engines is defined by the rigging and stripping down time at the test bench as well as the test bench non productive time (usually events which cannot be determined). A reliable technical supply of the test bench is another basic prerequisite.

The testing is followed by the evaluation of the measurement data and the simultaneous dismantling of the equipment under test. The conclusions gained from the test trail are important input parameters for the continuous improvement. The total efficiency of a test bench system is therefore determined by the equipment under test, the test bench and the overall organization. Hence, this process is the elemental starting point for the development of the building layout. In the preplanning phase, several building layouts and their arrangements on the premises were investigated. The layouts were compared and examined (also in their development and expansion phases) regarding the fulfillment of the task.

The durability test center was planned as a single story building without basement. The chosen building structure consists of four halls divided into six different areas. To achieve a high residual value of the property (usage neutrality) all areas are designed by their building construction such that the building can easily converted. The external supporting framework (shell) is decoupled from the internal supporting framework (test benches) so that it would be possible to gut almost the complete building with flexibility for future test bench requirements or other usage.

The **Title Image** shows the statical basic concept of the building. The foundation consists of a base plate made of reinforced concrete as a surface foundation with an ice wall around the perimeter. The footings for pillars and walls are single or continuous footings, respectively. The engine test benches in A2 and C1/2 have a false floor of 60 cm through lowering of the base plate. These areas were built in waterproof concrete. The outer construction is made of precast pillars made of reinforced concrete with bucket foundations. The roof trusses are gluelam trusses with a two-sided slope. The roof construction for the complete building is a light-gauge steel roof with a two-sided slope of 2 %. The external walls are made of steel sheet cartridges.

Another part of the planning consisted of the infrastructure and the external works. Here, all development requirements had to be registered and considered regarding potential expansions. Thus the plan for the laying of all supply and disposal lines as well as the building of the roads, parking lots, traffic areas, green areas and fence installations was developed. The building data are as follows:

Dimensions
- Hall A: length 105 m / width 25 m / height 10 m
- Hall B: length 50 m / width 25 m / height 10 m
- Hall C: length 105 m / width 25 m / height 10m
- Hall M: length 40 m / width 25 m / height 10 m

Building characteristics
- land area approx. 60,549.00 m²
- overbuilt area approx. 7.548,36 m²
- auxiliary buildings approx. 135.45 m²
- technical areas approx. 910.00 m²
- hard standing approx. 1,155.00 m²
- traffic areas approx. 4,129.00 m².

3 Test Facility Simulation

Similar to the energy flux in the engine the total energy flux in the “fired” test facility (primary energy fuel and auxiliary energies) for the test cell and technical media supply has to be calculated and optimized. Before the actual planning an intensive operational analysis for the calculation of the total installed dyno power (e.g. as an average power per year and probably maximum power) has to be performed for the dimensioning of the TBE and a realistic description of the emission and immission situation (approval procedure). This is achieved with a test facility simulation. This simulation distinguishes

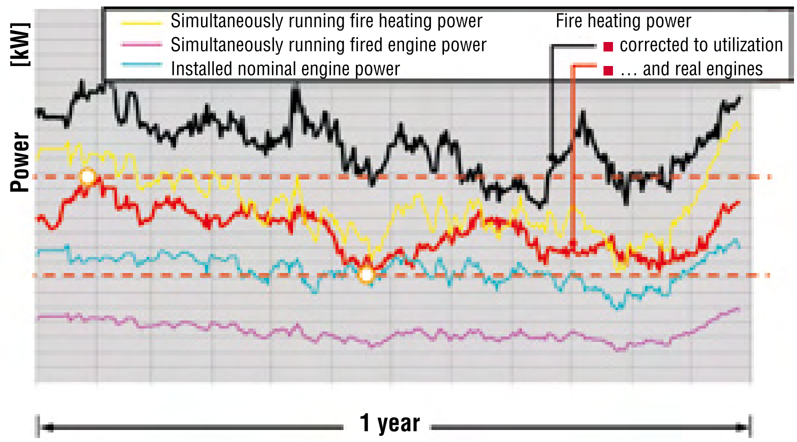


Figure 3: Test field power as exemplary result of the test field simulation

between installed nominal braking power, rigged engine nominal power and actual operated engine power (specific to the test program).

The results of the test facility simulation, the so-called utilization factor, can be used to derive the relevant characteristics for the planning of the supply systems.

The utilization factor is defined as the actually fired engine power divided by the installed dynamometer power (**Figure 2**).

Compared to the test facilities that are used primarily for development activities, due to the focus on durability tests the task of the DLP can be more precisely formulated. The design of development test facilities as well as the dimensioning of the technical facilities are based on input parameter arrays that cannot be precisely determined. The DLP allowed for more sophisticated specifications for the planning of the test facility due to the substantiated capacity planning based on test program collectives and the process-oriented execution, including:

- test facility configuration with number of test benches, performance clustering as well as specific properties
- definition of the different test programs (types, duration, frequency)
- number of the various test runs per year
- frequency distributions of the test run categories
- frequency distributions of engine performance categories.

The project team mapped the overall process in the test facility within a simulation software. With the aid of the named restricting dimensioning data and the developed program tool a variety of optimizing conclusions was possible and important parameters could be derived:

- total installed dyno power
- average installed dyno power
- fuel consumption of the test facility
- exhaust gas quantity
- cooling water quantity
- cold water quantity
- process heat
- mains connection
- pollutant mass flows
- pollutant concentrations.

The simulation through the course of the year does not only show the installed dyno power but also if and which areas are used to capacity or overloaded. Bottlenecks could be successively eliminated through parameter variation and parameter were optimized down to the number of pallets for the equipment under test. The test facility simulation allowed for:

- optimized parameters in the technical center for all important supply systems based on a simulated total installed dyno power and an average installed dyno power.
- data bank already during the approval phase according to German Federal Immission Law with more realistic prognosis for the emission behavior of the total facility
- more realistic dimensioning of the preparation workshops and the other service zones through an optimized workflow
- optimal appropriate investment costs already in an early project phase.

Figure 3 shows the test facility power as result of a test facility simulation over one year of operation. Apart from the direct simulation result (yellow, fired thermal output at simulated partial utilization and theoretical engine placement) the fired thermal output is also illustrated based on the placement of the real engines currently in development and an optimized test facility utilization (red, customer specific real engine collective).

We know from various studies of the EU and the ACEA that the nominal engine output of the vehicle fleets in Europe has increased from 1995 to 2005 by approx. 30%. To guarantee the future capacity of the test facility, the utilization factors for the dimensioning of all facility components for the construction phase 1 were determined according to the following criteria andbased on a prognosis about the nominal output of future engines and the optimized simulation result:

Expansion only possible with operational interruptions:

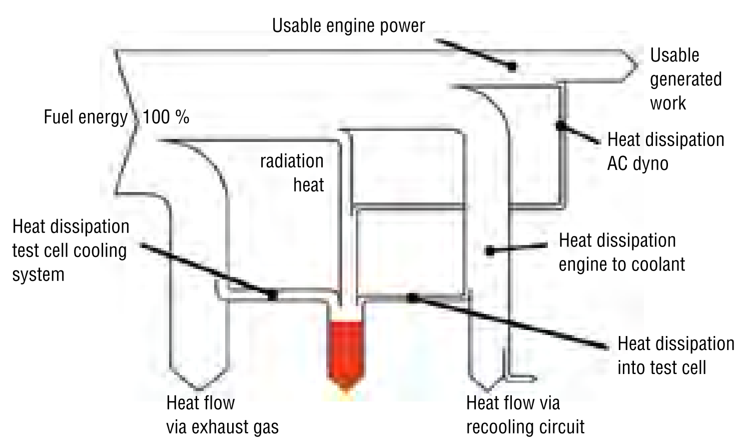
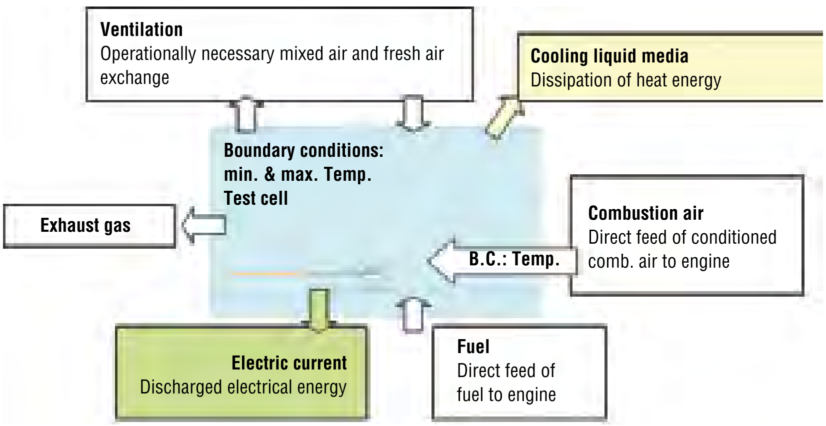


Figure 4: Sankey energy flow diagram of a test cell



$$Q_{into} - Q_{exhaust} - Q_{loss} - Q_{cool} - Q_{eff} = 0$$

Q_{into} = fed energy (fuel and air)

$Q_{exhaust}$ = exhaust heat current

Q_{loss} = overall loss heat current (thermal radiation and convection)

Q_{cool} = cooling heat (cooling water or cooling air)

Figure 5: Energy currents crossing the system boarders of a single test cell

- central, individual facility parts (e.g. media supply lines): GZ1 according to the long term development of the installed dyno output
- facilities clustered according to areas (e.g. cold temperature supply, focal point stations, transformer stations): GZ2 according to the long term development of the installed dyno output, GZ2 > GZ1.

4 Dimensioning of the Technical Facilities

The results from the simulation and the calculated characteristics of the test facility formed the basic data for the dimensioning of the central technical facilities. Starting with the individual test bench and its energy distribution for stationary engine operation (**Figure 4**), the individual technical media supply systems were dimensioned. These include for example, fuel, cooling water, cold water, combustion air, electricity and exhaust gas. If the walls of the test bench are taken as the system boundary, the following energetically relevant system flows can be listed (**Figure 5**):

- supplied fuel
- supplied air
- electrical power
- exhaust gas
- coolant in- and outflow
- heat transfer to the environment.

After the energy balance and the dimensioning of the required decentralized components for the supply and disposal systems of a test bench as exhaust gas, ventilation and cooling water have been completed, the individual test benches are summed up for the calculation of the total facility. With the simultaneity factors derived from the simulation, the energy balance of the total facility can be established (**Figure 6**).

For the formation of a long term stable and successful company the planning must not be limited to the investment cost. The so-called life cycle costs also have to be considered for the evaluation of an execution version. Apart from the investment cost the operating costs are a vital element of the overall consideration and of the project's or company's success.

Since the technical media supply is associated with significant costs, comprehensive life cycle cost analyses of various facility concepts were performed for almost all contracted work packages during the planning phase. Based on these analyses and the functional requirements for the facility the decisions on the technical facility design and its details were made. **Figure 7** illustrates the summary of such a life cycle cost analysis through the example of the test bench ventilation.

Additional central technical facilities of the DLP are:

- fuel supply
- cooling supply/heat exchange
- cold water supply
- compressed air supply
- combustion air supply
- ventilation devices for carrying off heat
- electrical supply
- exhaust gas removal with cooling tower
- heating
- cold temperature supply
- process measurement and control technology
- IT infrastructure
- fire alarm system
- air conditioning monitoring
- sanitary engineering with water supply
- heat insulation, fire sealing.

