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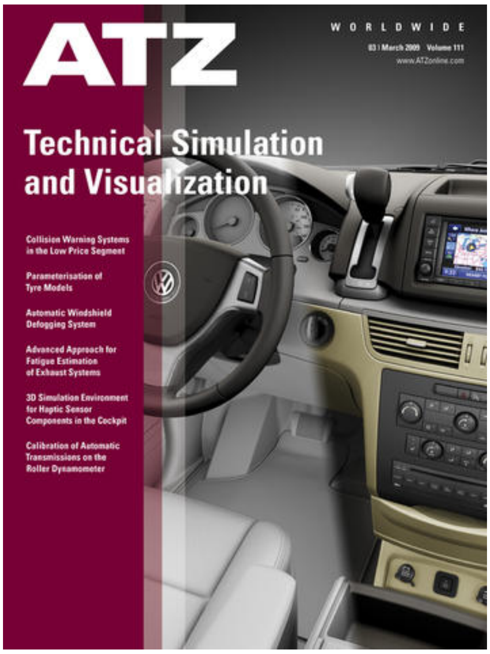

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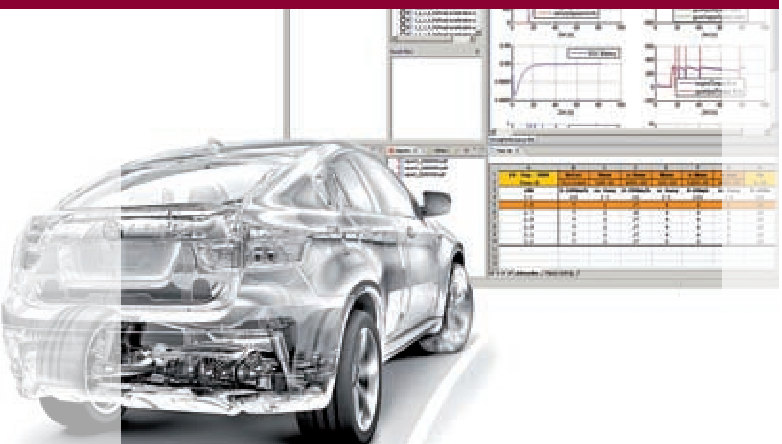

4
Technical simulation and photorealistic **Visualization** enable much better support of product development to engineers. the possibilities of Volkswagen is working with presentations, which are close to reality. BMW, in cooperation with Tesis, developed a tool to enhance the measures for fuel consumption reductions.

COVER STORY

DEVELOPMENT

RESEARCH

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Leading in a Crisis

Dear Reader,

We know from our regular readership analyses carried out by Emnid that around a third of our readers are from senior management. As a management executive, you are facing a special challenge in the present crisis. On the one hand, investors and your superiors expect you to observe a prudent business and budgetary policy. As an engineer, you might even have to face the problem of controlling cash flow for the first time in your life in order to safeguard or contribute to your company's liquidity. On the other hand, your employees are demanding investment to avoid putting the company's technical sustainability at risk. Some of your creative employees may not even be aware of how serious the situation is. To ensure that you succeed in balancing these two extremes without causing harm to yourself or your team, you should take the factor of communication seriously – in all directions. Employees and suppliers who are being asked to accept cost savings need to be informed just as quickly as your customers, superiors and shareholders. Unfortunately, many managers tend to focus on the latter group, cancelling major orders by fax, for example, without making the effort to inform suppliers in person, even though they may have been loyal and trustworthy partners for years. So do things differently. And convey confidence. Even a crisis like this will be resolved eventually. But those who waste their energy on symbolic gestures will not be the ones who help to resolve it. Imposing a ban on business trips, for example, is complete nonsense in view of the negligible cash savings and the negative consequences for staff motivation. Those who spend their time writing mails about new rules for travel expenses rather than optimising inventories or throughput times have understood nothing about the concept of cash flow. When it comes to investing in product development, there are many ways of preserving liquidity, including cooperation with competitors, universities or subcontractors, for example.

As far as business travel is concerned: set an example, and the rest will take care of itself. And don't economise when it comes to making contacts.

With this in mind, I look forward to seeing you at the Stuttgart Symposium at the end of March.

