Advanced Transmission Development

CO₂ REDUCTION ON VEHICLE LEVEL REQUIRES EFFICIENT, LIGHT-WEIGHT AND ECONOMIC TRANSMISSIONS
FEV belongs to the worldwide leading engineering service providers in the field of vehicle drive systems and combustion engines. In close cooperation with worldwide customers and suppliers, FEV develops and optimizes complete powertrain units from the idea up to industrial implementation. Hence one of FEV's fields of activities is the transmission engineering service and the complete development process. With extensive know-how of development, quality and cost oriented engineering FEV presents itself as the ideal partner for a successful close cooperation project that includes every kind of transmission.

FEV covers the complete area of transmission development from the "clean sheet" concept development via design, calculation and testing to software and functional development as well as the calibration in the vehicle together with the validation in the vehicle. In this process, FEV relies on various internal tools, comprehensive benchmark tests as well as a constantly growing team with broad (mass production) experience. A crucial advantage of FEV is its ability to offer the complete powertrain development – engine and transmission – supported by the required resources and divisions.
From the beginning of each development, the multidisciplinary hardware development at FEV relies on the contribution of important resources, e.g. the experts for calculation, testing, acoustics, FMEA and cost engineering and the use of the FEV tools. We offer examinations of the initial concept for our global customers as well as the complete development of a new transmission aggregate from the first concept design to the complete mass production development.

The realisation of the design is performed with current CAD systems (Catia, ProEngineer, Unigraphics) according to the requirements of the specific client. The construction process for manual as well as automatic transmissions of all types is constantly supported by further experts and happens in close contact with the client. Another focus is the development of new transmission systems and therefore the realisation of FEV’s own ideas initially in design, simulation and detailed calculation, and the subsequent realisation of first prototypes for initial functionality and durability tests as well as the construction of demonstration vehicles.

Different modelling depths are used for structural and strength considerations depending on the scope of the project. In the conceptual phase first analyses are performed with the calculation software KissSoft based on rough geometry data (e.g. package dimensions) of potential wheel sets and shaft designs. In this phase, only single wheel pairs and shafts without system interaction are assessed according to DIN calculation rules.

In the detailing phase, a complete transmission system is used. The input parameters are the wheel set parameters from the conceptual phase. In contrast to the conceptual phase, the spatial layout of the shafts and the wheel pairs is now also considered. Further, a load configuration (load, dwell time, gear) can be used with this model, and the damage of bearings and gearwheels can be determined.

A further result is the shaft flexing which can indicate meshing faults. The highest detailing level is reached through the integration of flexible structures into the MBS model. These describe the vibration behaviour of the bodies in detail, and allow the execution of resonance and strength calculations (local tensions / safety margins).

The previously determined maximum bearing reaction forces or force amplitudes respectively (KissSys or MBS model) are used as boundary conditions on the transmission case. In the subsequent strength analysis, average and amplitude tensions are calculated with the aid of critical cross sections from node to node. The local safety margins are determined using further influencing parameters as the surface roughness, the magnitude, the temperature etc.
Automotive drivetrain development is trending towards the engine and transmission as a single unit. With this trend, more and more transmissions are developed in accordance with the specific requirements of the engine. Diversity of transmissions is thus steadily rising. Furthermore, the rate of development due to modern technologies (e.g., DCT, AT, AMT, networked drive systems) is rising while the concurrent target is shorter development times and lower costs. As one of the world’s leading automotive service providers, FEV rises to these challenges by providing integrated driveline development in close cooperation with customers and suppliers.

The transmission development at FEV consists of CAE, NVH, application and comprehensive transmission testing; this includes in-vehicle and bench testing. The test portfolio covers functional and durability tests of transmissions for front wheel, rear wheel, and all wheel drive configurations. Detailed test procedures, developed based on FEV’s extensive test experience, are meticulously followed to ensure comparable results.

FEV offers the development of
• manual (MT)
• automatic transmissions (AT)
• automated manual transmissions (AMT)
• dual clutch transmissions (DCT)
• hybrid transmissions and
• continuously variable transmissions (CVT)

Complete transmission development programs also include the layout of hydraulic and electrical circuits, along with components and actuators. Furthermore, FEV regularly carries out benchmarking studies to add to our extensive database allowing for comparison of transmissions relative to the ‘state of the art’. FEV’s transmission test and analysis portfolio also includes detailed failure analysis of damaged parts from durability runs.

Test bench testing and verification including e.g.:
• Temperature investigations
• Efficiency and drag investigations
• Lubrication tests, at standstill and top speed
• Shift comfort and shift force tests
• Speed stability tests
• One stage/multi stage load cycle runs
• Verifications of synchronizers

FEV offers transmission testing as
• Durability Bench Testing
• Functional Bench Testing
• Durability Vehicle Testing
• Functional Vehicle Testing
• Clutch Durability Bench Testing
• Clutch Functional Bench Testing
• Component Testing for Drive Shafts, Differentials, AWD Transmissions, …
Transmission Automation Hydraulics and Actuation

Modern transmissions:
- DC
- AMT
- AT
- CVT

Contain a high number of electromechanical and electrohydraulical components as well as a multitude of different sensors.