The variety of the systems with their various individual solutions and their fre-

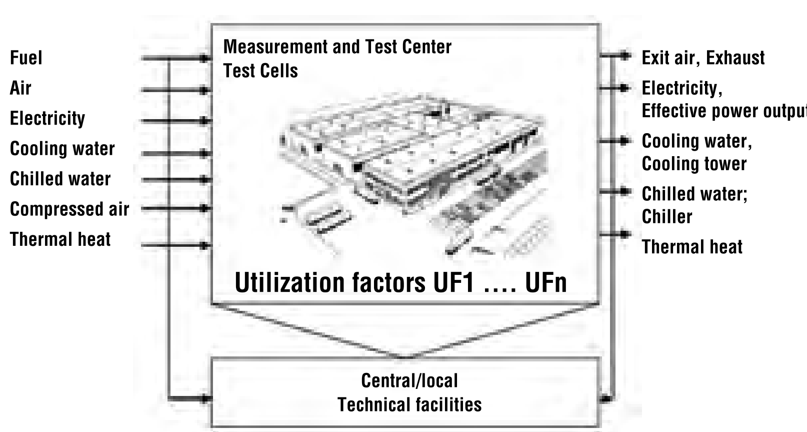


Figure 6: Energy balance of the whole facility - schematic

quent interaction demonstrates the complexity of the task at hand. The supply and return concepts are the result of system comparisons, the conclusions of the test facility simulation as well as the investment and the operating costs. The local climate data (DIN 4710) were also considered. Through the exclusive use of dynos the test facility also produces electricity which is partly used and, if produced in excess, fed back into the public electricity mains.

Another special challenge was posed by the requirement of an availability of more than 85 %. Therefore, special emphasis was placed on uniform test benches and test bench equipment. This guarantees additional freedom for the utilization planning. The uniformity of the test benches was achieved through the choice of standardized modules (enclosure) with identical media connections. Further, the highest variability possible regarding transversal and longitudinal setup was considered. For example the test benches designed for transversal setup can also used for longitudinal setup.

The test devices as e. g. conditioning units or exhaust gas measuring devices were largely designed as modular and mobile appliances. Apart from the high flexibility regarding their location of deployment this also guarantees a quick exchange in case of maintenance or repair. The critical central facility components, e. g.

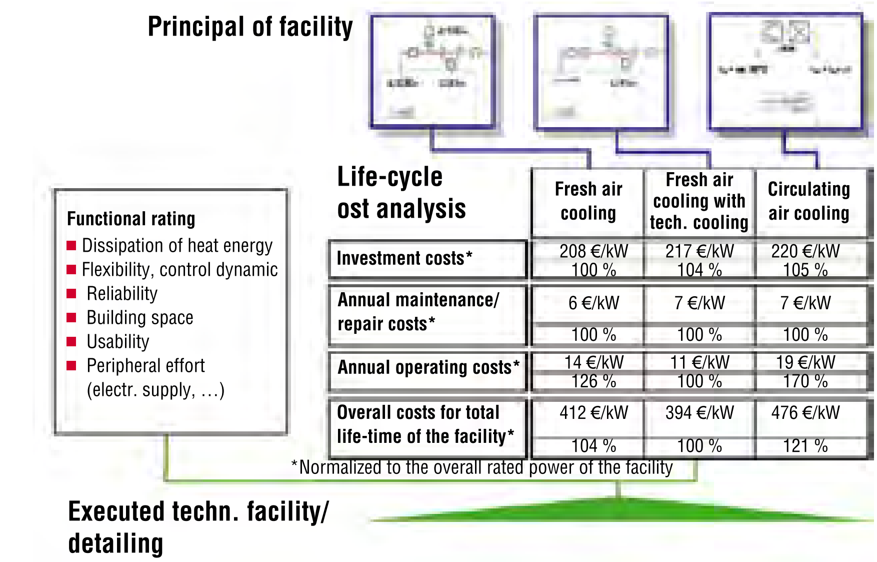
- coolant water/cold water supply
- electrical supply, electricity feed
- fuel supply
- heating (heat generation and heat distribution in the halls/test benches)
- exhaust gas system (suction)
- compressed air generation
- IT network

were investigated during the planning phase to identify the technical solutions that are most suited for the special application area of a durability test facility.

The safeguarding against failure was either achieved through the redundant use of components as pumps and valves, or wiring concepts (or component splitting respectively) were developed which guarantee that the failure of subcomponents will not lead to the still stand of the total test facility (**Figure 8**). The **Table** summarizes the technical data of the most important systems of the DLP.

Further, a complex system monitoring was installed. Such, various parameters can be determined apart from the operating hours, and functions can be monitored which present fundamental input values for a preventative maintenance. The durability test facility is determined by the variety of the test requirements.

Eventually the technology serves the human and vice versa – it also has to be operated by humans. In the test facility people work in the control room, in the workshops and in the offices. It is important to create a comfortable working environment for these employees. The building services for these rooms has been planned and realized according to the usage requirements and the workplace regulations. The building is equipped with all require safety systems as fire alarm system, smoke/heat suction systems or fire extinguishing systems.



Life-cycle ost analysis	Fresh air cooling	Fresh air cooling with tech. cooling	Circulating air cooling
Investment costs*	208 €/kW 100 %	217 €/kW 104 %	220 €/kW 105 %
Annual maintenance/ repair costs*	6 €/kW 100 %	7 €/kW 100 %	7 €/kW 100 %
Annual operating costs*	14 €/kW 126 %	11 €/kW 100 %	19 €/kW 170 %
Overall costs for total life-time of the facility*	412 €/kW 104 %	394 €/kW 100 %	476 €/kW 121 %

*Normalized to the overall rated power of the facility

Figure 7: Summary of performed life-cycle cost analysis and the functional rating – example: test cell ventilation

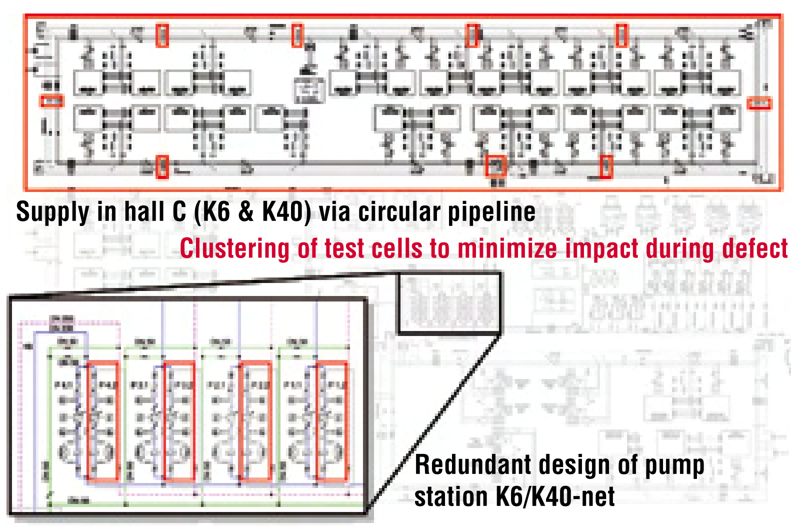


Figure 8: Ensuring the availability of facilities by clustering and redundancy – as example the cooling water supply

5 Technical media supply Design and Execution in the DLP

High availability, redundant system design, fully continuous operation and central system monitoring of a durability test facility require a target-oriented execution of the supply systems. The financial scope for the planning and erection of the technical media supply is a significant proportion of the total project cost. Therefore, a few important central technical systems and their design will be described in the following.

5.1 The Media Supply

The comprehensive supply of the test facility includes the following media: cooling water K40, cold water K6, cold water K12, cold water K-20, heating heat H70, compressed air network 4/6 bar, potable water and natural gas (**Figure 9**).

The supply with cooling water (K40) and cold water (K6) accounts for the biggest part of the media supply in the DLP. The necessary supply was established on the central technical area in its full scope (**Figure 10**). The cold temperature generation for the cold water circuit (K6) is secured through five air cooled cold water sets of different sizes with a total power of 3250 kW. Each cold water set contains at least two independently functioning compressor circuits (redundancy) with screw type compressors. The central control technology selects and connects the machines in series depending on the system temperature.

Four dry cooler modules with a total power of 3740 kW supply the cooling water circuit (K40). The cooling water exit temperature of 38° C is guaranteed through 16 variable-speed axial fans per heat exchanger. A heating system provides for the stabilization of the cooling water temperature at low load operation. To achieve the supply safety necessary for the media supply of the DLP, the media lines were installed in the form of a closed loop in each building part. Redundant and frequency controlled pump stations are added, and the differential pressure at the most disadvantageous consumer location is the manipulated variable. The total supply network is run with a glycol water mixture (34 / 66 %).
This poses special requirements for the facility concept. For the automatic refilling as well as draining and ventilation at almost every point of the facilities a glycol line was built parallel to the supply line. The refilling of the system is performed automatically dependent on the facility pressure through an underground glycol tank with a volume of 10 m³. The drain lines also lead to this tank, so that a closed system is created. The equipment of the DLP also contains diverse building installations as static heating supply, dynamic heating supply for ventilation facilities as well as sanitary areas, (**Figure 11**).

Another, technically more sophisticated part of the DLP consists of the five climate test cells for rated powers of 200, 300 and 600 kW. Each of these five test benches was provided with an additional self-supporting cold climate chamber made of sandwich elements for a cabin internal temperature of -10° C. The room temperature is controlled by a recirculating air cooler with corresponding power. For this purpose, air quantities of up to 75,000 m³/h have been estimated.

A special air conditioning system with adsorption system is used for the air conditioning in the climate test cells. This prevents undesired formation of ice in the test room. The further equipment of the test chambers includes the supply of the coolant conditioning with the K-20 coolant. Two special fluid coolers with R507 coolant generate the very cold medium K-20.

The resulting execution period of seven months for the implementation of the

Table: Main facilities technical data

No.	Facility	Power	Preparation for expansions
1.	Cooling water generation	approx. 4 x 985 kW	approx. 935 kW
2.	Chilled water generation	2 x 290 kW 3 x 1200 kW	approx. 1200 kW
3.	Deep cold generation	approx. 520 kW	approx. 130 kW
4.	HVAC – supply air, outlet air test cells	approx. 1,200,000 m³/h	approx. 530,000 m³/h
5.	Exhaust gas system	approx. 230,000 m³/h	approx. 100,000 m³/h
6.	Heat supply	approx. 1,5 MW	approx. 0,5 mW
7.	Electric power	6 transformers, 1000 kVA 2 transformers, 630 kVA	2 transformers, 1000 kVA
8.	Fuel supply	8 Sorten approx. 280,000 l	2 grades approx. 120,000 l

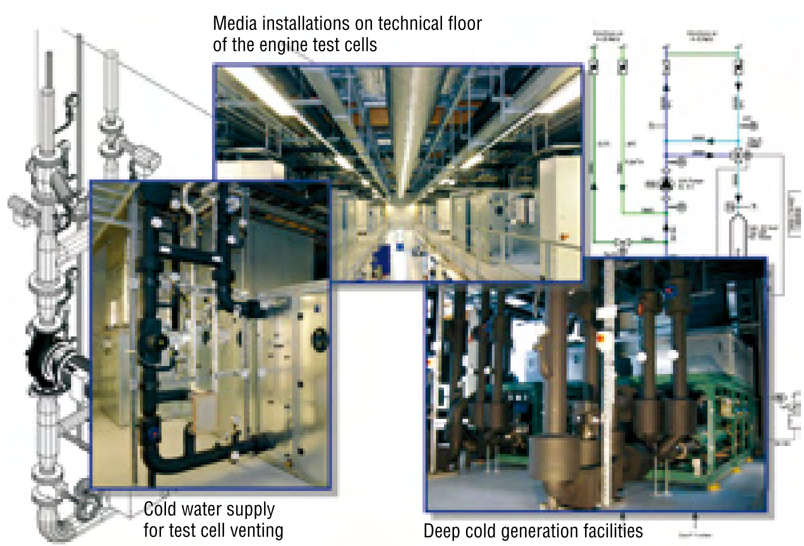


Figure 9: DLP media supply

Figure 10: Generation of cold and cooling water at the central technical area

complete media supply with costs of several million Euros posed extreme challenges for the contracted company. 16,000 m pipelines, approx. 3,000 m welding seams, 25,000 m power and control cables as well as 65,000 kg steel, to just mention a few crucial data, may give an idea for the scope of the deliverables in the aforementioned period.