Johannes Winterhagen
Frankfurt/Main, 10 February 2009

Johannes Winterhagen
Editor-in-Chief

ATZ WORLDWIDE
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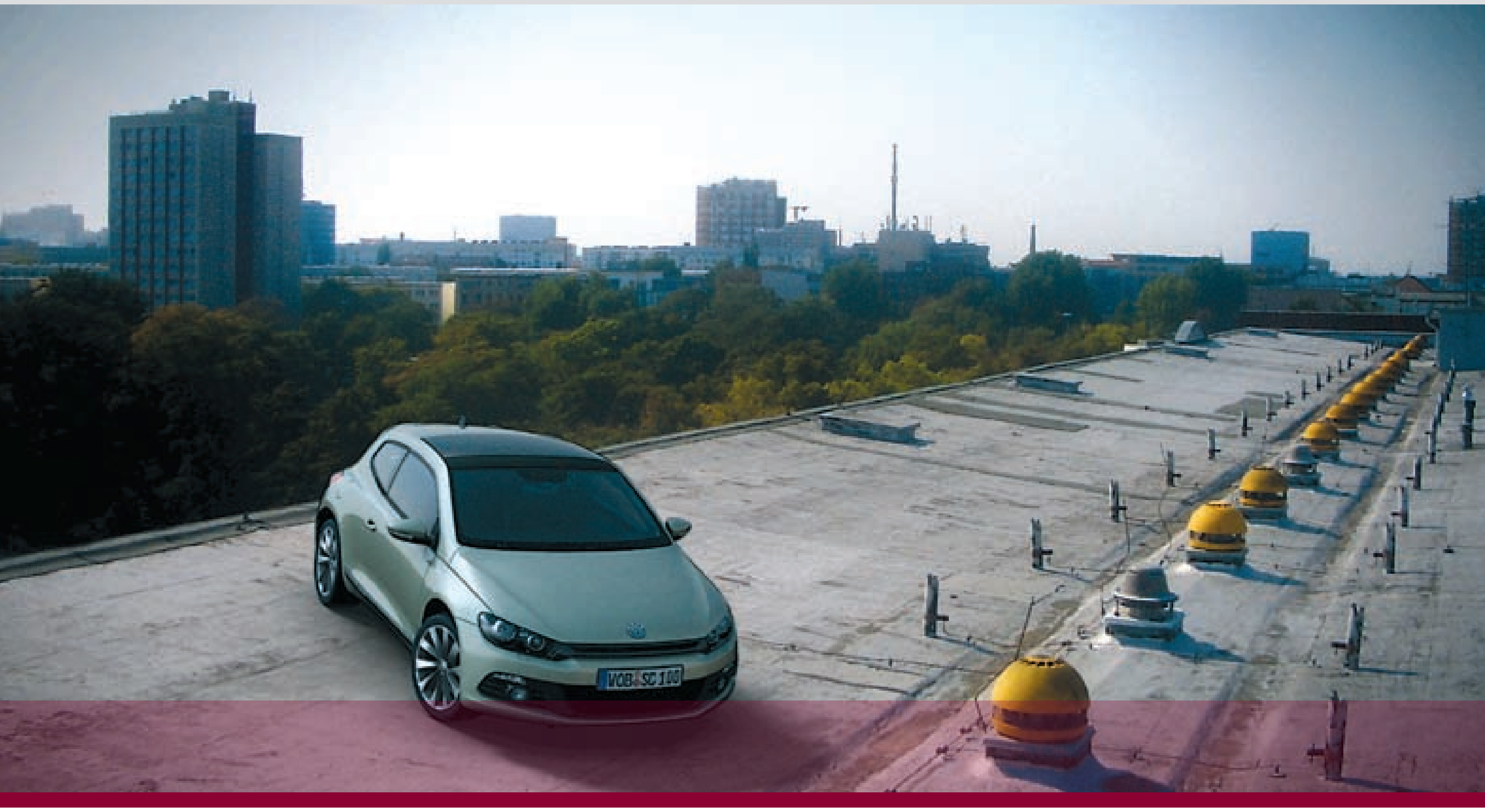

Opportunities of Photorealistic Visualizations for the Product Process of a Car

Photorealistic visualizations are an inherent part of the work and design processes both in the film and advertising industry and in automotive development. Besides conventionally filmed real world sequences, also completely virtual scenes and worlds are created. At Volkswagen, the future belongs to the co-operation of the disciplines photography and computer graphics, to rate quickly new stylings and car models. It is shown with the examples of Scirocco, Tiguan and Passat CC, how therefore the chances are, to use both technologies optimally in a combined form.

1 Introduction

Photorealistic visualizations are an inherent part of the work and design processes in the film and advertising branch. Besides conventionally filmed real world sequences, also completely virtual scenes and worlds are created. Picture material from real and virtual sources are reworked and merged with the help of digital image processing. In today's fast moving times advertising and film industry can hardly get by without the support of digital media. **Figure 1** shows an example for a car detail visualisation for marketing purpose. Here, a TDI diesel engine and its components are presented virtually.

Photorealistic visualizations are the results of a highly creative design process with distinct handcraft skills using the computer as a tool. Equally important is the fun of designing and the joy at a felicitous picture composition. **Figure 2** illustrates how such pictures emerge in four steps for example with a VW Scirocco. In the first step, the environment and light settings have to be captured and designed, Figure 2a. The CAD geometry is identified and processed in the second step, Figure 2b. In the third step, surface materials are identified, recreated and assigned, Figure 2c. The fourth and last step consists of creating and merging of image layers, and finishing of the picture, Figure 2d.

