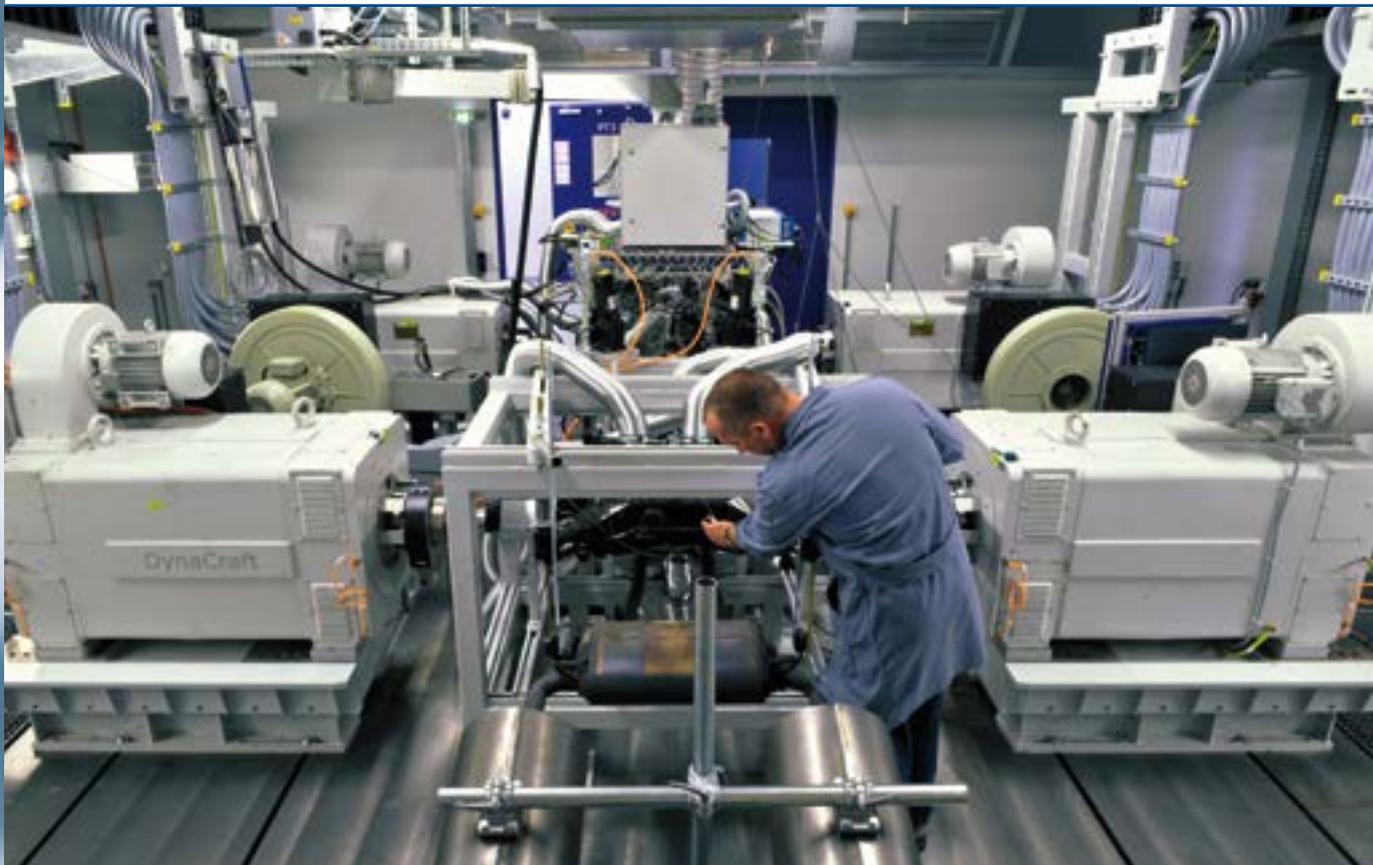


SPECTRUM

Transmission Development and Calibration

Special Edition, August 2009



FEV Transmission: The Upshift in Driveline Technology

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As a result of the strong market demand for powertrain development, FEV has significantly expanded its capacity for transmission development over the last decade. FEV long ago recognized the importance of a total drivetrain approach rather than specializing on a specific unit. FEV is able to handle complete transmission development programs through its four transmission divisions (Design, Testing, Hydraulics and Calibration).

