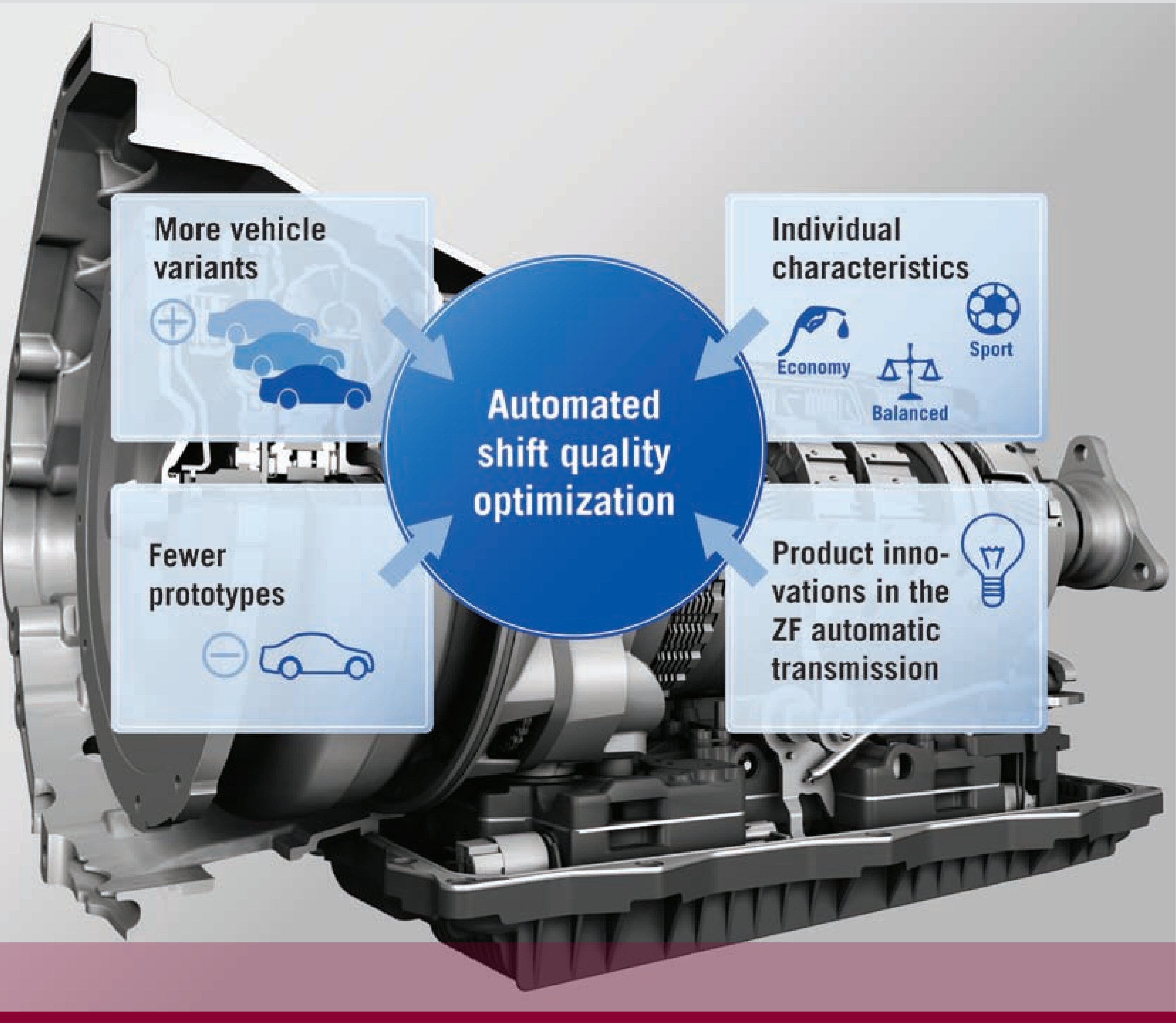

Model-based Methodology for the Automated Optimization of Shift Quality for Automatic Transmissions

The causes for the increase in the cost and time taken for the calibration of converter automatic transmissions include complex shift strategies and shift processes with a very high number of control parameters coupled with an increasing number of gears and transmission variants. AVL and ZF developed jointly a methodology for the automation of a model-based process for the calibration of shift quality. First tests on the test bed have shown that good results have already been achieved in sections of the driveable range.