2 Working Steps

A first general working step focuses on the virtual vehicle bodywork, which is based on engineering data from the product development process. The goal of this virtual bodywork is to compile data material of all parts visible to the customer. The result is a surface model which includes all vehicle parts relevant for the visualization. This so-called data model follows the product programme and includes all visible vehicle parts of the interior and exterior according to one previously defined configuration. The approach described before allows for the creation of a geometric exact image of what the customer will see when he buys a real car.

In the following step materials are applied to previously tessellated surface data. For the interior, this includes various kinds of leather, fabric, metal, wood, as well as synthetic materials. For the virtual processing all these real materials must be emulated in impression and reflection properties.

The Volkswagen departments working on photorealistic visualisation have developed their own special methods and techniques for the emulation. In general, the more sophisticated and the more optimized the methods are, the more realistic becomes the visual impression. Essential for the realistic impression is the experience of the operators of the tools. In the ideal case, they combine the diverse methods and techniques in a way that makes the resulting picture indistinguishable from a real photo.

Figure 3 shows an example of an interior covered with virtual leather in comparison to a real photo. The virtual illustration can be used to complement real photos as it is shown in this example.

For the visualization of the exterior the focus of material preparation lies mainly on the combination of car paint, chrome and plastics. Due to its multilayer structure, some today's car paint must often be rendered multi-coloured. The material properties represented by shaders [1] must, for example, simulate the so-called flip-flop effect of real car paint. This versatile play of colours has to be reproduced with, amongst other things, a virtual lighting and virtual car paint. Depending on the requirements concerning physical correctness of the car paint's the reflection properties, different methods for the car paint representation can be employed. For some paints exact reproduction of the optical impression is still subject to research. **Figure 4** shows virtual car paint sample on a sphere. The applied technique of car paint measurement for visualisation is going to be optimized in present research work [2] in cooperation with researchers form the University of Bonn and does already find its way into car visualization projects.

After the vehicle has been processed in the described manner, it is ready for being placed into a natural environment in a further step. For the positioning of the car it is essential to overlay the virtual car and the real environment using the correct perspective. For this task so-called camera matching methods are employed, which automatically calculate the virtual camera position fitted to the real environment picture situation.

The single parts of the final picture are combined by using digital image processing techniques. It was essential for the work shown in Figure 2, that the natural lighting situation is applied correctly on the virtual car. In order to seamlessly integrate the virtual car into the natural environment, the environment was captured with a high dynamic range

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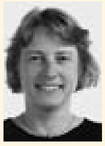

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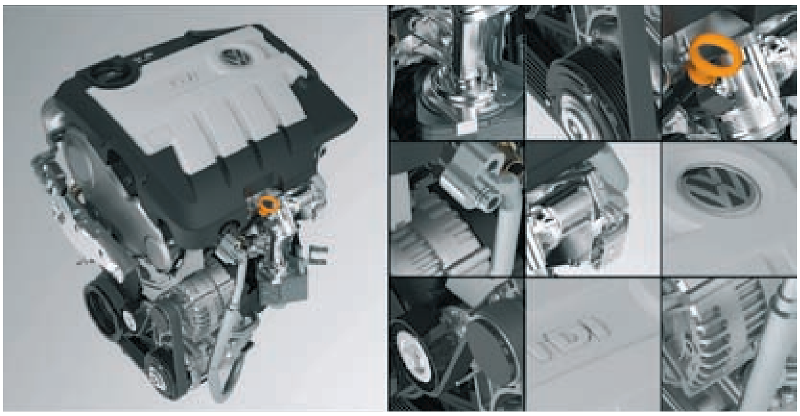

Figure 1: Example of a photorealistic visualization for marketing purpose – TDI diesel engine and its components, presented virtually

Figure 2a: Capture and design of environment and light settings

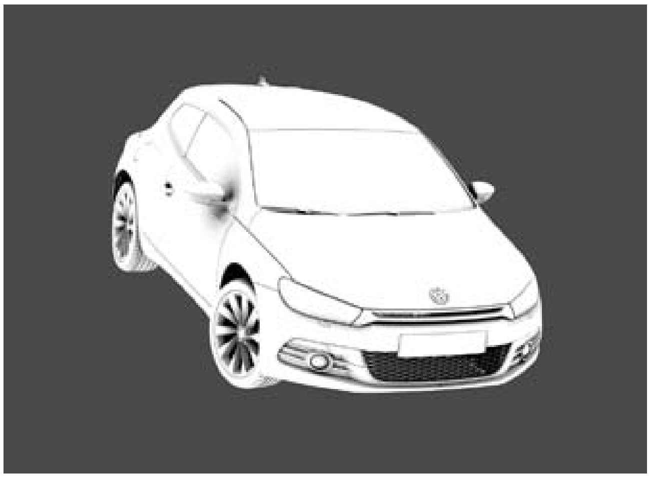

Figure 2b: Identification and process of the CAD geometry

Figure 2c: Identification, recreation and assignment of surface materials

Figure 2d: Creation and merging of image layers, finishing of the picture

(HDR) camera. In the subsequent rendering process, this recorded light information was the basis for the illumination of the scene. By using this generally documented process [3] it was possible to create realistic reflections of the complete environment on the car paint and car's glass parts. The result is a computer-generated picture which comes very close to a photo. Finally, the picture is reworked using additional digital image processing techniques. In this so-called post production process the picture is finished for publication.