In addition to our normal development projects, FEV further focuses its support on transmission development by benchmarking new transmissions, using FEV's well-known scatterbands and troubleshooting during the development process and after SOP. ▶

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Special
Edition

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Preface

Dear Readers,



Transmission development has seen a revolution in technology over the last decade. The market has witnessed a large diversification in technology with CVT, AMT, DCT and hybrid transmissions.

Major advancements have also been made in conventional transmissions. The role of the transmission within automated powertrains is becoming increasingly important, with the modern automatic transmission being the most important element in the vehicle's drivability.

Competition between the various powertrain and transmission concepts is at an all-time high. In addition, the electrification of the powertrain offers new alternatives. Against this background the transmission plays a significant role in CO₂ emission reduction.

FEV has intensively expanded its transmission development group over the last decade. We develop and optimize complete powertrain units. The complete process from concept through development and ultimately to implementation is our continual focus.

We are looking forward to supporting you in your development work!

Dr. Ing. Markus Schwaderlapp
Executive Vice President FEV Motorentechnik GmbH

► **Transmission development at FEV provides the following:**

- Complete solutions from the concept phase up to SOP
- Development support during all phases of development
- Benchmarking of new transmissions and powertrains
- System solutions including hybrids
- Vehicle integration and calibration
- Comprehensive testing including calibration demands
- Troubleshooting during development and after SOP

The different groups of transmission development specialists are fully integrated within the requirement-driven FEV organization, to achieve the greatest synergy. For example, the transmission calibration group is integrated into the vehicle application center and cooperates with all other parties that work directly on vehicles, such as engine calibration or vehicle NVH. Using this approach, FEV is capable of controlling the growing complexity and dependencies between powertrain components such as the transmission, combustion engine, chassis and – in case of a hybrid transmission – the electric motors.

Within the last decade, FEV has conducted over 100 powertrain benchmarking programs. The entire range of available technologies and their potential has been assessed for each of these projects. All key data from these analyses are processed, analyzed and stored in a database. With this data, FEV not only has an independent, objective opinion, but also benefits from an objective ranking using its comprehensive scatterbands. Integrating the transmission into the particular vehicle's powertrain has also been a part of some development programs, and has proven particularly useful in providing a detailed understanding of sub-system CO₂ contributions and interactions, or hybrid technologies.

Detailed knowledge of modern transmissions is an important attribute in understanding the critical parameters for future solutions; accordingly, experience gained in benchmarking is directly used in development projects and vice versa.

janssen_p@fev.com





Fig. 1: 7H-AMT developed by FEV

Transmission Design and CAE

In close cooperation with our customers and suppliers, FEV develops and optimizes complete powertrain units. In such projects, the focus is on the complete process from the initial concept through development and ending with implementation for SOP. FEV presents a broad field of capabilities including transmission engineering services and the complete design and development process.

FEV, with its extensive knowledge of development, quality and cost-oriented engineering, is the ideal partner for a successful close cooperation project that includes a variety of transmissions and special applications (e.g. MT, DCT, AMT, AT and hybrid solutions). FEV offers complete solutions, beginning with a detailed concept phase featuring early involvement of the relevant transmission experts. The solution continues with modern CAE-supported approaches for optimization of driveline dynamics, stresses and acoustics and is finalized with a detailed design, including complete machining drawings considering all process relevant aspects.

The 3D design employs all of the important CAD systems and the support of an extensive risk analysis (FMEA), as well as all relevant benchmarking data. The detailed investigation of major components, such as gears, shafts, synchronizers, housings and the shift mechanism, using various modern CAE tools, is a significant step toward bringing a new transmission closer to production. These investigations begin with a kinematic gear set layout that includes detailed geometry and safety calculations and continues with Finite Element Analysis (FEA) as well as dynamic simulation tools to calculate stresses, deflections as well as resultant forces for the structural investigation and optimization of housings.