The commissioning of the facilities was performed in close cooperation with the DLP operations team as well as all of the contracted work packages involved. Each individual test bench was tested and optimized. The media had to be supplied gradually for this purpose. This posed high demands for the scheduling as well as the assembly planning and execution phase regarding preparation and interface coordination. The benefit was that provisional measures could be eliminated completely, which minimized the cost significantly.

5.2 Plant Process Control (PPC)

Such HVAC facilities are also a challenge for the automation technology. An ambitious project of building automation technology can be described by the basic data of approx. 6,000 hardware data points distributed on five Siemens S7 417H high availability processors as well as 27 Siemens S7 300 processors. But not only the number of PLC components, also the requirements regarding the availability of the facilities and individual devices were additional challenges during the short realization time of this project.

To achieve a minimal failure risk with a nevertheless lean budget a concept was developed in close cooperation of FEV and the executing contractors that almost prevents the failure of total supply systems completely. The executing company responsible for the process measurement and control technology of the contracted work packages cold temperature, very cold temperature, heating and media supply, also realized the integration of the process control for the ventilation and fuel systems on the plant process control (**Figure 12**). Under these conditions an automation system was developed which combines the various contracted work packages of the executing contractors in a user interface that is uniform for all of the DLP. This starting point allows an individually customized intuitive operation and monitoring in the test facility control room and a simple maintenance in a homogenous automation system.

The system topology for the automation of the HVAC/supply technical facilities shows that from the plant process control to the head stations of the five information focal points (cold, heating, ventilation, fuel and cold temperature supply) redundancy has been created by doubling the automation and operation components as well as the data pathways. This setup allows a continuous operation of all control programs which are directly responsible for the constant supply of all test benches. A redundant bus system that is also redundant, controls the hardware I/O to minimize the possibility of a failure of the total facility. Only from the input/output level on this redundancy is dispensed with because the danger of a supply gap is already minimized through the redundant execution of the technical media supply components like double pumps or the respective power reserves of the supply components.

The setup of the individual test benches was also realized without high availability controls and redundant layout. This rational

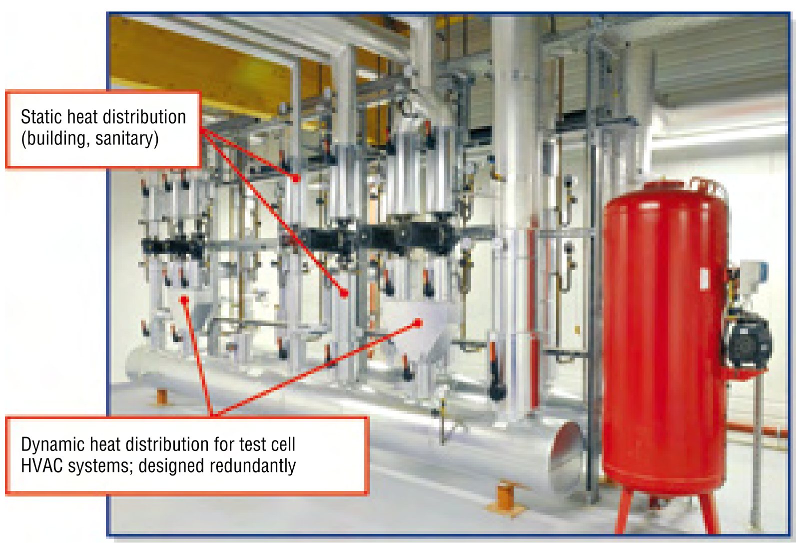


Figure 11: Static and dynamic heat distribution, partially redundant

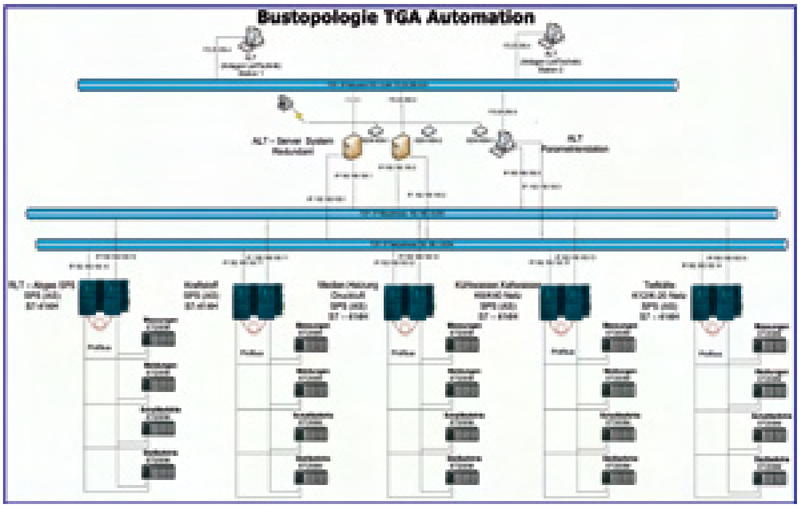


Figure 12: Network topology for technical building equipment automation

structure guarantees an extreme operational safety for the superior facilities and the total supply of the DLP without implementing exaggerated redundancy measures with their associated costs.
Another important point apart from the automation level is the secure setup of control voltage circuits in the switchgear. Here, a redundant control voltage supply with a consistent backup division was performed to eliminate failure risks and bottlenecks for maintenance and repair on this level as well.

To create optimum boundary conditions and homogenous climate conditions for the DLP, an Ethernet IP coupling between the test bench automation system (TCM) and the ventilation facilities was installed. This system controls the boundary conditions regarding air quantity, temperature and safety matrix and passes requirements on to overlaid systems as the fuel supply. This point is particularly important for the area of the climate test cells because they pose correspondingly high requirements for the conditioning of the test rooms. To guarantee a procedure that is optimized to the measurement processes, a variety of parameters must be controlled and monitored, as well as supply facilities for the climate test cell temperature generation and air drying must be optimally integrated into the operations.

Two operator workplaces have been established for the operation and monitoring of the complete technical facilities which receive their data from the two PPC servers (**Figure 13**).

Due to its redundant setup the server system allows a continuous operability of the complete performance range also during maintenance and modification work. Such a setup naturally also has advantages regarding the data safety of the operational history which is constantly recorded and stored in data bases. A system maintenance workplace with remote dial-in option is available for the maintenance and modification of the PPC. This allows for a fast and straight forward support as well as a targeted assistance of the DLP personnel during the complete duration of the test center.

The Siemens system WinCC was chosen as a powerful and flexible control technology software with high future suitability. The choice of a homogenous product line from the automation station to the control technology creates a variety of advantages for the maintenance and continuous adaptation of the facilities to the needs of the durability testing operations. For example, not only can the control level be maintained via the system maintenance workstation, but the monitoring and the programming of the automation stations can be performed as well.

5.3 Ventilation

The ventilation facilities of the DLP consist of:

- 31 decentralized ventilation facilities (VS) for the engine, power train and mock-up test benches
- a central exhaust gas system
- two ventilation and air conditioning systems (VAC) for the mock-up test benches as well as the workshops and offices.

Consistently precisely planned, aligned execution scenarios up to the handover of the facility to the personnel of the DLP were required for the commissioning, the trial operation and the running in of the facilities in connection with the specific user requirements, the safety and alarm tests as well as for the function of the centralized superior building control technology. The realized plant technology is described in the following on the basis of the example of the test bench ventilation of the durability test cells and the central exhaust gas system.

The cooling of the test cells is perfor-

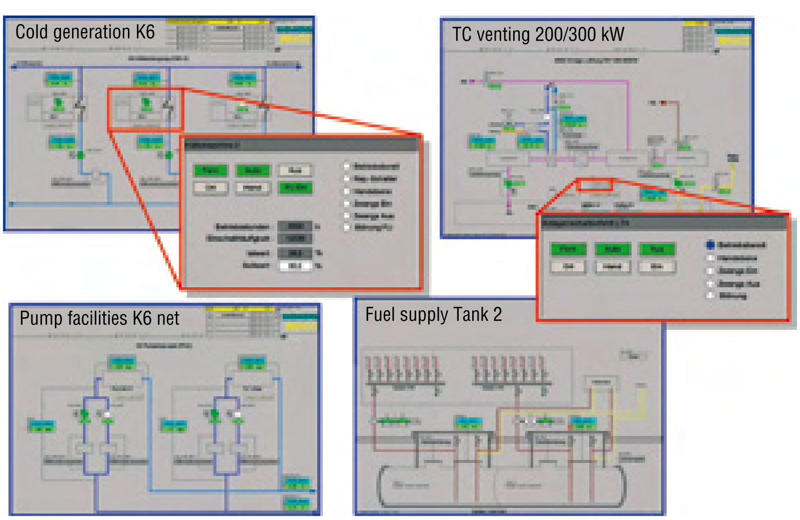


Figure 13: Supervision and user interface of technical building equipment automation

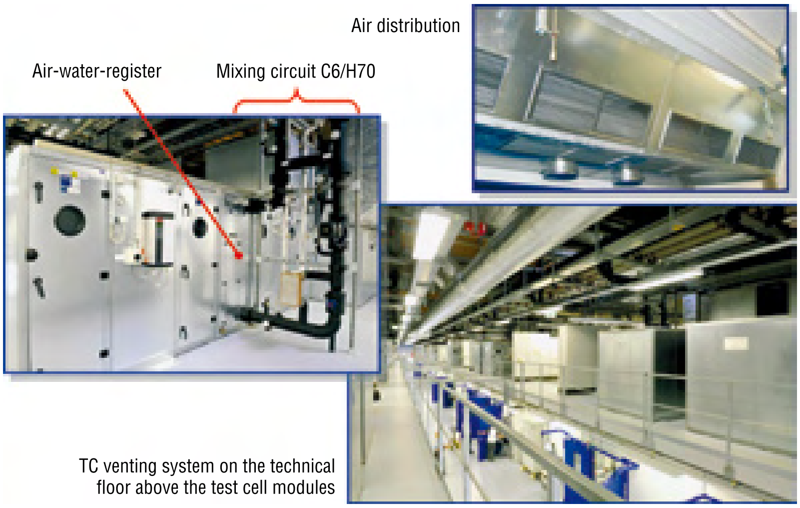


Figure 14: Test cell venting systems with air/water and supply via mixing circuit

med by the ventilation system mounted on each test module. External air is taken in through the weather screen in the façade. The conduit routing of the escaping air runs from the ventilation system through sound absorbers and roof hoods to the outside. The additional air conditioned in the ventilation system is blown into the test cell through an air distributor with integrated ventilation screens and branch necks. The ventilation concept consists of the following basic functions:

– heating of the test cell before the start of the equipment under test and at low load in winter
– cooling of the test cell at higher test loads through removal of the generated heat from the test cell
– room pressure control of the test cell combined with maintaining the mass flow balance at different operating states of the equipment under test.

For this purpose the energetically optimized operating mode of the ventilation system was calculated and realized through the associated control technology in the switch cabinet of the system. For the load case cooling, the temperature in the suction chamber of the exhaust air is regulated to +40 °C for energy reasons. For the load case heating the additional air temperature is regulated to +10 °C in the pressure chamber of the additional air. These two boundary values guarantee that the test room temperature range stays in the defined and required limits.