In the mentioned example a "real" environment is used, in which one integrated a virtual vehicle. By using a 360° HDR camera the complete light impres-

Figure 3: Virtual interior (left) in comparison to a real captured interior (right)

sion and the environment geometry was captured and – in the next step – computationally merged with the virtual car. The "real" environment was "wrapped around" the car.

In **Figure 5**, a virtual vehicle was placed in a purely virtual environment scenario. A virtual environment is a modelled room with a defined lighting situation, which is adapted to the presented object. Again, the result is a photorealistic picture of a car in a defined environment.

Figure 4: Virtual car paint sample on a sphere (Source: University of Bonn, Germany, Institute of Computer Science, Computer Graphics Group, Prof. Dr. Reinhard Klein)

3 Using Visualization Technology Within the Product Process

For the above renderings one needs very mature and complete data models. They are usually available near the end of the product process. The possibilities of using visualizations go far beyond the so far shown. On the basis of the visualization process chain in **Figure 6**, additional utilizations of visualization in the product process are presented in the following four phases.

3.1 Phase 1 – Visualisation of Ideas

A picture says more than a thousand words. Each developer must advertise his ideas in order to get them considered and implemented into the next car. It is not sufficient to have a good idea. It needs persuasive power to get others enthused about this idea. Visualization is the perfect means to help achieving this. The closer the description of the idea gets to reality, the easier it is to judge it and make a decision. In this internal competition of ideas the instrument of visualization is of special importance in the first phase.

A big part of these visualizations of ideas are essentially based on the same technology as the above mentioned single pictures in Figure 2 to Figure 5. But now, the camera additionally moves along a defined path, the lighting situation need not be constant, and by using sound recordings it is possible to focus on certain aspects of the content.

If not only the camera is moving, but also the car, then another visualization module is employed: "Das bewegte Fahrzeug" (Virtual moving cars). In order to let a car drive realistically, it must tilt during driving through curves (inclination) and bend forward when braking (suspension) for example. On a cobbled street the chassis and the wheels must therefore move adequately. For the visualization approximations will usually be sufficient. There is no need for a physically correct multi-body system computation. Only the principle of the driving dynamics shall be illustrated.

If this internal hurdle is jumped, now the potential customer must discover the opportunities of the idea, before development work for the implementation of the idea was performed. Visualization allows testing the idea for its final customer value [6]. This safeguards the decision and helps in determining the precise specification of the planed development. From the visualization's point of view, here starts the visualization process chain.

3.2 Phase 2 – Design, Visualization of Class-A Surfaces, and Technical Visualisation

In the second phase, the development of a car has already begun. Now the styling and class-A surfacing process with its virtual approvals is an essential user of the visualization possibilities. Main interest lies on real-time systems, that means systems, which can visualize interior and exterior 3D models with their materials in real time rendering lights, shadows,

Figure 5: Virtual vehicle in a virtual environment – the result is a photorealistic picture

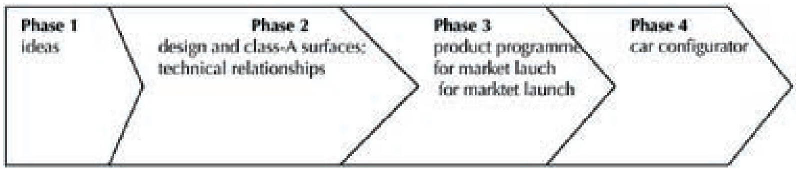

Figure 6: Visualization process chain within the product process

Figure 7: Visualization in the area of driver assistance systems for explaining technical relationships

as well as reflections in the mirrors and panes. These programs allow for the coordination about the whole car in the daily work. This includes the judgement of the run of gaps, the integration of ergonomic requirements, and – especially – the impression and quality of surfaces. For further details about this surface process, it is referred to the literature [4]. The technical product details are defined and documented in parallel to the surface process with its real-time systems.

Visualization also shows its power in explaining and transporting technical relationships and modes of operation. Films and animations concerning driver assistance systems for the VW Tiguan and the VW Passat Coupé are illustrating examples for this task, **Figure 7**.

3.3 Phase 3 – Visualisation of the Product Programme for Market Launch

In the third phase, the product process proceeds and increasing amounts of model data become available until finally the complete product programme can be used. Another user group for photorealistic visualizations comes along, when the configuration alternatives are defined, car paints and interior materials are fixed, and the first cars with almost series-production readiness are manufactured: marketing in combination with sales and dealer service.