FEV's transmission development support also includes the benchmarking of new transmissions and

hybrid powertrains, featuring reporting and troubleshooting during the development process and after SOP. FEV employees can also leverage their long-term experience to support FEV's customers by monitoring their system suppliers.

Continuously increasing comfort level requirements also drive an increased importance for transmission NVH in vehicles. Potential issues in the shaft and gear design are calculated and optimized in the first design loop with a combination of FEA and MBS (multi body system) models. Transmission housing NVH optimization is standard in any development program. These measures help to achieve high acoustic transmission quality in the first prototype, which dramatically reduces the experimental NVH effort in the subsequent development process.

The transmission design and CAE process includes:

- Concept and detailed design in 3D CAD
- Generating specific production drawings
- MBA and FEA of:
 - Gear teeth (profile and micro geometry layout)
 - Complete gear set, shifting parts and synchronization
 - Strength of shafts, housing and shift mechanism
 - Dynamic vibration analysis of the complete system
- CAE optimization loops
- Risk analysis (FMEA)
- Comprehensive tolerance analysis
- NVH optimization of transmission components and the complete driveline system
- Procurement of prototype parts
- Benchmarking and reporting in the context of FEV scatterbands
- Accompanying documentation



Fig. 2:
FWD/RWD
Transmission
test bench

Testing and Actuation Development

There is a recent trend in automotive drive-trains towards developing the engine and transmission as a single unit. Allowing for this trend transmissions are now being developed in accordance with the specific requirements of the engine. Transmission diversity is steadily increasing. Furthermore, as the result of modern technologies, the development rate is growing, whilst simultaneously allowing for shorter development time and lower cost. As one of the world's leading automotive service providers, FEV meets these challenges by providing integrated driveline development in close cooperation with customers and suppliers.

FEV offers the development of Manual (MT) and Automatic Transmissions (AT), Automated Manual Transmissions (AMT), Dual Clutch Transmissions (DCT) and Hybrid Transmissions as well as axles, clutches and complete powertrain testing. The transmission development chain at FEV consists of CAE, NVH, application and comprehensive transmission testing; this includes in-vehicle and bench testing. Locations for transmission testing are the Engineering Centers in Aachen, Germany and Detroit, USA. The test portfolio covers functional and durability tests of transmissions for front wheel, rear wheel, and all-wheel-drive configurations. Detailed test procedures that have been developed based on FEV's extensive test experience are meticulously followed to ensure comparable results.

At FEV we also regularly conduct benchmarking studies to add to our extensive database, allowing for a comparison of transmissions relative to the "state of the art."

Testing and verification on a test bench includes:

- Temperature investigations
- Efficiency and drag investigations
- Lubrication tests
- Transmission and powertrain NVH tests
- Speed stability tests
- Single stage / multi-stage load cycle runs
- Verifications of synchronizers

In-vehicle testing and verification includes:

- Subjective/objective transmission evaluations
- Temperature investigations
- High-Speed/hill- and abuse tests
- Assessment of the clutch characteristics

Complete transmission development programs also include the design and specification of hydraulic and electrical circuits, along with components and actuators.

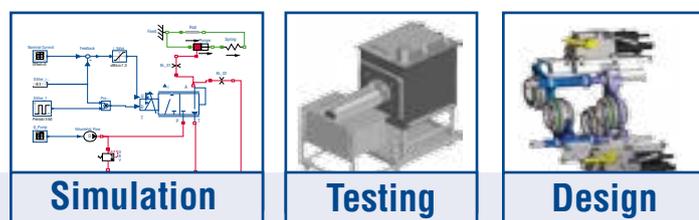
Moreover, FEV is able to support customers with simulation, characterization and testing of hydraulic or mechanical components like gear pumps, valves and actuators. Complex hydraulic power circuits of AT, DCT or AMT transmissions can be tested under hot and cold conditions.

The scope of simulation and testing includes:

- Pump efficiency
- Valves (pressure, flow, dynamics)
- Functional testing hot/cold

katthoef@fev.com

Fig. 3: Hydraulic development





Calibration, Tools and Software Development

Powertrain application activities are integrated into FEV's vehicle application center, in which all vehicle-related activities and departments are co-located. In complete powertrain development projects, one project leader is responsible for both the engine and the transmission. The close interaction between engine and transmission development guarantees high quality and a very effective application processes.