1 Introduction

Transmissions play a major role in the race for dynamic, comfortable and fuel efficient vehicle powertrains and can bring decisive advantages to the customer. The automatic transmission, in particular, is gaining in acceptance because it provides a harmonic combination of these three attributes. The calibration effort has risen rapidly due to the number of new mechanical transmission concepts in combination with different engine types, or the re-packaging for hybrid solutions [1]. Higher numbers of gears and new control functions place further challenges on the transmission calibrators. At the same time, it is a general trend to reduce the number of expensive prototype vehicles and therefore requiring the calibration engineer to make intensive use of the short time available. This demanded increase in efficiency is focused around the electronic transmission control unit (TCU) with its rapidly increasing software data content.

The engineering services company AVL and the transmission supplier ZF are presenting here a methodology for calibration of this data born out of the necessity of meeting the challenges of the increasing complexity. The shifts are automated on a chassis dyno, whereby the transmission control parameters and operating conditions are varied and the shift quality is objectively evaluated. The optimum control parameter set for the transmission control unit is found using modeling and optimization algorithms on the measured data.

2 Calibration Process and its Steps

A calibration engineer carries out a wide range of tasks when adapting control software data to new vehicles, engines or transmission variants. At ZF-Transmissions GmbH, the engineer accompanies the development project for shift quality and shift strategy from the prototype development stage up to series production. His main task is the optimization of the software data with over 5000 transmission control parameters (labels) pertaining to the shift process (comfort and spontaneity) and shift strategy. Suggestions for improvement concerning the transmission mechanics, the hydraulic clutch control or the software functions are usually gained from road tests.

At the beginning of 2000, ZF, in cooperation with the Institute for Vehicle Technology at the TU Braunschweig, began a research project to investigate the area of automated transmission calibration and continued the development with AVL. An analysis of the manual process revealed the necessary pre-requisites:
– objective evaluation of the shift quality
– automated test execution
– algorithmic optimization.

The objective evaluation is calculated on the basis of physical measurements and, as for the subjective evaluation of shift feeling, portrayed on an ATZ scale from 1 to 10 (1 corresponds to unacceptable, 10 is excellent). The most important basic value for the feeling of comfort is the translatory acceleration of the vehicle, which is mainly registered by the sense of balance in the human inner ear. Further measurement signals such as engine and transmission speed are used to calculate the shift spontaneity. Values describing the vehicle state such as vehicle speed and pedal position or brake torque affect the driver's expectations and must therefore also be taken into account in the evaluation.

In order to execute the shifts quickly and fully automatically, the tests are no longer carried out on the road but on the

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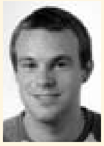