The monitoring of the freely programmable threshold temperature (+38 °C) above the equipment under test is performed by an additional sensor which corrects the permissible exhaust air temperature to lower temperatures if the set value is exceeded. The air quantity is controlled depending on the load entered into the test cell through variable speed fans.

An air water register has been implemented in the VS for compliance with the aforementioned limits (**Figure 14**). This register serves for the functions of "cooling" and "heating" according to the thermal output entered into the test cell. To guarantee a dry cooling of the air the register is supplied through a mixed circuit which increases the flow temperature of the K6 so that no dehumidification is performed in the cooling register.

To avoid the overflow of air from the cell into the hall, the cell is kept at a negative pressure. The pressure difference to the hall is 10 Pa. This pressure difference between the test cell and the hall is measured with suitable instruments. The negative pressure in the test cell is regulated via the speed control of the exhaust air fan.

The filter monitoring is performed through the differential pressure measurement at the PPC with corresponding message to the process measurement and control technology. Since the PPC is dimensioned for operation with clogged filters, an alarm message is not necessary.

5.4 Intake Air Temperature Control, Exhaust Gas Suction

Within each test module is another ventilation device with the functions filtering, electrical heating and cooling for the supply of temperature controlled combustion air of 20 °C directly to the equipment under test installed (**Figure 15**). Advanced requirements for the combustion air conditioning regarding humidity and pressure are covered by mobile FEV intake air conditioning systems.

For the disposal, the resulting exhaust gases from the combustion engine operation of the test benches flow through individual dead end lines at the test benches, through collection lines in hall C and hall A as well as a central suction chamber to the exhaust gas fans at the central technical area. The pressure-side collection of the exhaust gases from the individual exhaust gas fans happens in the pressure chamber, from where the exhaust gases are led through the pressure-side exhaust gas sound absorber and the exhaust gas chimney into

Figure 15: Venting device in TC for standard combustion air tempering

the environment. The speed of the exhaust gas fans is controlled by independent frequency converters. The control input is the differential pressure at the most disadvantageous consumer location, which is measured by a suitable sensor at the exhaust gas collection line. With the speed control of the exhaust gas fans a defined negative pressure compared to the atmosphere (hall C1/C2/M/A1/A2) is regulated at the most disadvantageous consumer location.

5.5 Fire Safety, Extinguishing Technology

Fire events in test benches are usually accompanied by direct and indirect danger for the staff. Heat and smoke pose a primary danger which prevents manual extinguishing attempts, in particular for rapid fire spread. If gases like e.g. CO2 are used in automatic extinguishing systems, employees are endangered due to the toxicity of the gas. Due to this boundary condition, usually a lead time of about 30 seconds is observed. During this time period of course the fire and the smoke gases can spread uninhibitedly and therefore cause a comparably high primary fire damage.

Because of the volume expansion through the CO_2 flowing into the test bench, pressure relief shutters are mandatory. If pressure relief and CO_2 removal/suction cannot be achieved directly through the façade, complicated exhaust air systems are required. This requirement is a particular challenge for climate test cells.

The demand for an effective fire protection solution for the DLP consisted therefore of the following criteria:

- personnel security
- minimization of primary fire damage
- short operational interruptions
- low influence on infrastructure
- unmanned permanent operation.

The DLP uses high pressure fog extinguishing technology. This method fights fires with the smallest droplets of untreated tap water which are distributed in the extinguishing area like a gas. Hence also hidden sources of fire, e.g. in the area of the equipment under test, can be reached safely. The most important extinguishing effects are the cooling and the inerting effect. The cooling effect also protects personnel and technology from heat. Apart from the extinguishing effects described above a comparably significant washout of corrosive smoke gases and soot can be observed in contrast to gas extinguishing systems.

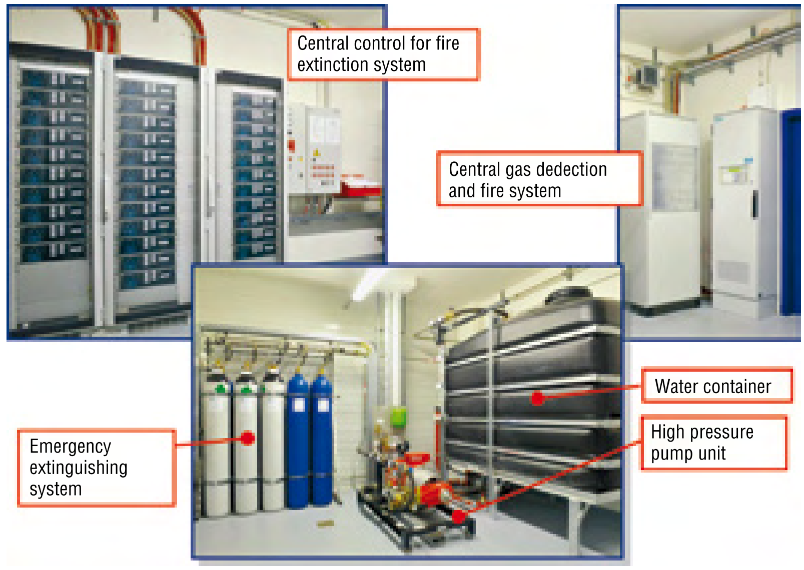


Figure 16: Central extinguishing system room with water container, high pressure pump unit, emergency extinguishing system, and controller systems for fire detection and extinghuishing, located in building section M

This is an overview of the advantages:

- lower risk for the personnel
- no lead time
- rapid fire fighting
- washout of smoke gases
- homogenous cooling of hot surfaces
- short operational interruption
- no logistics or removal of extinguishing agents that are dangerous to people e.g. CO_2
- no pressure relief shutters.

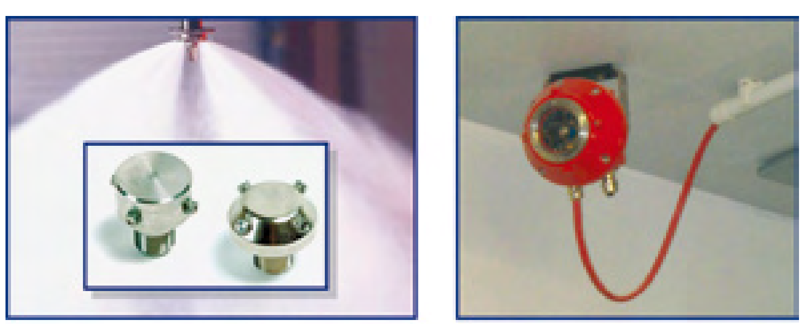
The high pressure fog system consists essentially of the following components:

- fire water container
- high pressure pump unit
- emergency extinguishing system
- main distributor and branch pipe network
- area valves
- nozzle base and nozzle heads
- fire alarm/extinguishing control center.

Reservoir, high pressure pump unit, emergency extinguishing system and fire alarm and extinguishing control center are situated in a central extinguishing room (**Figure 16**).

High pressure plunger pumps and a pressure of at least 100 bar produce a fine fog through special fog nozzles (**Figure 20**).

In case of a fire, approx 4.5 l/min fire water are released on to a protection area of up to 6.25 m² per nozzle head. The fire water quantities are between 23.00 and 100.00 l/min depending on the size of the extinguishing area. Additional measures have been implemented in the climate test cells, which keep the system functional at every operating point or in the complete temperature profile, respectively. Apart



Water fog injector

mounted flame detector

Figure 17: Water fog injector for the generation of the water mist and mounted flame detector

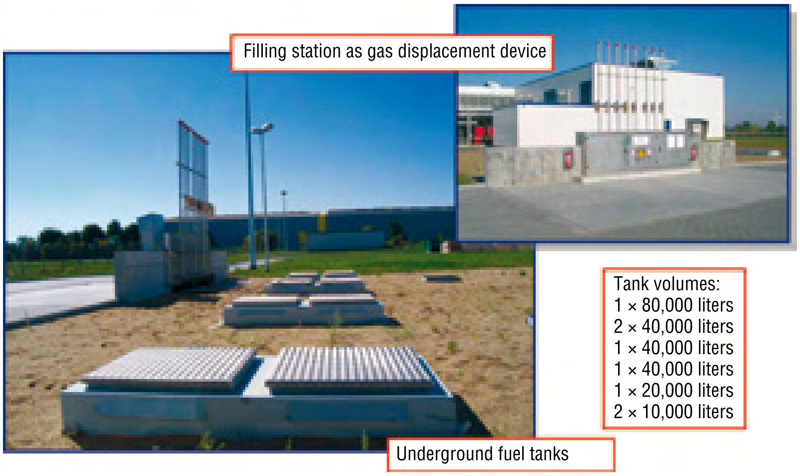


Figure 18: Underground fuel tanks and filling station with gas displacement device

from the test benches, their false floors as well as the central rooms of the fuel supply are also considered fire extinguishing areas. An area valve is installed in each of the extinguishing areas.

The main and the distributor pipe network between extinguishing center and area valves are filled with fire water and pressurized for monitoring purposes. Such the extinguishing already starts after approx 5 sec.

The fire water reservoir is dimensioned with only 4.0 m² for 30 minutes. If in case of a fire the public electricity network is interrupted or if a rare pump defect occurs, the function of the emergency extinguishing system is guaranteed for ten minutes with the help of an energy-independent pressure bottle unit.

The fire alarm and extinguishing control technology also consists of the automatic monitoring of the described protection scope as well as the monitoring and selection of the extinguishing system. The test benches have a mixed equipment of smoke, thermal difference and flame detectors (**Figure 17**). The triggering of the extinguishing system is based on a two fire alarm concept. Two detectors for the same or different characteristics trigger the extinguishing system. In addition to the automatic fire alarms, a manual trigger is installed in each extinguishing area.

Further, the test benches were equipped with a so-called extinguisher cutoff button to interrupt the extinguishing e. g. in case of a spurious alarm. To be energy-independent, fire alarm and extinguishing center have an emergency electricity supply that lasts for 72 hours. In addition the trigger elements have their own power supply, CPU and emergency supply for each extinguishing area for redundancy.

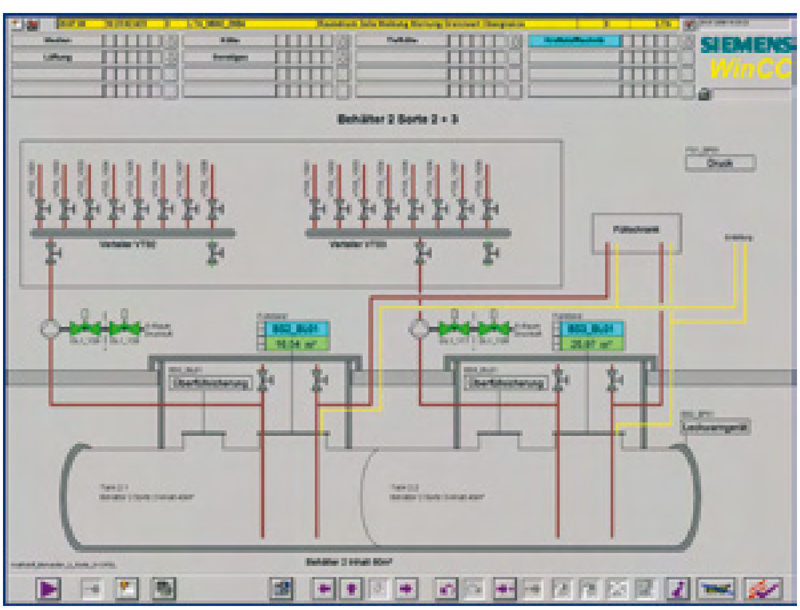


Figure 19: Monitoring of tank filling level by facility control center

5.6 Fuel Supply

A central fuel supply system was established for the supply of the engine test benches with the following boundary conditions.