Here, the earlier created virtual models are used for renderings of the interior and exterior: By providing detailed graphical material a great variety of special car paints and interior configurations can be shown to the customer. In addition, the virtual models are used to illustrate and communicate technical relationships of the new cars. This cooperation of technical development and marketing allows for the creation of customer brochures long before the market launch of the car.

The new car's technical contents and the principle descriptions of the innovations' modes of operation are the basis for some planned marketing campaigns. The draft for a campaign can be started with web specials, internet presentations, catalogues, posters and other possible media long before market launch of the car. Besides the pure time gain, visualization products have the advantage of being very flexible. It is possible to quickly provide colour options, different seat concepts, or details like headlights according to the campaign, without the need to build a real car, **Figure 8**. The Cost-benefit analysis concerning the use of visualisations over the whole process shows a clear plus.

3.4 Phase 4 – Visualization for the Car Configurator

In the fourth phase, which is the market launch, another challenge waits for the visualization: providing data for the car configurators. For a highly diverse product like an automobile the complete data logistics must be tuned to fit the new possibilities of visualization. The process of compiling data for one specific single virtual car can be compared to the supply of single parts for the production of a real car. As virtual and real world are based on the same mechanisms and logistic relationships, the expenses for a car configurator with virtually generated car renderings are immense. **Figure 9** shows a small detail of a variance examination for a VW Golf Plus cockpit.

Figure 8: Virtual detail view onto a headlight

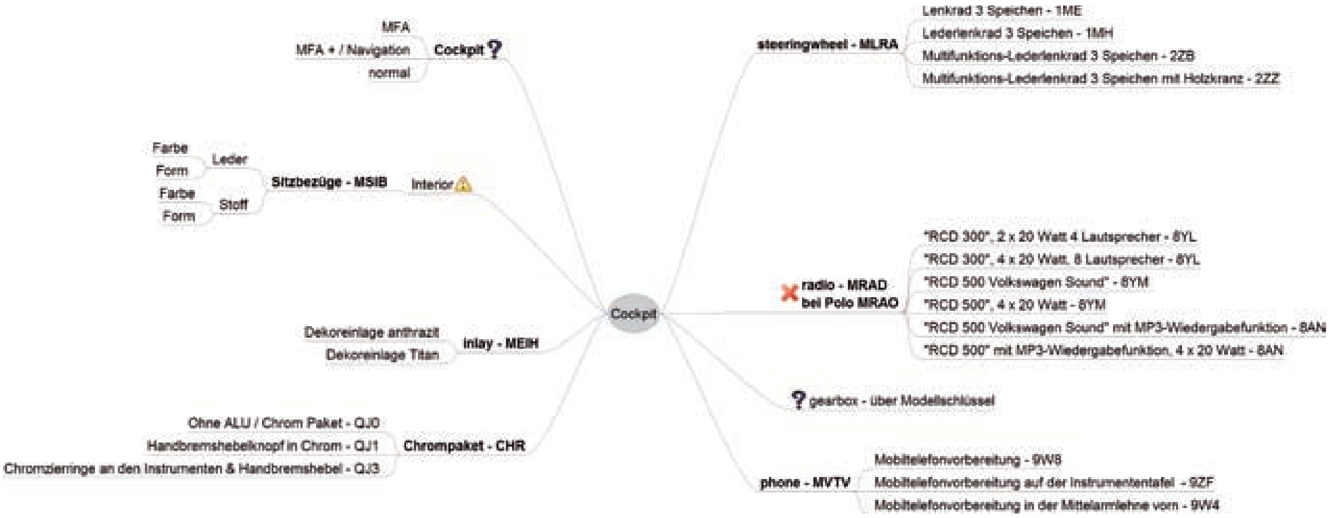

Figure 9: Detail of a variance table for the VW Golf Plus cockpit

A car configurator for the VW Golf Plus needs, for example, 2300 single pictures and a logic for combining these renderings according to the customers inputs. These single pictures are the basis for the illustration of the total variance. Each of the pictures represents a variant of one construction part. This can clearly be seen when choosing between different wheel rims.

For determining the desired views in the car configurator purely technical illustrations are used in the working process. **Figure 10** shows the perspective views on the complete car and on the interior. This working step focuses on neutral judgement of views and car details while the aesthetic impression of color and material is not important. It must be possible to display every customer-wanted configuration of the car in each of these six views in Figure 10. This leads to high demands concerning data logistics for providing the virtually generated graphic material.