The three pillars of the development are:
- Conception
- Design
- Calculation and simulation
- Testing

Conception:
FEV has accumulated know-how in actuator design through many internal projects
- Electrical and mechanical concepts
- always aiming at market-driven, robust and low cost actuator design

Design:
The close cooperation with the transmission design engineers makes life easy.

Calculation and Simulation:
Experience from many projects leading from design to realisation demonstrate the absolute necessity of simulating automation systems in advance as comprehensively as possible. For this purpose physical models like Dymola or ITI-Sim are built. This procedure also allows a system analysis regarding the desired control behaviour and the qualities in the early phase of the project. Furthermore the simulation serves to limit the problem areas (troubleshooting) and helps to find solutions.

Testing:
Experience shows that it is possible to remove components from the overall system and test them separately. This allows for considerable cost savings. FEV uses a variety of component test benches for this purpose. Amongst others, a valve measurement station and a pump test bench are available.

FEV Actuation System engineering
- Actuation Concept
- Simulation & Disturbance Variable Analysis:
  - Hydraulic (Dymola, Matlab)
  - Electromechanical (Matlab)
- Design (7-ECAT, 7H-AMT)
- Component Testing

Due to the increasing comfort requirements of the customer and continuous NVH optimization of the power train other noise shares e.g. from the gearbox, which previously only played a secondary role, are coming up in focus of vehicle interior noise. This is particularly relevant for aspects of the noise quality, e.g. tonal noise frequencies of the meshing order or rattling noise of the idler gears.

The new or further development of a transmission begins at FEV with the conceptional dimensioning and the definition of target values which can be derived from FEV's benchmark data. The acoustical transmission development at FEV is divided into the two areas:
- CAE based calculation tools
- Tests on the acoustic aggregate test bench

Within the CAE development, commercial as well as FEV’s own developed tools from the multi-body simulation (MBS) and Finite Element (FE) calculations are employed. The goal of the CAE development is to minimize the excitation at the origin by using MBS-calculations as well as the optimizing of the gearbox housing structure by FE-calculations with regard to transmission-specific excitations.

The acoustical examination of the transmission is performed on the acoustics aggregate test bench which allows the examination of transmissions for longitudinal as well as lateral installation. The transmissions for lateral installation are examined without locked differential and the associated effects on the acoustical behaviour.

For the acoustical measurement of the transmission, direct sound emission as well as structure-borne excitation at the suspension points of the transmission are considered. The measurement data are evaluated in comparison to State-of-the-Art as well as by using transfer paths developed by FEV with regard to possible interior noise concerns.

Tools and Methods for NVH Development

NVH Engineering Comprising:
- MBS Simulation of Shaft and Gear Layout
- FE Simulation to Optimize Transmission Housing Structures
- Testing on NVH Aggregate Test Bench
- Benchmarking (CAE & Testing)
- Evaluation of Interior Noise Relevant Transmission Noise Shares
All powertrain application activities are integrated within FEV’s vehicle application center, in which all vehicle related activities and departments are bundled together. In complete powertrain development projects one project leader is responsible for both engine and transmission. The close cooperation between engine and transmission departments guarantees high quality and very effective application processes.

FEV’s tool chain and processes enables rapid and effective project workflow. Typical tools and processes are:

- FEV ShiftAnalyzer: Calibration tool for pedal map, shift lines, driving resistance and (hybrid) load / boost calibration. This tool reduces the required time for shift strategy calibration significantly.
- FEVos: FEV’s objective shift and transition quality online-tool that allows to analyze, quantify and track shift quality of automated gearboxes.
- HIL testbenches 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.
- Requirement based parameter database system for effective handling of calibration datasets in projects with numerous vehicle variants.

The combination of requirement based parameter databases, offline tools and automated HIL tests allows a high quality calibration of first applications and variants. FEV’s capabilities reach from early concept to after SOP and covers all tasks from concept to design, testing, software and calibration. FEV has the experience from numerous projects with AT, CVT, AMT and DCT transmissions to handle multivariant series transmission calibration projects. Therefore FEV has developed an own calibration process that allows a secure and reliable project management. Main features of the calibration process are:

- Clear change management of calibration labels based on a web server to enable project traceability and risk management also from the customers side.
- Defined maturity levels for datasets to track the actual status of calibration level of TCU functionality and the overall project status.
- Easy adaptation to customers processes to support the needs of different customers regarding project realization.

With this organizational level FEV has the capability to take over series calibration projects with turn key responsibility including project management, supplier handling and homologation support.
Function Development for Transmission Applications

In the field of function and software development for transmission systems, as well as for hybrid-electric power train systems and engine or aftertreatment control systems, FEV is experienced in developing functions from the early concept to production code and support beyond SOP.