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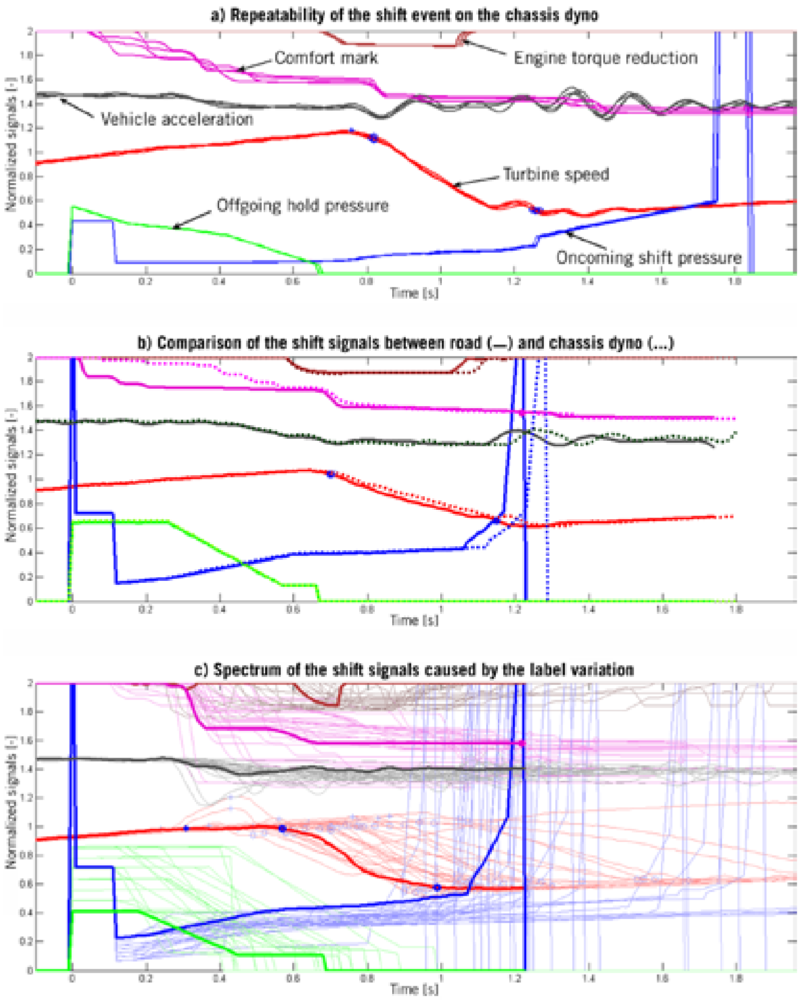

Figure 1: Shift signal sequences of selected quantities

Figure 2: Cameo Transmission workflow

chassis dyno (roll test rig) using an "intelligent" test procedure. The acceleration is calculated from the force measured by the device connecting the vehicle to the chassis dyno [1]. High reproducibility can be achieved since the conditions are constant (no traffic, constant weather, no seasons, constant road surface), see part a of **Figure 1**. Part b of Figure 1 shows the correlation between chassis dyno and road using important signals from the shift sequences [2].

The algorithmic optimization comprises the test planning, the mathematical modelling of the data, the variant optimization (different target criteria) and calibration generation. The test plan consists of a variation of the control labels over the complete test design space. Figure 1c shows the spectrum of the signal traces through the label variations, for example showing the clutch pressures for a constant operating condition (constant speed/load). The bold trace shows the best calibration.

3 Workflow and Integration in Cameo

The described methodology is completely encapsulated in a software workflow called an iProcedure inside the AVL Cameo transmission product. The iProcedure is organized such that the user is led stepwise through the workflow, **Figure 2**.

3.1 Test Planning

The first step in the test planning is the configuration of a vehicle acceleration model (for example engine torque map and transmission data). Using this model, the complete vehicle operating range for each shift type (for example upshift from second to third gear, US23, with and without load changes) can be calculated. Both the forced upshift and downshift curves are taken into account as well as the full and zero load conditions or the wheel slip limit. Using this method, it is possible to plan operating points depending on the control values in the TCU (for example turbine speed/turbine torque or shaft speed/pedal position). The test procedure uses this model to approach each operating point directly without a learning phase. This way, 99 % of all the shifts can be successfully run.

The second step involves the design of a global (cross-operating point), multi-layer, S-optimal DoE test plan. The first layer defines the operating points using as a constraint the driveable operating range (green, Figure 2, middle). The variation range for the TCU labels can be limited using maps or curves (Figure 2, right). The second layer involves the calculation of the actual global optimal DoE plan with start and repetition points. The advantages of a global test design lie in the robustness to deviations from the operating points and in a significantly lower number of measurement points compared to local test plans.

The test preparation is the last step. The calculated shifts are automatically ordered in the optimum manner (execution list). For example, a shift order like US23 – US34 – DS43 – DS32 is created. Necessary but missing shift types are compensated for with “dummy” shifts. In addition to this, the sorting is done so that shifts with low differences in vehicle speed are preferred and that shift sequences cause the least clutch wear. In this way, measurement plans with different shift types can be run with maximum performance.