4 Challenges for the Visualization in the Product Process

Three things are needed to tap the full listed potential for the optimal visualization in the product process of a car:

1. People first: What is needed is a group of committed, motivated, and enthusiastic people, trained in different fields. It emerged [5] that in a team of computer visualists, theory computer scientists, mathematicians and automotive engineers very good synergies between the qualifications could be achieved. One profession alone cannot cope with this very computer-focussed and car-specific subject. Only the diversity of the group can handle the complexity of the requirements.
2. In addition, high performance computer cluster are needed for real-time presentations, photorealistic pictures, and movies. In principle these clusters are similar to those used in the engineering computation department. For the software tools it must be distinguished between those for real-time presentations on a power wall and those for creating pictures and movies respectively. For the picture/movie task, the same software is used as for movies and computer games. In these industries huge amounts of money go into the development of software products, which are also very interesting for the photorealistic visualization of cars. Other systems for cutting and dubbing films are developed for these industries, and they can be used for technical films without any further adaptation. These software products are interesting with regard to

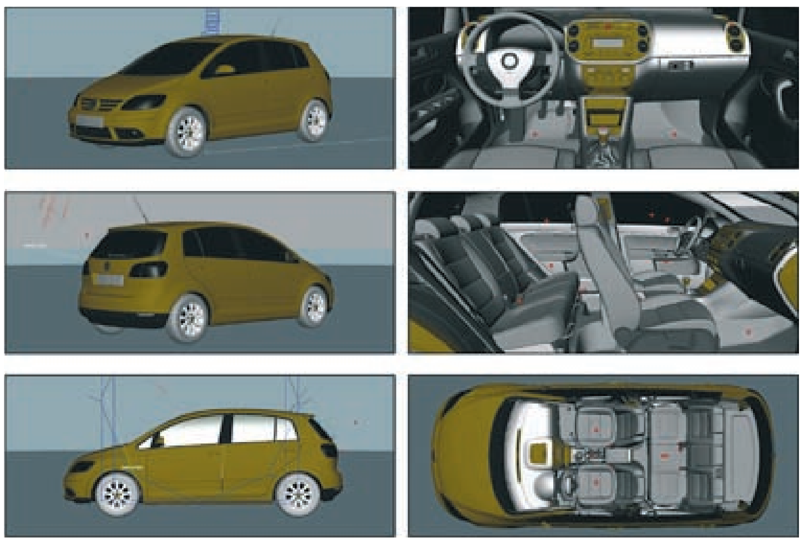

Figure 10: Technical illustration of six perspectives for exterior and interior views in the car configurator

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price, because they were made for a mass market, and the automotive industry is just another user.

3. For the whole process of using computer-generated data the accessibility of 3D model data is crucial. Photorealistic visualization for the car development is only possible with reasonable effort since 3D model data is available throughout the whole product process.

5 Conclusion

Apart from the enthusiasm about the possibilities of visualization, it is beyond all questions that for an optimum result you need the direct cooperation with the traditional photography. The artistic eye of the photographer is still most important for achieving brilliant finial result.

At Volkswagen, the future belongs to the co-operation of the disciplines photography and computer graphics, to rate quickly new stylings and car models. In the further steps, we must again and again revise the border between virtual and real world in order to optimally use the opportunities of both techniques.

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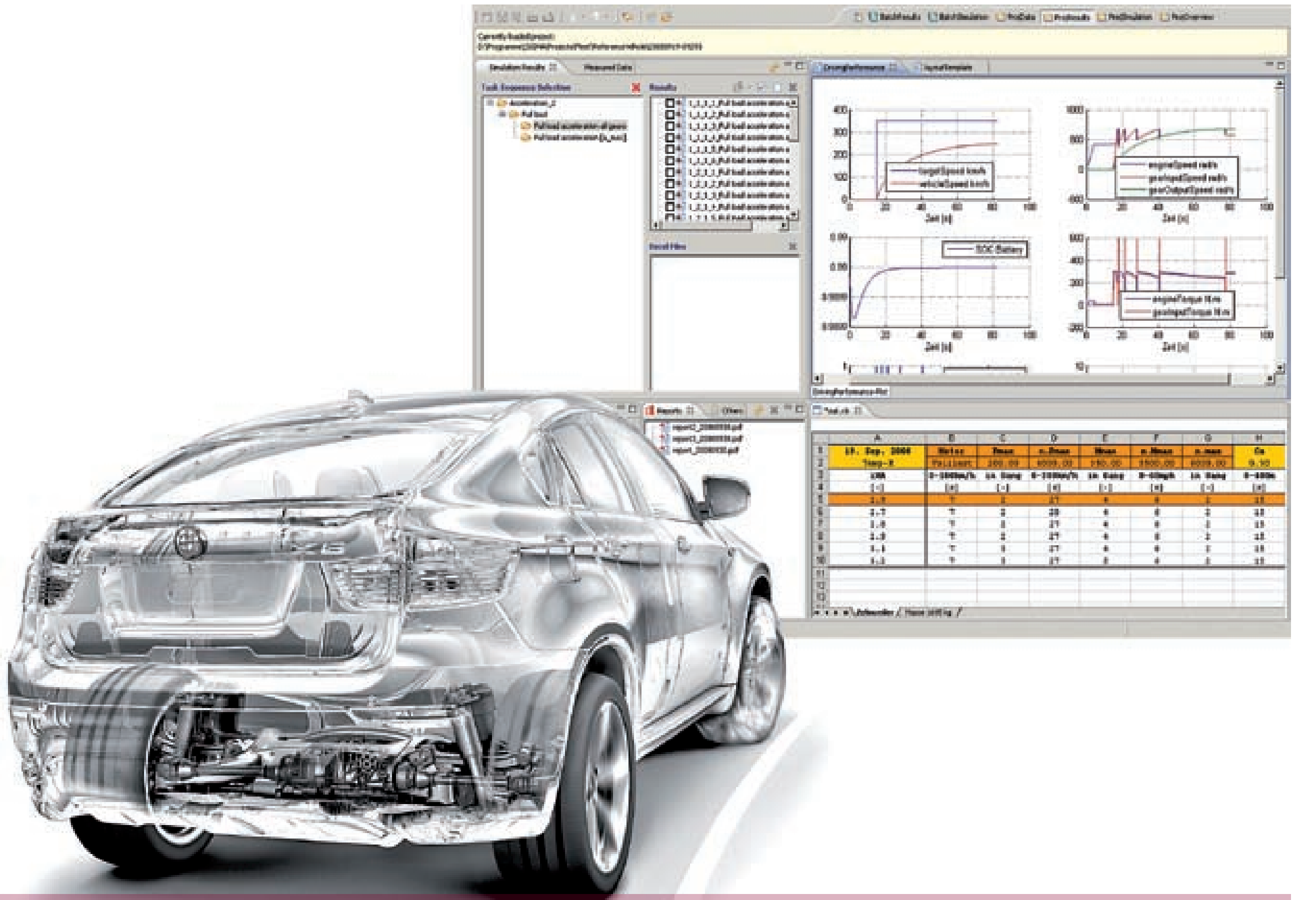