- compatibility of all test benches with special fuels
- optimized storage volume regarding consumption and availability
- high supply reliability for durability tests
- low costs, in particular during operation and for maintenance
- compliance with all legal regulations.

A special fuel distributor provides the DLP with 100 % compatibility for special fuel supply of all test benches. The fuel supply was realized in compliance with the water law suitability examination of the German Water Resources Act (WHG), the regulations on facilities for treatment of substances hazardous to water (VAwS) as well as the approval according to the regulations on operational safety (BetrSichV). As a result, the operation with future bio fuels as ethanol, methanol or mixtures of standard fuels with bio diesel is possible without restrictions.

The compatibility with special fuels poses special requirements for the resistance of the materials used and the properties of the individual facility components. To guarantee an optimal material resistance against a most diverse range of fuels, all components as storage reservoirs, pumps, armatures and pipelines were manufactured in stainless steel. The feed pumps are sealless magnetic drive frequency-controlled gear pumps with a maximum pump capacity of 7 l/min. All additional seals are PTFE seals.

The choice of tank number and size was influenced by the estimated fuel consumption in the test bench as well as the demand for various special fuels. It also had to be considered that the storage tanks must have a sufficiently large buffer until the subsequent delivery of new fuel (also in

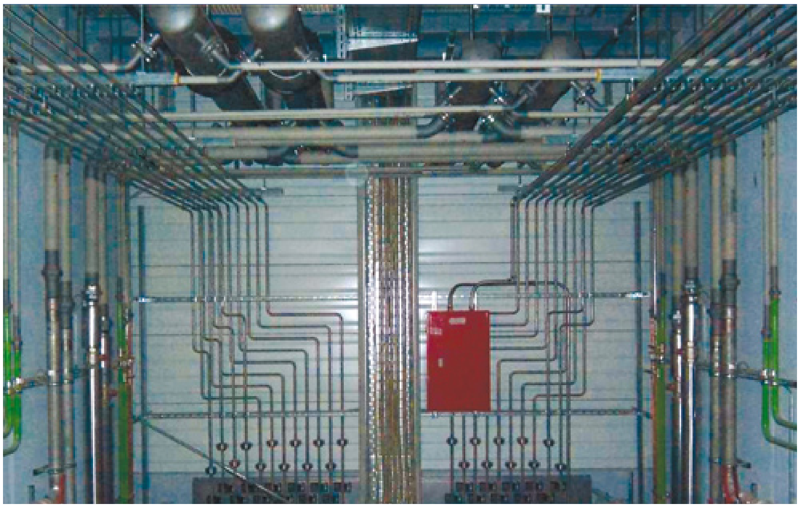


Figure 20: Entering of fuel single piping into building C1/C2

case of a potential road blocking according to the German regulations on transport of hazardous good by road) is guaranteed. Further, it must be possible to empty the complete content of a tanker to minimize fuel purchasing prices.

The underground fuel depot is filled through a central filling cabinet which contains the filling connections and the associated gas displacement device connections (**Figure 18**).

To achieve a first overview over the current depot levels the tanks were equipped with a manual dipping device and an electronic continuous level measurement device based on the principle of guided microwaves. Hence, the tank levels can be determined at the plant process control at all times and used for the fuel logistics (**Figure 19**).

An independent supply system via barrels allows the supply of the engine test benches with special fuels in smaller quantities. Each test bench can be operated with special fuel via a barrel (there are four active barrel slots available).

An essential aspect of the conception of the fuel supply system was a high system availability. It became clear that an individual supply of the test benches with a pump assigned to each test bench and an individual line to the test bench is optimal (**Figure 20**). The principle of loop lines for the distribution of the required variety of simultaneously usable fuel types in the building would lead to a significantly higher installation effort with an equal number of loop systems. On the other hand, with a reduced number of available loop systems high flushing wastage would result for a fuel change and the redundant design of the fuel supply would require additional efforts in this case.

A fuel distributor with dry clutches is used for the type preselection of a maximum of eight different fuel types in construction phase 1 (**Figure 21**). The effort for the flushing of an individual line for a fuel type change at a test bench is low.

Apart from the high quality mechanical components a Siemens control with high availability was also installed, which communicates with the fuel supply via redundant Profibus systems. Further the system can be operated independently without the plant process control. The direct communication of the individual PLC controls provides the electronic linking of the individual contracted work packages. The plant process control provides the general control.

The planning of the central fuel supply for legal approval according to WHG, VAwS and BetrSichV posed special challenges. At the time of the permit application there was no legal basis for tank reservoirs with fuels containing ethanol. Hence, the option for an application on the basis of a suitability examination had to be used. In cooperation with the Technical Inspection Authority (TÜV) Hesse a concept was created with which the authorities granted their approval for the erection and operation of the tank reservoirs and the supply systems. This concept contained specifications for the execution as well as specifications for the maintenance and repair of the respective facilities. This was particularly important for the design of the fluid-tight tanker emptying station, the container equipment for inflammable substances, the design of the fuel pump room as well as the pipelines laid above and under ground.

All mentioned requirements for the fuel supply were realized within a short time period of only six months. Due to the individual supply of the test benches it was possible to commission test benches successively according to their availability by the user. Also, because of the option for independent operation it was possible to commission the facility first without the completed plant process control.

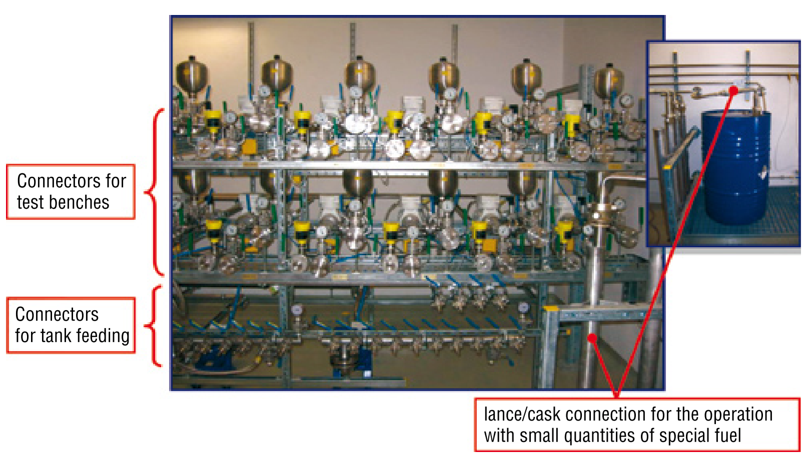


Figure 21: Fuel rail with quick-connectors and test benches related pumps for supply of single pipes to test bench

FEV Master Program

Driven by new markets and vehicle applications, the range of engine variants and areas of application is constantly increasing. This makes the task of developing a combustion engine and its variants to the stage of volume production more and more complex. Each variation involves complex tests to demonstrate the reliability of an engine with regard to its theoretical lifespan. This fights against the current trend of reducing development time and containing costs. To maintain this trend, while at the same time ensuring that a suitable service life is attained for the different engine variants, FEV has developed a program named "MASTER" (MASTER = Map for Synchronized Testing, Engineering and Engine Reliability).

FEV MASTER has three main components: motor test analysis, synthesis and validation. The relationships and interconnections are shown in Figure 1 on the basis of a V cycle representation. It is immediately evident that the process is characterized by deep integration, which is a synthesis of all the information on the engine that is relevant to the analysis. These insights are used to develop detailed analysis test matrices and test cycles, together with a validation plan. During the trial phase, the test plans are constantly verified with regard to attaining their goals for engine life, cost and time. This applies to the baseline engine and to each of its components.

Figure 1 shows a simplified extract from a test program, which FEV developed, successfully implemented and evaluated. The evaluation based on test runs according customer driving cycles, which are highlighted in yellow. Furthermore, a variety of test cell and vehicle test runs are listed with the corresponding number of test hours/kilometers. The test hours are then converted into 'real' equivalent kilometers. Upon completion of the tests, the 'real' equivalent values in kilometers are entered into an additional table and combined with the results and data on wear to calculate the numbers of 'predicted' equivalent kilometers. This value is extrapolated for the baseline engine, for its components and its variant parts. The estimated data is processed with the aid of further Weibull analysis software and used to establish the theoretical lifespan of the engine, for example according to B10.

By using synergies during the testing of the different engine variants, FEV MASTER is able to generate a standard development program that is so lean that the corresponding theoretical lifespan can be attained and documented, while at the same time reducing both costs and development time.

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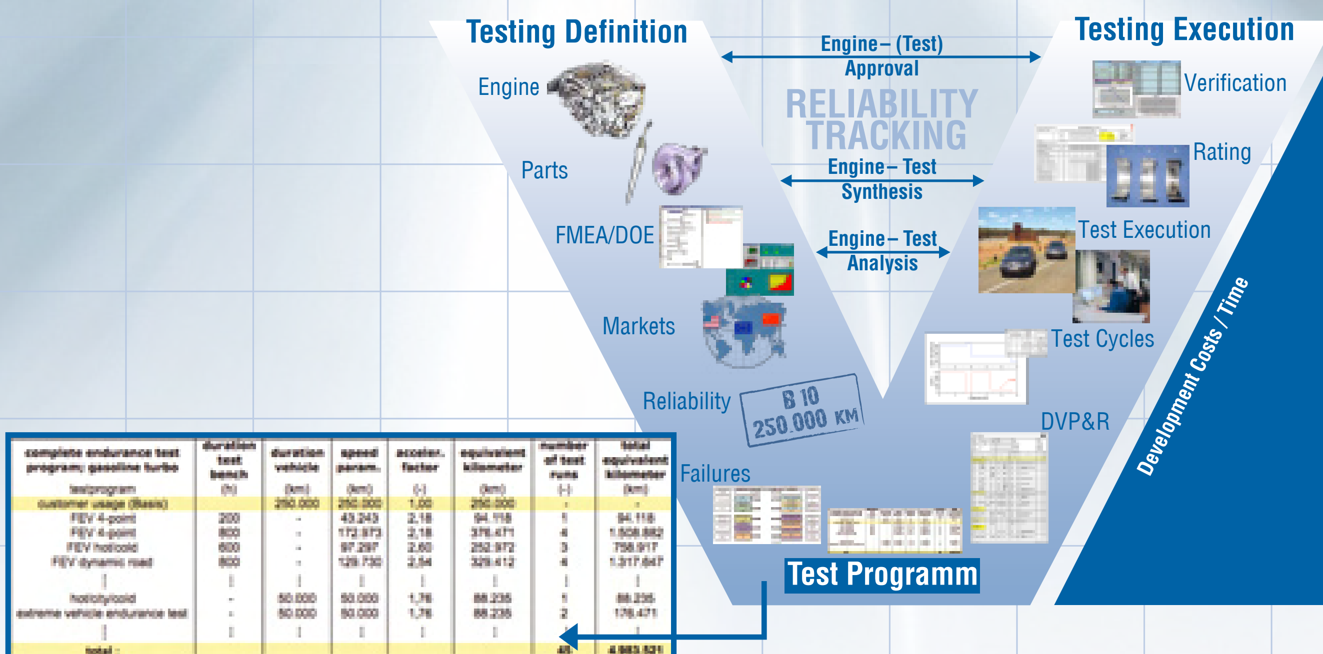
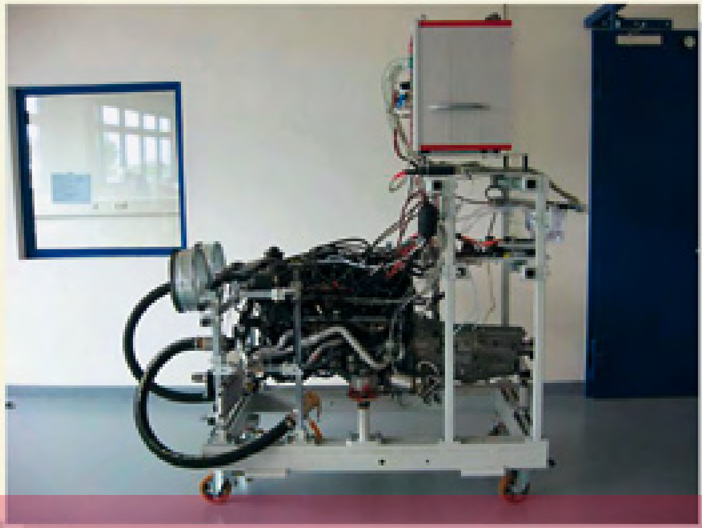


complete endurance test program; gasoline turbo	duration test bench	duration vehicle	speed param.	acceler. factor	equivalent kilometer	number of test runs	total equivalent kilometer
testprogram	(h)	(km)	(km)	(-)	(km)	(-)	(km)
customer usage (Basis)		250.000	250.000	1,00	250.000	-	-
FEV 4-point	200	-	43.243	2,18	94.118	1	94.118
FEV 4-point	800	-	172.973	2,18	376.471	4	1.505.882
FEV hot/cold	600	-	97.297	2,60	252.972	3	758.917
FEV dynamic road	800	-	129.730	2,54	329.412	4	1.317.647
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
hot/city/cold	-	50.000	50.000	1,76	88.235	1	88.235
extreme vehicle endurance test	-	50.000	50.000	1,76	88.235	2	176.471
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
total :						49	4.983.521