3.2 Test Execution

Unlike semi-automatic tests run on the road, this concept can initiate a shift every 10-12 s in average. The speed control on the chassis dyno ensures that the new operating points are reached far faster than on the road. Time limiting factors are mainly transmission and engine temperatures, maximum dyno force and wheel slip. The control of all sub-systems is done by Cameo, **Figure 3**. The test bed receives speed and road resistance control commands and the shifts are executed via driving robot or shift by wire.

While the new operating point is being reached, Cameo sends new label values to the TCU. Simultaneously, the evaluation of the last shift (ATZ rating and characteristic parameters) by AVL Drive and the last measurements are transferred to Cameo. A system for error diagnosis and handling detects and corrects bad shifts.

3.3 Modelling, Variants’ Optimization and Verification

The first step in the modelling phase is the automatic re-ordering of the measured shifts from the test sequence and their separation into the corresponding shift types. In order to be able to start the optimization, models are then built of the ratings for shift comfort and spontaneity, shift and shift-delay times and “flare” using proven algorithms [3]. In addition, expert knowledge is used in the form of model templates (pre-definition of relevant model terms), which makes the handling of such a large

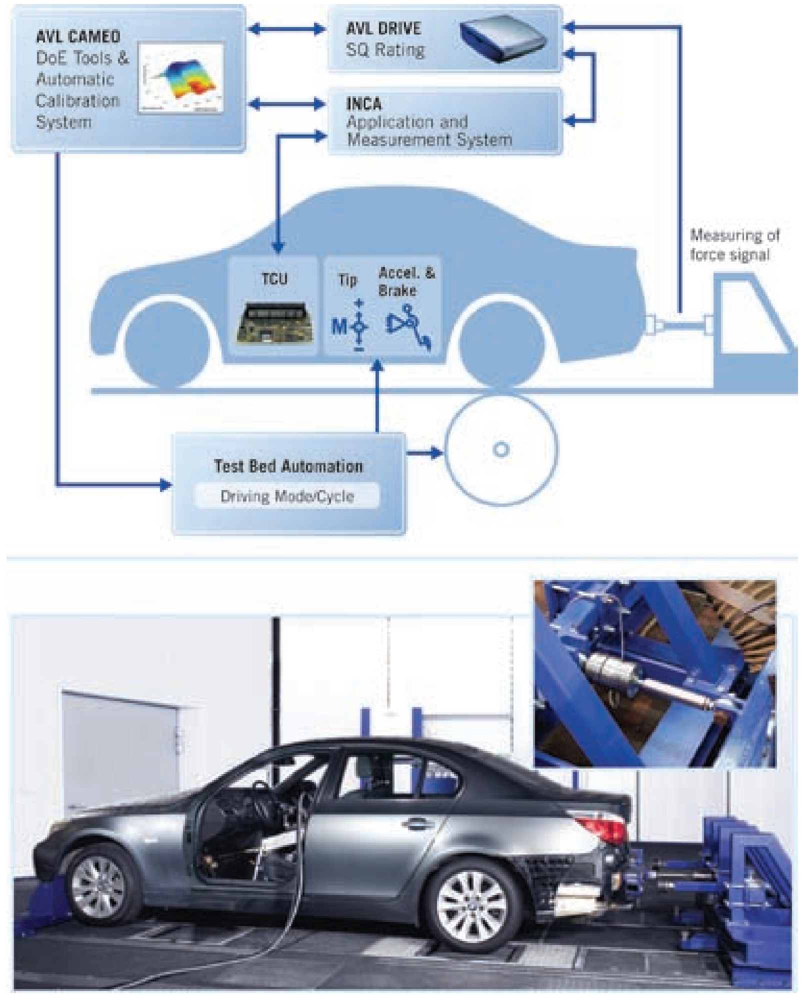

Figure 3: System setup for the test execution

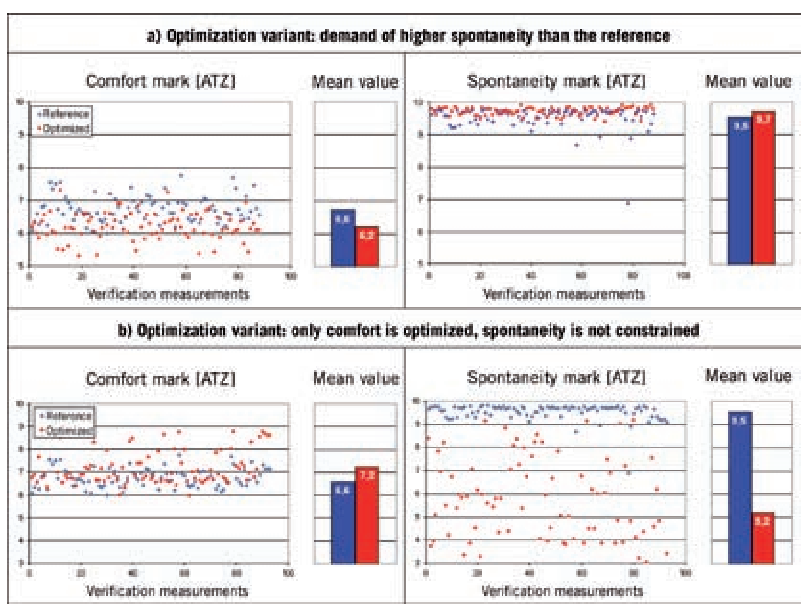

Figure 4: Verification of two optimization variants for the 23 upshift

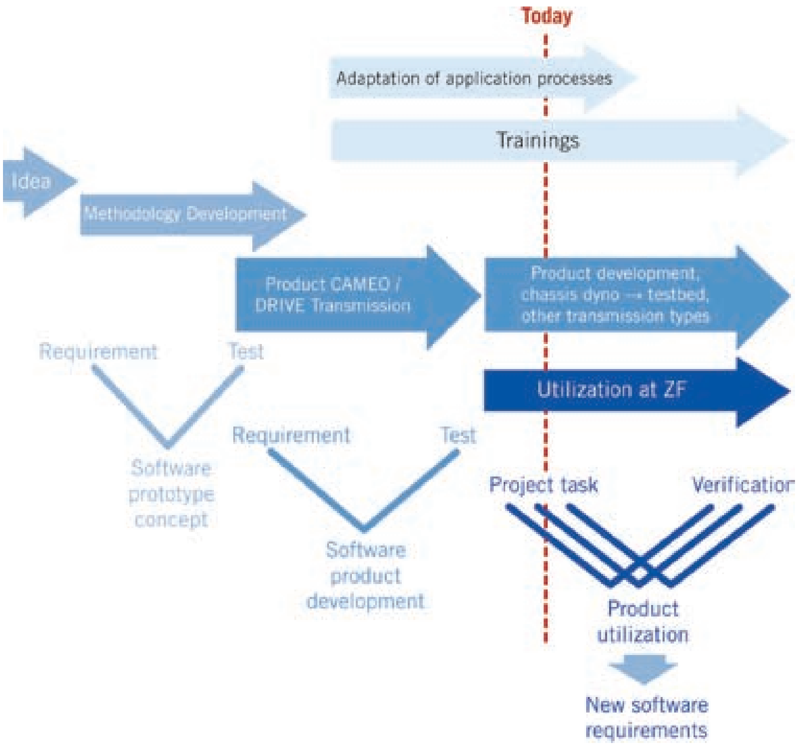

Figure 5: Industrialization of automated calibration for transmission (ACT)