FEV's tool chain and processes enable rapid and effective project workflow. Typical tools and processes in this workflow include:

- FEV Shift Analyzer: Offline calibration tool for pedal map, shift lines, driving resistance and (hybrid) load/boost calibration. This tool significantly reduces the required time for shift strategy calibration
- FEVos: FEV's objective shift and transition quality tool that allows FEV engineers to analyze, quantify and track the shift quality of automated gearboxes
- HIL testbenches (level 6) allow rapid, high quality development and calibration as well as automated software testing.
- Rapid prototyping systems (Matlab/Simulink in combination with dSPACE products, ASCET) and universal transmission controllers.
- Commercial calibration systems like INCA, ATI, CANape and CalDesk.
- Application of measurement systems for the development and calibration of transmission- or hybrid-control systems in prototype vehicles.

Control unit architectures and functionalities of automated drivetrains or hybrid vehicles are highly complex and create a challenge for functional development and calibration. FEV uses advanced tools and strategies to conduct system optimizations.



Fig. 5: Turn key transmission integration project

The key attributes of the powertrain are rapidly understood with the support of detailed system knowledge. This helps reduce the complex interactions inside a transmission or a powertrain system to simplified subsets, which then illustrate the significant relevancies. This allows for the development of effective simulation models as well as easy to understand software and calibration tools, despite a continuously increasing system complexity. Mature simulation methods and virtual system synthesis allow system designs to be optimized close to final production status. Verification of project targets requires in-vehicle testing to prove the final results.

The combination of requirement-based parameter databases, offline tools and automated HIL tests provides a high quality calibration of the first applications and variants. FEV's capabilities extend from early concepts to after the SOP and cover all tasks from concept to design, testing, software and calibration.

kirschstein@fev.com



Fig. 4: HIL Testbench for TCU testing and calibration



Fig. 6: In-vehicle transmission calibration

Reference Projects and Test Tracks

Another expertise in FEV's requirement-driven organization is the realization of turn key projects. FEV works intensively and directly either for an OEM or a Tier 1 supplier.

Recently, a project was completed in which FEV was responsible for the complete application development of automatic transmission vehicles. This global project featured a project management team in Detroit, manufacturing in Thailand, vehicle development in Japan and transmission production in Europe. The tasks of this global project included:

- Vehicle integration of Automatic Transmission (AT)
- Prototype builds
- CAN bus development
- Project Management
- Vehicle NVH responsibility
- Powertrain Calibration
- Testing and validation

In an ongoing project for a German OEM, FEV is also responsible for the complete AT program and the majority of the engine calibration.

Increasingly dense traffic conditions make calibration and test drives on public roads much more difficult.



Fig. 7: Ford J97/U268 DI-AT development test trip



Fig. 8: Test track at the FEV Vehicle Application Center

Therefore, FEV has conceptualized and is in the process of realizing a test location close to its European vehicle application center.

The test location will provide a very effective and safe calibration facility for vehicle development and will contain of the following key features:

- Handling skid path
- Gradients
- Low mue and mue split tracks
- Oval track

In addition to this test track, FEV will continue to use a global complement of established test tracks as well as public roads for testing, calibration and validation of powertrains.

janssen_p@fev.com



Fig. 9: FEV 7-speed hybrid powershift transmission

CONTACTS

FEV Motorentechnik GmbH
Neuenhofstraße 181
52078 Aachen · Germany
Telefon +49 241 5689-0
Fax +49 241 5689-119
E-Mail marketing@fev.com
Internet www.fev.com

FEV, Inc.
4554 Glenmeade Lane
Auburn Hills, MI 48326-1766 · USA
Phone +1 248 373-6000
Fax +1 248 373-8084
E-Mail marketing@fev-et.com
Internet www.fev.com

FEV China Co., Ltd.
No. 35 Xinda Street Qixianling
High Tech Zone · 116023 Dalian · China
Phone +86 411 8482-1688
Fax +86 411 8482-1600
E-Mail fev-china@fev.com
Internet www.fev.com