Fig. 1: V-Cyclus for Testing-Definition – Excecution – Tracking



Measurement and Testing Technology of the DLP

For the fulfillment of the diverse technical specifications a number of facilities has been newly developed or further developed from the existing product portfolio of the technical division Test Systems of FEV. To secure a high availability the measurement and testing technology has been designed maintenance free or requires little maintenance.

1 Technical Planning and Execution of the Test Technology/Test Benches

According to FEV's definition the test technology consists of the decentralized equipment for the operation of equipment under test that is assigned to a test cell. It is usually mounted at or in the test cell and has its own – normally standardized – interface for central supply. The test technology employed in the DLP corresponds to the product portfolio of the technical division Test Systems of FEV (**Figure 1**). In addition to the test technology components illustrated in Figure 1 it also comprehends the mechanical and electrical equipment of the test bench:

- basic frame/foundation for equipment under test
- dyno assembly frame
- pallet system and pallet clamping mechanism
- piping, valves, connections and quick connections on the test bench side
- boom for vehicle interface
- test cell housing, false floor
- general electric supply of the test bench
- frequency converter, power cable for the load machine.

Only a few main components and functions are described in the following.

2 Test Bench Foundations, Dyno Adjustability in the Power Train Test Bench

The foundations of the engine test benches consist of a welded steel construction. A 7x7m cast mounting plate with grooves and collection channel around the perimeter is installed in the power train test benches. All test bench foundations are equipped with a level regulation so that they can also be driven upon at varying

loads without a step to the grating floor.

A diverse range of vehicle sizes was considered for the creation of the technical specifications for the power train test benches. Vehicles with a wheel base from 1.7 to 5.5 m and a wheel gauge of up to 1.8 m relative to the wheel seat can be operated. The modification effort for the operation of vehicle drives of different sizes was to be reduced to a minimum according to the technical specifications. Therefore the easy adjustability of the asynchronous machines had to be guaranteed and the connection and disconnection of the power cables had to be avoided. In addition, the cable must not restrict the traffic routes in the test bench. To meet these requirements the load units are moved by dedicated constructed lift-trucks. The power cables do not have to be disconnected for this process but are modified via drag chains with the load machines.

3 Pallet for the Equipment under Test and Positioning in the Test Bench

The equipment under test is placed into all test benches of the test facility on the same pallet. The engines are mounted on the pallet with an alignment tool. The alignment tool allows the correct engine alignment outside the test bench. The pallets have wheels and are moved within the test facility without additional engine power support. Guiding rails installed in the test bench yield an easy threading into and out of the test bench seat. The alignment in three spatial dimensions and three planes and the attachment of the pallet in the test bench is performed through a common work process. The pallet is lifted with a compressed air tool and simultaneously aligned for height. No additional attachment is necessary because the clamping device is self-locking.

The measurement system (FEV IntegRate-Module) for the measurement signal reception is permanently installed to the pallet together with the engine.

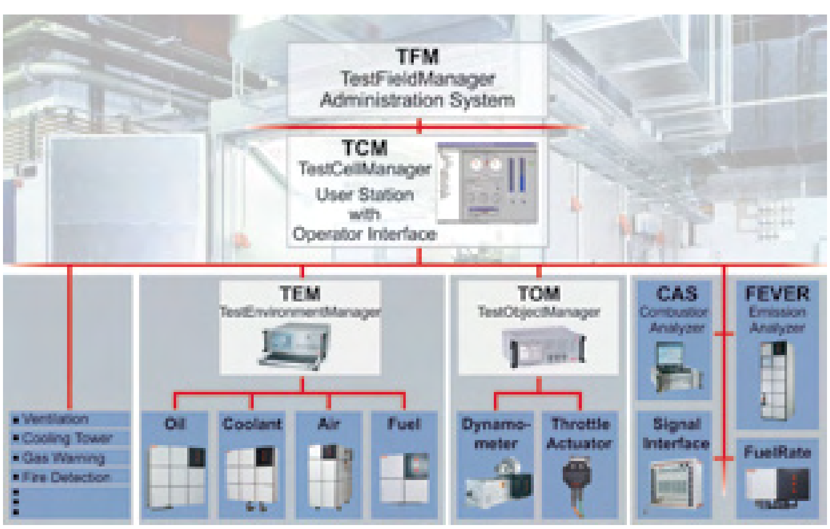


Figure 1: Products of the department Test Systems of FEV Motorentechnik, which is applied in DLP

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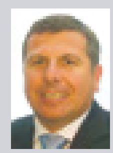
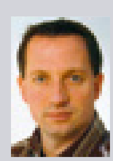


Lothar Müggenburg is Project Manager at FEV Motorentechnik GmbH in Aachen and was responsible for the development of the measurement and test technology of the DLP.

Ralph Hülsmann is Senior Engineer at FEV Motorentechnik GmbH in Aachen and was responsible for the development of the conditioning technology of the DLP.

Davy Politsch is Product Manager at FEV Motorentechnik GmbH in Aachen and was responsible for the test bench control and simulation of the DLP.



Frank Peters is Team Leader at FEV Motorentechnik GmbH in Aachen and was responsible for the electric supply and the electric test technology components of the DLP.

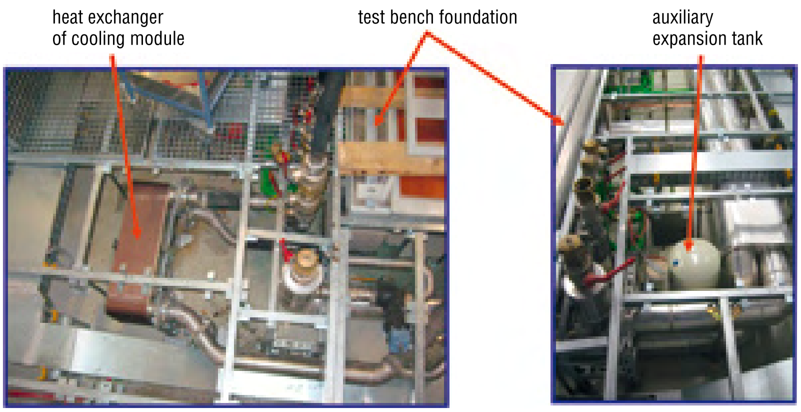


Figure 2: Cooling module and expansion tank in double floor of test bench, close to the engine

The running preparation and the testing of the engine as well as the associated measurement technology are performed in the rigging workshop. In the near functional test bench the engines are run fired and without load, **Title Image**.

In the test bench the media connections, the shaft connection, the exhaust gas system and the electrical connections are connected after the pallet with the equipment under test has been moved into the test cell and clamped. The measurement signal is transmitted via CAN lines to the test bench automation (FEV-TCM).

The extensive parallelization of preparation activities in the rigging workshop (mechanical/electrical setup, measurement technology application), the pretest at the functional test bench, the quick clamping and the quick couplings in the test bench allow a very fast commissioning of the equipment under test and a fast test run start. Should defects occur and test runs be canceled, a fast exchange of the equipment under test and a change intensive operation of the test bench are possible.

4 Conditioning Units

For the fulfillment of the diverse technical specifications a number of facilities has been newly developed or further developed from the existing product portfolio of FEV. To secure a high system availability the systems have been designed with the choice of components that are maintenance free or require little maintenance. When maintenance or repair are necessary, they should be possible without major test interruptions. This requirement is fulfilled by the realization of the systems in the form of movable and therefore easily exchangeable units which can preferably be operated outside of the test bench. All conditioning units communicate via CAN bus with the FEV TestEnvironmentManager (TEM).

In principle, three system types with two performance levels each are intended for the cooling water conditioning, where due to their concept the system types can be easily exchanged in or at the test bench:

- cooling module for tests with coolant set value temperature of 50 to 120 °C (no external heating of the coolant)
- coolant conditioning for cold temperature tests (with coolant set value temperatures from -10 to 120 °C)
- thermal shock system (for engine cooling water exit temperatures up to -25 °C).

All system piping is made of stainless steel. The cooling module is installed in the false floor of the test bench and connected directly to the heat exchanger circuit 40/50 °C on the secondary side. Through the positioning near the pallet with the equipment under test in the false floor a minimal water volume with at a simultaneously extremely low, vehicle-like pressure loss can be achieved despite the high rated power of the test benches. To compensate for the thermal expansion of the cooling module-side coolant an additional compensating reservoir has been installed (**Figure 2**). The engine setup therefore can be performed with the original vehicle cooling water compensation reservoir and such without intervention into the engine's own cooling system.