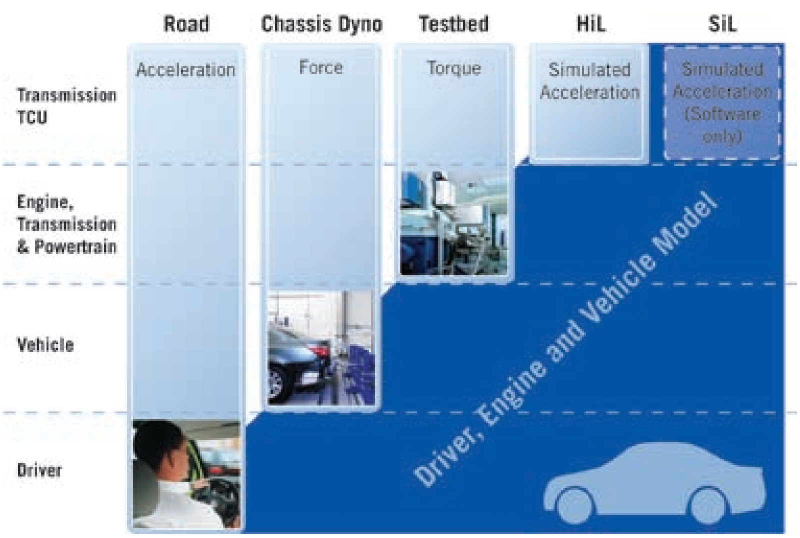

Figure 6: From road to model based calibration

number of model inputs possible (see section 4).

Optimization can now be carried out quite easily using these models with different criteria. For example, maximization of shift comfort rating for a defined shift duration and shift delay. By using different constraints, all variants can be created, from very sporty to very comfortable without the need for further measurements and tests. Unlike using local models for each operating point, global models can be used for optimizations with a dense coverage of the operating range along the possibly critical edges as well as directly on the map grid.

The final step is to generate an optimum calibration map/curve/value set out of the optimization results using a map generator. Finally, this calibration is downloaded into the TCU and the optimization variant can be checked using a verification test run.

4 Example of a Shift Sequence Optimization

The methodology described here was used on a mass-produced vehicle. For each of three upshift types (US12, US23 and US34), approximately 1300 measurements were taken and optimized over the complete driveable operating range. Compared to previous projects with considerably fewer variation labels per shift, this application varied 20 labels that affected the clutch pressures and the engine torque reduction during a shift. The set value for the labels was limited by limit maps and also the limiting effect of labels upon other labels was taken into account. This avoids unnecessary or non-driveable combinations of labels. During the test preparation phase, downshifts were automatically inserted and a sorted execution list with approximately 9,000 distinct shifts was created. The complete test was run fully automatically on a chassis dyno within two days.

During the modelling phase, the computational time was reduced through the use of model templates, resulting in 10 minutes of calculation per model on a standard PC. The optimization of a total of 5 different variants was done with different optimization targets for the spontaneity and comfort values. Part a of **Figure 4** shows the verification of an optimization variant with the task to maximize spontaneity. A trade-off was permitted of 0.5 ATZ below the reference rating for shift comfort. The points show all verification measurements for the US23 over the total driveable range (88 single shifts) with the reference and the optimized calibration. Part b of Figure 4 shows an extreme variant with maximized shift comfort without limiting spontaneity. The average possible gain in comfort compared to the reference is +0.6 ATZ with the expected low spontaneity. Since no further chassis dyno and test object time is required, the time to generate a new optimization variant is approximately 1 h.

5 Industrialization and Further Development

In order for the methodology of automated calibration for transmission (ACT) to be rolled out in different international sites, it is necessary to have product development with proven algorithms, user-friendly GUI and documentation, **Figure 5**. The introduction and customization of this calibration process at ZF requires accompanying measures such as the formation of a team and specific training.

Beside the roll-out of the new process, the methodology and the product are being further developed with the targets of moving many calibration tasks to the engine/transmission test bed, or even HiL/SiL, **Figure 6**, and the reduction of expensive vehicle prototypes. The development of the methodology on the chassis dyno with the force measurement via connecting arm is justified, since in this case, the test vehicle is still available. This makes it easy to correlate with the road.

When using the methodology on the engine/transmission test bed, the measured torque and software to simulate the drivetrain and vehicle replace the acceleration signal and the real vehicle. The quality of the simulation and the torque signal must be correspondingly high. First tests on the test bed have shown that good results have already been achieved in sections of the driveable range. The final step towards HiL/SiL requires in addition very good models for the transmission hardware and the dynamic behavior of the engine itself and requires further development before it can be used for a wide range of applications.

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