Fuel Economy Simulation for the Vehicle Fleet

Forecasting the fuel consumption of an entire vehicle fleet has become a crucial challenge for all car manufacturers. Over the past few years, simulation of the entire vehicle has become an essential means of making precise predictions of the effectiveness of fuel economy measures at BMW. An effective, reliable simulation framework has been developed in cooperation with Tesis Dynaware to master both the complexity of a single vehicle and the large number of vehicle variants.

1 Goals and Focus of the Simulation Model

During the development of a new vehicle, it is important to understand and optimise the behaviour of the entire vehicle as a system. The interactions in a vehicle are becoming more and more complex, with the result that it is increasingly difficult to analyse them. Under these conditions, development that is based merely on component and vehicle hardware tests would be too time-consuming and expensive. Quality and efficiency can be improved by using virtual methods. An important tool is the simulation of the entire vehicle behaviour.

1.1 Model Requirements

The model is intended to support development work, during which the comprehension of the entire vehicle and the interaction between subsystems is necessary. An important application is fuel consumption optimisation. The vehicle model must offer the possibility to examine how effectively possible innovations reduce carbon dioxide (CO_2) emissions. There must exist a convenient way to design and test the necessary functions and components.

Furthermore, the vehicle model must fulfil the following requirements: The model must be able to represent every vehicle produced or planned by the company, a Mini as well as a Three-Series BMW or a Rolls-Royce. All variants have to be considered: automatic and manual transmissions, petrol and diesel engines, rear, front and all-wheel drive. The future fleet must also be evaluated, which means that models for hybrid, electric and fuel cell vehicles must be available.

Furthermore, it is essential that this variety of models can be maintained and updated with as little effort as possible. A modular configuration with flexible interfaces is necessary to ensure that the models required can be arranged according to a modular design principle. The components must be reusable and adaptable to new developments without great effort.

The model must offer the possibility to evaluate different design options. For that reason, the computing time should be as short as possible. The models should run on a normal Personal Computer, ideally faster than real time.

1.2 Focus and Level of Detail

A complete vehicle is an extremely complex system. It is hardly possible to reproduce all aspects of this system in a clear and manageable model. This model focuses on the description of energy flows in the vehicle, that is the conduction and conversion of electrical, thermal, mechanical and chemical energy.

For the simulation goals described here, only the vehicle's longitudinal dynamics have to be considered. This makes several simplifications possible: The lateral dynamics can be completely ignored and the modelling of the vertical dynamic model is limited to the height profile of the cycle driven. The modelling of the longitudinal dynamics can focus on the necessary items, and details such as dynamic stability control do not have to be modelled. Since the relevant time frame is relatively long, high-frequency events are of little interest. Approximations are in some cases necessary (for example the response behaviour of the internal combustion engine), whereas some behaviours can be completely left out (for instance vibrations in the powertrain, as the system is assumed to be stiff).

The submodel level of detail has a great impact on the complexity of the entire system. For each component, a decision must be made as to which parts of its behaviour can be described physically and which correlations can be derived from data that have been determined empirically.