Further, the coolant conditioning comprehends an external heating of the coolant and is designed to simulated the temperatures occurring in the test bench for low load profiles and low outside temperatures. For this purpose,

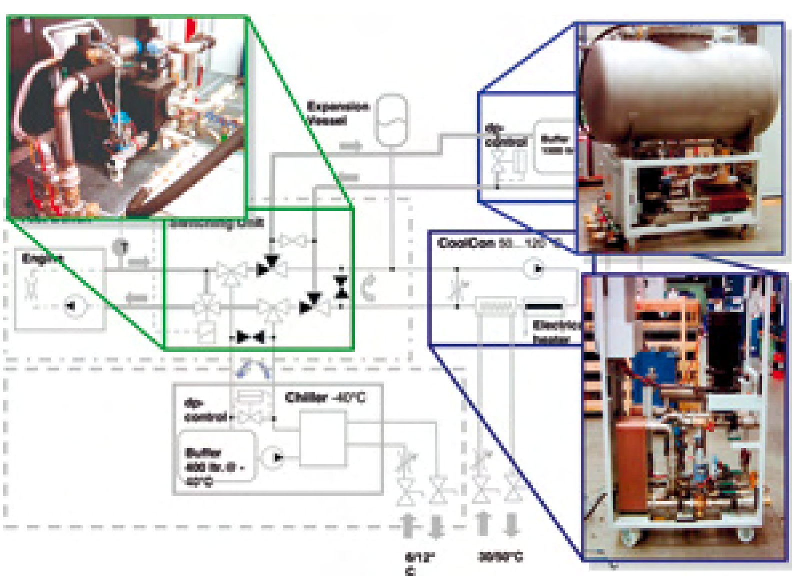


Figure 3: System configuration of thermo shock device with the components FEV CoolCon, thermo shock module, switching unit and chiller (optional)

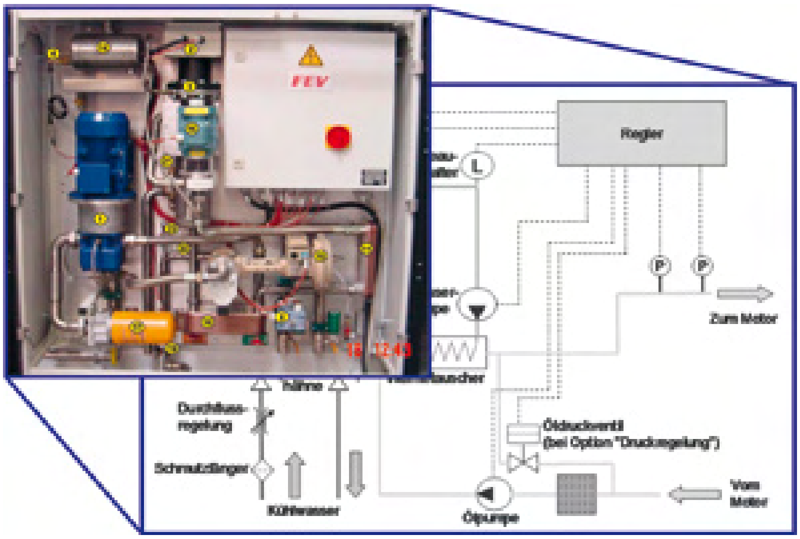


Figure 4: Lube oil conditioning, also for deep temperature tests (FEV LubCon)

it is essential to have a heating and fast cooling of the engine to values below 0 °C that are faithful to the vehicle conditions.

The thermal shock system used in the DLP is employed for standard thermal shock runs of up to 25 °C engine cooling water exit temperature.

It consists of:

– a movable cooling water conditioning FEV CoolCon, which conditions the warm phase of the test cycle
– a movable thermal shock module consisting of a storage volume with pump and heat exchanger to the 6/12 °C supply system
– a movable switch unit (valve block) with switch valves to realize the individual phases of the thermal shock. Here, the gradient of the cooling canbe controlled individually and precisely with a selectable mixing valve in the branch to the engine.

The storage volume of the thermal shock module provides the necessary cooling capacity to cool down the engine quickly. The advantage of the storage volume is that the warm phase of the cycle can be used to cool down the energy storage. This reduces the required power to be installed on the supply side (**Figure 3**).

For the -25 °C thermal shock test the system is expanded by a system component, a refrigerating machine with a flow temperature of -40 °C. This is a water-cooled unit with a cooling power of 50 kW.

The conditioning of the lubricating oil is performed by the FEV lubricating oil conditioning system (LubCon) and an oil water heat exchanger (**Figure 4**). Therefore, oil cooling and heating is possible at the engine and mock-up test benches. For mock-up tests, a LubCon with higher heating power is used. The oil conditioning is designed such that the lubricating oil is not stressed by high heating area temperatures at any point. The control deviations from the set value are smaller than 1 K (stationary operation) even at the switching point between heating and cooling of the oil.

For the realization of the cold temperature tests at phases of -10° C (e. g. starting conditions) the oil conditioning is equipped with an additional heat exchanger with supply connections for a chiller or for the cold temperature supply of the five climate test cells. Further, the LubCon allows controlled oil temperatures up to +150 °C.

The fuel temperature influences the thermodynamic operating behavior of a combustion engine. Meaningful and reproducible test results and therefore an efficient test bench operation are only achievable with fuel temperature control. For this purpose a fuel conditioning is used, which regulated the preset fuel temperature independently of the test room temperature or the engine operating point automatically. The system used in the DLP is designed such that the fuel is not stressed by high heating area temperatures at any point.

A FEV fuel conditioning with expanded measurement range and advanced functionality for the low temperature range (climate test cells) is employed in the DLP. The fuel conditioning was specified and dimensioned for the use of all commercial SI and diesel engine fuels, all special fuels with country-specific additives, reference gasolines, all ethanol and methanol mixed fuels (up to 100 %) and bio diesel mixed fuels.

The fuel thermostat allows the cooling and heating of the fuel being supplied from the storage reservoir. The fuel consumption measurement device FuelRate as well as a bypass near the engine were integrated into the system (**Figure 5**). The bypass near the engine provides the engine with the necessary

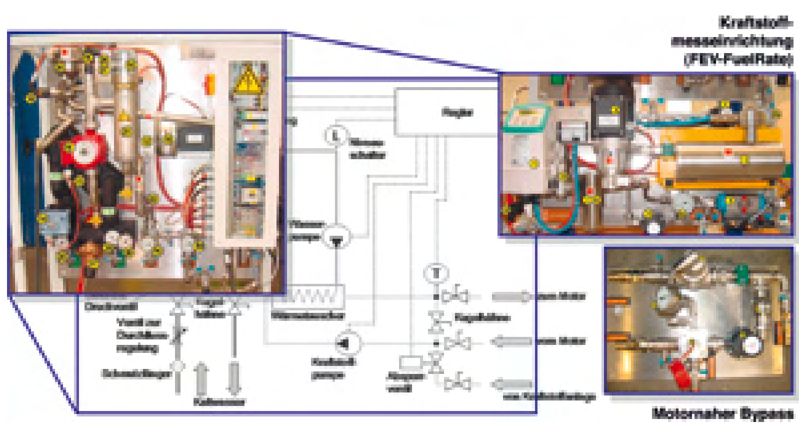


Figure 5: Lube oil conditioning, also for deep temperature tests (FEV LubCon)

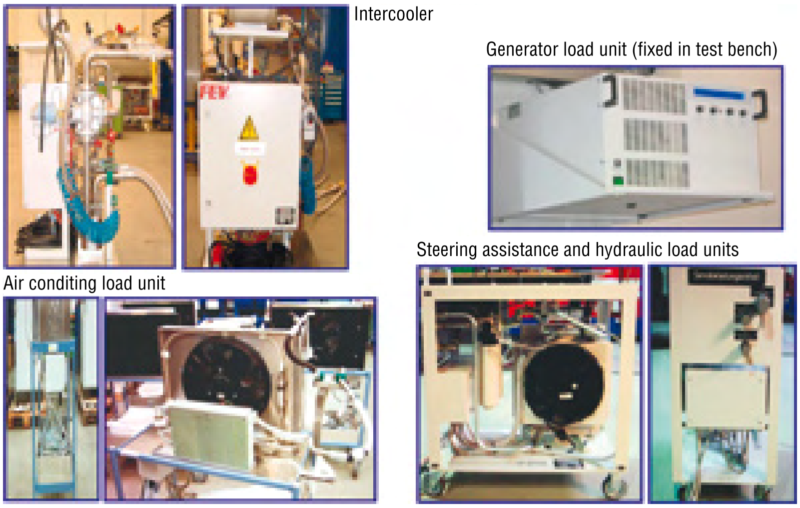


Figure 6: Intercooler and mobile load units for auxiliary devices of engine

fuel pressure and at the same time with a high control precision. The measurement range of the sensor based on the Coriolis principle is 0.5 to 150 kg/h or 1.0 to 250 kg/h dependent on the system.

The supply of the combustion engine with temperature controlled intake air of regulated 20 °C is performed with a test bench-permanent intake air conditioning in the form of cooled air ventilation. For special tests each system can modularly be expanded by a heating to realize and intake air temperature of up to 70 °C.

A controlled cooling of the charge of supercharged combustion engines in the range of 40 to 150 °C is possible with the separate mobile charge cooling. No external heating of the charge is intended. The system consists of an intermediate circuit (heat carrier circuit) with the respective heat exchangers to the engine-side charge and the secondary side cold water of the central supply (**Figure 6**).

Further, the DLP possesses a large number of mobile auxiliary aggregates and load units. These systems are used for the controlled loading of climate compressor, generator (test bench-permanent), power assist steering pump and chassis hydraulics.

The load units are coupled to the various auxiliary aggregate types with corresponding adapters. All systems consists of movable carts which carry all necessary components. The connection tubes to the compressor are also mounted on these carts.

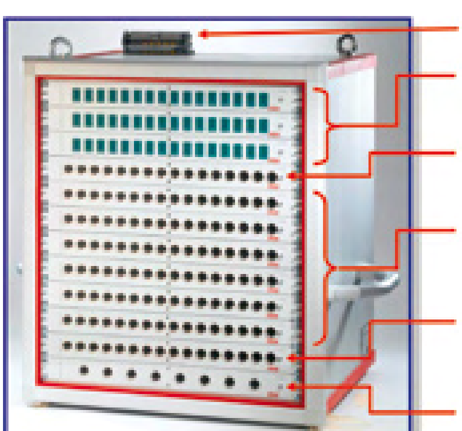


Figure 7: FEV-IntegRate-measurement module with example equipments

5 Load Unit for the Equipment under Test, Frequency Converter

All engine test benches of the DLP are equipped with a FEV DynaCraft System for the loading of the combustion engines. These are four quadrant IGBT frequency converters with high speed asynchronous drives, torque measurement device and the FEV TestObjectManager (TOM), the regulator unit for the monitoring and control of load unit and equipment under test.

Due to the low angular momentum and high overload capacity the DynaCraft systems can be used for stationary, transient and dynamic tests in a speed range up to 9,000/min. The reaction times of the converter for torque requirements from the superior control are measurably smaller than 1 ms.

The converters work with the most modern technology of IGBT bridge circuits (two circuits) coupled via a DC intermediate circuit. Sinus currents flow on the mains side in the engine as well as the generator operation. A pure active power is drawn from or fed into (in the generating case) the mains network, respectively. The cos phi can be adjusted and is almost 1. The total efficiency is approx 95 % and independent of the energy direction. Power outages in the generator as well as the engine operation are automatically recognized and lead to the blocking of the complete test bench.

These properties combined with the fast superior control through FEV TestObjectManager form the basis for the dynamic test cycles with simulations of gear shifts that are increasingly modeled on road tests and such yield realistic results.

6 Measurement Data Acquisition

Basic requirements for the measurement data acquisition are the scalability and the modularity for the adaptation to varying test tasks. A simple integration of the FEV IntegRate-Module into the TCM based on the standardized CANopen interface facilitated this adaptation. Within its open structure the CANopen interface allows the automatic configuration of a network with up to 127 logical devices per node. The CANopen integration allows uniform access to all device parameters. Specific automation options of the IntegRate modules are also supported beyond the protocol features standardized in EN 50325-4.

24 bit digitizers and individual input channels for standard signals as voltage, current, temperature or pressure as well as for the incremental (digital) signals of frequency, speed or distance allow precise measurements. All channels are separated galvanically to minimize EMC interferences. The universal measurement amplifiers used also provide the option of a sensor supply. Digital, selectable outputs allow the simple selection of mechatronical components of the equipment under test.

The FEV IntegRate measurement module (**Figure 7**) has analog processors for signal preprocessing. The such mathematically calculated virtual channels produced by the module yield an efficient data reduction. This property allows real time monitoring of thresholds without involvement of additional systems. A result calculation in the measurement module allows the possibility for reduction of the bus load.

Further, the DLP is equipped with lambda probes, blowby and smoke detectors, on-line FEVER exhaust gas measurement systems as well as measurement technology for the pressure measurement of engines and for vibrational analysis. ■

Engine Development Techniques for Reducing Friction

Reducing engine friction offers great potential for reducing fuel consumption and supports the efforts required to achieve a reduction in CO_2. Therefore, it is essential to have techniques in place, which can support the design even during the crucial early phases of the project. FEV Motorentechnik uses numerous commercial and internally-developed tools, which can be used in both complete engine development programs and detailed design improvement projects.