FEV follows the V-model during the software development. Typically, a first iteration for algorithm development is performed using Rapid Control Prototyping (RCP) to allow for a first validation and very fast requirement detailing. This iteration leads to a first prototype and the procedure is also applied e.g. when developing concept or technology demonstrators. It is characterised by:

- Model based control concept development
- Requirement development and specification
- Team work of transmission experts and software experts
- Plant modelling and simulation
- First limited calibration in simulation or at HIL

To ensure a smooth transition from the RCP control unit to a customer specific Target Control Unit, the following aspects are taken care of from the very beginning of any project:

- Software Architecture
- MISRA and MAAB compliance
- Block library for efficient modelling
- AUTOSAR compliant modelling and naming
- Documentation generation from model

The following processes are accompanying the function development as well:

- Configuration Management
- Version Management
- Change Management
- Bug Tracking

After validation of the functionality at a test bench or in the vehicle, the model based development of the software is continued in further iterations to improve functionality and quality to the status of mass production software. This means that extra functionality like e.g. special I/O handling, increased safety functionality or OBD functions, error management and general diagnostics are added. At the same time, all deficiencies found are removed furthermore. Testing activities are typically ending with a base calibration for a selected application. The software is released by FEV after all verification and validation activities have been passed successfully.

FEV is pleased to perform the series calibration of it’s own software for any application.

FEV supports diverse cooperation models together with a control unit supplier, starting with Components-off-the-Shelf with specification of software change requests up to Software Sharing either on model, code or object level. FEV offers specification of Target Control Unit Hardware and Control Unit Base Software. FEV is experienced in Screening, Selection and Management of Control Unit Suppliers, as well as for other E/E or mechanical parts.

FEV applies a model based software development procedure incorporating automatic code generation wherever possible.

FEV's Areas of Expertise:
- Model Based Control Concept Development
- Simulink/Stateflow/RTW/TargetLink or ASCET MD, RP, SE Based Tool Chains
- Rapid Control Prototyping (RCP) at HIL-Simulator, at Test Bench or in Vehicle
- Model Based Software Development
- Software Code for Series Production
- CMMI Process Model for Software Development
- Expertise in Functionality and Software Implementation
- Efficient and Rapid Development

Integration of the high-level functionalities in an automotive base software and development of a target specific link layer software in close cooperation with all major control unit supplier Tier-1 is performed in many series production projects.

FEV follows the V-model during the software development procedure incorporating automatic code generation wherever possible.

Specially designed human-machine interfaces, like displays in hybrid vehicles, facilitate the consumer’s acceptance and promote identification with new products and technologies.
As the technical complexity of powertrains is increasing significantly the effort for system engineering and function development will increase in the same way too. Especially the role of feedback control functionalities for automatic and hybrid transmissions will get more and more important. Therefore FEV has developed a structured approach of system analysis and controller design that helps to identify system requirement parameters and reduces the time-range and costs for function development.

The so called 4-Step-Approach uses four development phases:

- Simplified modelling of all involved system components like hardware, sensors, actuation and software functions. FEV is experienced in finding the right level of detailing that makes sure, that all main effects are modelled in a model that is as simple as possible.

- System analysis of the simplified model using methods from state of the art control theory. In this step important system characteristics can be analyzed like eigenfrequencies, stability of a closed loop circuit or the robustness of a system against external parameters.

- Synthesis of the enhanced system as a result from the previous step. This could be system requirement parameters like the needed bandwidth of actuation systems or an optimal clutch gain. But this could also be an enhanced control functionality inside the TCU.

- Implementation and testing of the enhanced system to verify and optimize the project targets. FEV’s experienced to test functionalities either in a RCP environment or in a series TCU.

Structured System and Controller Development Results in:

- Shortened Development Times
- Reduced Development Costs
- Enhanced System Understanding
- Replacement of Expensive HW by Intelligent Controllers

All Systems:
- Use only 1 E-motor
- Package neutral or smaller
- Almost weight neutral
- Also useable as conventional transmission
- High take-off performance allows downsized engines

Vehicle Class

<table>
<thead>
<tr>
<th>Small</th>
<th>Medium</th>
<th>Luxury</th>
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<tbody>
<tr>
<td>FEV HAMT</td>
<td>FEV ECAT</td>
<td>FEV EPGS</td>
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Hybrid Transmission Systems Developed by FEV

- FEV 7H-AMT
  - No torque interruption
  - Micro/Mild/Full Hybrid

- FEV 7-ECAT
  - Power shift
  - No hydraulics
  - 9 and 11 speed possible
  - Micro/Mild/Full Hybrid

- FEV E-PGS
  - c/o base AT transmission
  - Excellent ICE start quality
  - Mild/Full Hybrid
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