Every concept phase begins with an estimation of the friction of every relevant engine component using the geometric data of the engine and empirical equations. These equations are derived from the world's largest friction database, currently containing motored friction investigations from approximately 480 engines. The results can be directly compared with existing benchmark scatterbands offering an immediate indication of the potential for design changes.

The dimensioning of the oil and coolant pump is carried out with standard software, such as FLOW-MASTER or GT COOL. Simultaneously, the dimensioning of the crank train components is completed with FEV Virtual Engine. Special attention is paid to the precise dimensioning of components according to their requirements. The continuous expansion of the coolant circuit model using a lubrication, friction and vehicle map allows for later simulation of thermal management measures or a pre-layout of vehicle tests conducted under extreme conditions.

In addition to both motored and fired friction investigations, special measurement techniques are available, such as the piston friction force measurement system known as PIFFO. PIFFO is based on the floating liner principle and is capable of measuring the friction force between the piston, piston rings and the cylinder liner in a crank angle domain within one degree of resolution.

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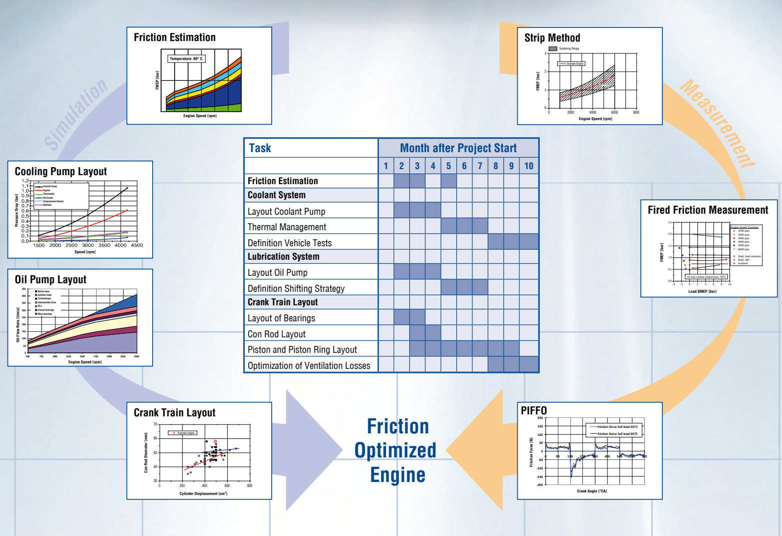

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Summary

The new FEV durability test center (DLP) at the location Brehna near Leipzig was completed after only 27 months of planning, construction and commissioning. The planning and turnkey construction of the test center was performed by the technical division Test Systems of FEV Motorentechnik with the support of external partners. Key to the success of the project was a consistent management by FEV of the various interface relations between the individual contracted work packages and the suppliers. This was the only way the project could be realized on time and without major cost deviations.

1 Introduction

During the facility conception the technical foundations for the testing of future power train technologies were already implemented to achieve the project goals.
In addition, current and future testing methods were considered (**Figure 1**).

Apart from the facility conception the necessary personnel and organizational prerequisites for an efficient operation of the test benches at maximum utilization of the investment were determined and implemented from the start.
These conditions also have effects on the technical design of the test center, e. g. when it comes to questions of the monitoring of the equipment under test or the redundant systems (**Figure 2**).

2 Conclusion

The FEV Dauerlaufprüfzentrum is the most modern test center for durability tests of engines and power trains worldwide. The challenges of a modern technical concept combined with a high facility availability at simultaneously optimum organizational boundary conditions for the efficient operation of the test benches absolutely exceeded the known efforts for the planning and erection of conventional test facilities. ■

- Installation of original vehicle exhaust gas system possible, including after treatment components as longitudinal and transversal setups
- Permission and technical equipment to operate with any kind of special fuel (ethanol, methanol, biodiesel, and any combination)
- Load with asynchronous dynos to more often perform dynamic test cycles derived from actual driving tests
- Power train test rigs to perform tests with the respective combinations of engine/transmission/power train components
- Deep cold test cells to simulate winter conditions
- Emission analysis benches for a well established judgment of engine conditions

… for the most modern durability testing, following today's and tomorrow's testing methods

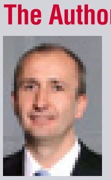
Figure 1: Highlights of technical concept at DLP to cover future power train technologies and prospective test methods

- Concept of central control room for the supervision and control of tested units and technical facilities
- Maximum availability of central technical facilities by redundant systems
- Fully continuous operation: 365 days/year, 7 days/week, 24 h/day
- Highly qualified team of test engineers in multi shift operation
- Complete and consistent control of enterprise resources by ERP system

… for maximum efficiency in modern durability testing

Figure 2: Highlights of company organization and associated technical boundary conditions of DLP for efficient operation of test benches

The Author



Dr.-Ing. Stefan Trampert is Senior Project Manager at FEV Motorentechnik GmbH in Aachen and Managing Director of FEV Dauerlaufprüfzentrum GmbH in Brehna and had overall responsibility for the ready-to-use erection of the DLP.

Appendix Abbreviations

ACEA: Association of European Automotive Manufacturers (Association des Constructeurs Européens d'Automobiles)
PPC: Plant process control
BetrSichV: German regulations on operational safety
CAN: Controller Area Network
CAS: Combustion Analysis System
CoolCon: Coolant Conditioning
COP: Conformity of Production
CVS: Constant Volume Sampling
DLP: Dauerlaufprüfzentrum (durability test center)
EMC: Electromagnetic Compatibility
ERP: Enterprise Resource Planning
FEVER: FEV Emission Rate
FuelCon: Fuel Conditioning
FuelRate: Fuel Consumption Measurement
GGVS: German Regulations on Transport of Hazardous Goods by Road
IGBT: Insulated-Gate Bipolar Transistor
IntegRate: Modular Measurement Signal Interface
ISMS: Information Safety Management Systems
CIP: Continuous Improvement process
VS: Ventilation System
LubCon: Lubricant Conditioning
OEM: Original Equipment Manufacturer
PTFE: Polytetrafluor Ethylene
VAC: Ventilation and Air Conditioning
PLC: Programmable Logic Controller
TCM: TestCellManager
TEM: TestEnvironmentManager
TFM: TestFieldManager
TMS: Technical Media Supply
TOM: TestObjectManager
VAwS: German Regulations on Facilities for Treatment of Substances Hazardous to Water and on Specialist Firms
WHG: German Water Resources Act

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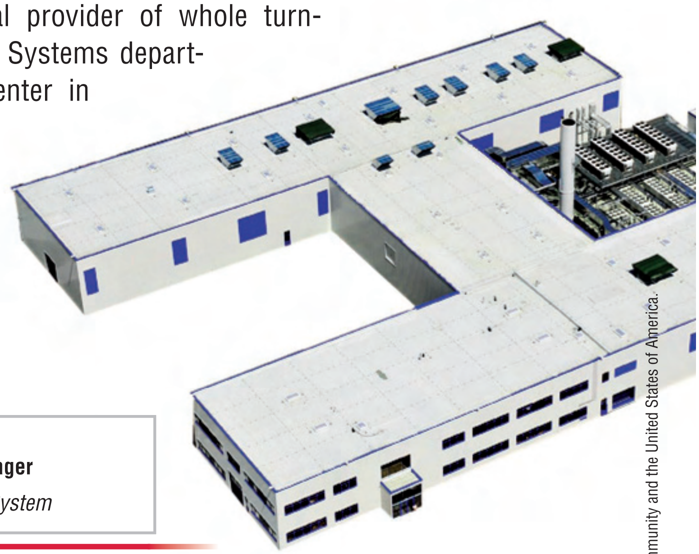
FEV Test Systems

Main contractor of FEV Dauerlaufprüfzentrum GmbH

FEV Test Systems was founded in 1995. Started as manufacturer of single test bench components and measuring devices, Test Systems has grown up to a substantial provider of whole turn-key test facilities all over the world. As main contractor FEV's Test Systems department has planned and fully equipped our new durability test center in Brehna with up-to-date and future-oriented test field technology.

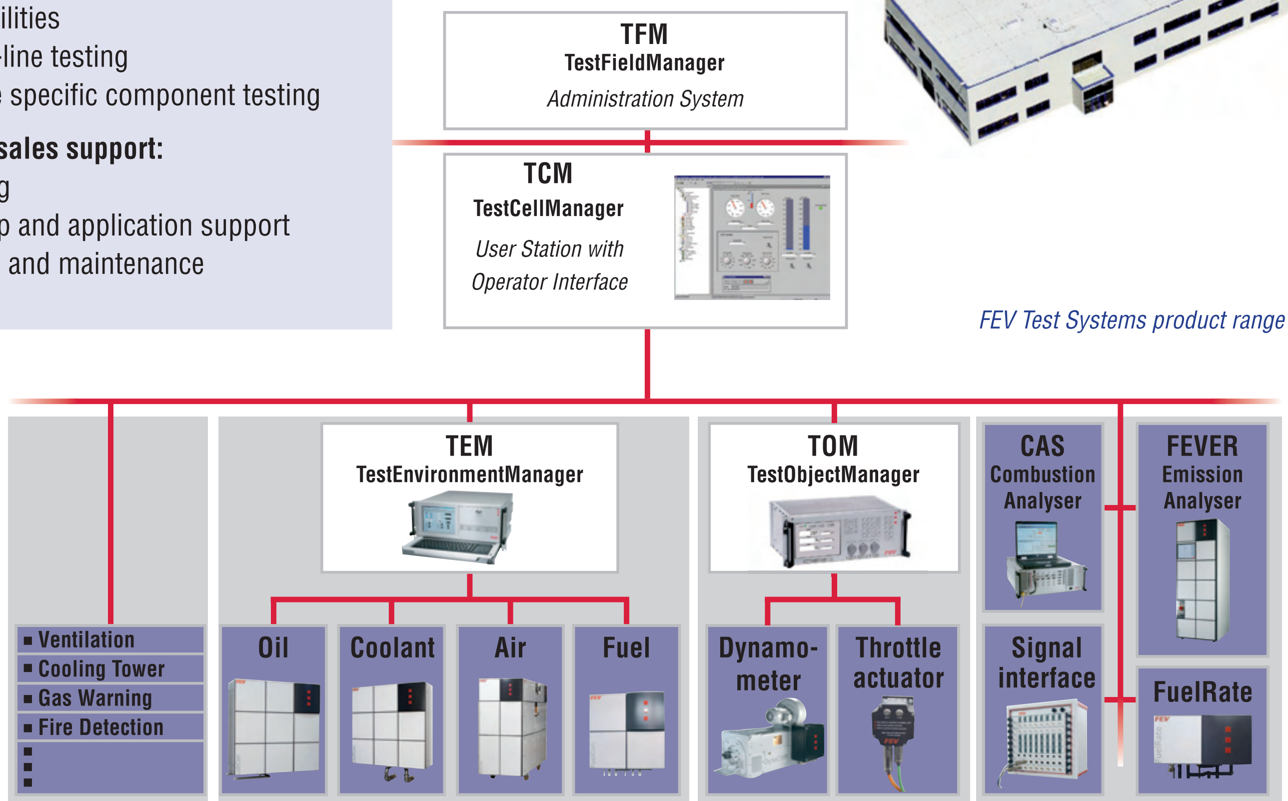


Turn-key test solutions for:

- Research and development activities (diesel, gasoline, hybrid, fuel cells, ...)
- Durability projects, incl. screening test facilities
- End-of-line testing
- Flexible specific component testing

Full after-sales support:

- Training
- Start-up and application support
- Service and maintenance



FEV Test Systems product range

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