In all modelling objectives, the energy flow analysis on a system level is the central issue. Therefore, the energy flow must be modelled physically, that is as a function of the torque and speed or the current and voltage. In contrast, simplifications on the component level are necessary and permitted. Component models do not have to be built purely physically. Simple partially physical (grey-box) models or purely characteristic map-based (black-box) models are easier to parameterise and require less computing time and data.

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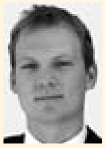

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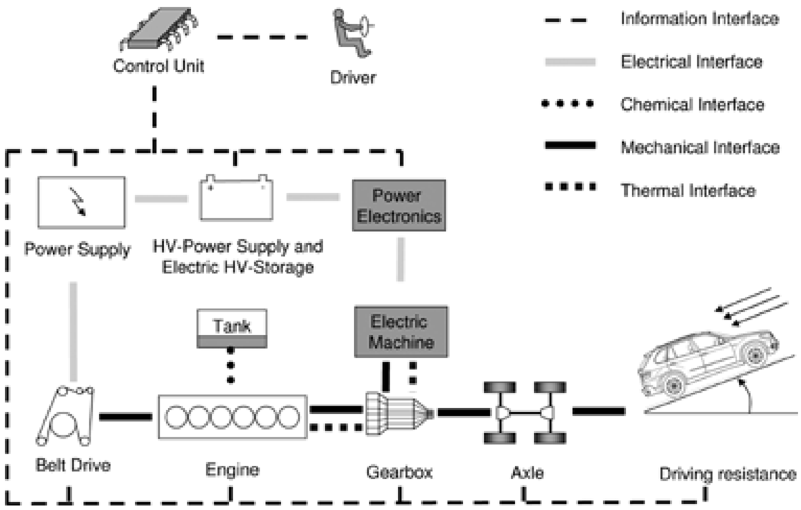

Figure 1: Structure, components and interfaces of the vehicle model

If it is necessary for a more special analysis to have a closer look at single components, the simple models can be selectively replaced by more detailed ones.

2 Implementation

2.1 Simulation Environment

Different commercial tools are available that show the advantages and disadvantages of the simulation goals described. Many of them are specialised for a single domain, and the modelling of components of other disciplines is therefore not possible or only possible to a limited extent.

The programming language "Modelica" matches the requirements of the vehicle modelling very well. "Modelica" is a freely available, object-oriented language for the modelling of complex physical systems. Models in "Modelica" are mathematically described by Differential-Algebraic Equations (DAEs). The causality of each component is handled automatically. For example, only one description of an ohmic resistance is necessary in "Modelica", no matter whether it is connected to a current or a voltage source.

"Dymola" is the most frequently used commercial simulation tool based on "Modelica".

2.2 Simulation Model

The vehicle model is built physically at the topmost level. The subsystems are connected to each other by mechanical, electrical, thermal or information interfaces. The information interfaces are implemented as a bus system. The model is a so-called causal model: The virtual driver controls the acceleration and brake pedal to achieve the predefined target speed.

The subsystems that have to be represented in the model are the internal combustion engine, transmission, axles, driving resistances, electrical power supply, hybrid components, controls and driver model with the driving cycles. Not every simulated vehicle has all of these components. Component models that are not required can therefore be left out. **Figure 1** shows the structure of the complete model. Essentially, all of the component models are modelled as grey or black boxes.

Suitable subsystem and component models can be selected according to a modular design principle. The submodels are stored in component libraries that are continuously updated, validated and improved.

In most cases, different variants of a subsystem differ from each other only in their parameter set, and the structure of the submodel then remains unchanged. For the modelling of two power supply variants, for example one with a 70 Ah and one with a 90 Ah battery, the same model structure can be used. Scaling is carried out via the different data sets for the battery capacity, the internal resistances and the thermal capacity. A precondition for this way of reusing models is the strict separation between the model structure and the parameter set.

If the alternative characteristics of a subsystem cannot be represented by different parameter sets, variants in the model structure are necessary. Excessive functional differences between the alternative characteristics of a subsystem are the most frequent reason for variants. For example, two structurally different axle models are needed to represent rear-wheel and all-wheel drive. Detailed models are another motivation for variants. A simple model of the internal combustion engine is used as a default, and a special model is available if a more detailed analysis is necessary.

In order to allow suitable submodels to be exchanged and chosen, the different variants must be compatible with each other. A basic condition for this is having the same interfaces. Thus, the submodel interfaces are defined in a base model, and all variants of a subsystem inherit the interfaces from the same base model. This object-oriented propagation of qualities also makes it easier to implement structural changes to the common interfaces, as a change to the base model extends to all variants.

3 Simulation Process and Software Framework

It is a major challenge for the simulation of the entire vehicle at BMW not only to be able to simulate single vehicles but to provide reliable statements for the fuel consumption and driving performance of the entire BMW vehicle fleet. Complete vehicle simulation accompanies the vehicle development from the early phase, continues through series development and extends right up to life cycle measures for all vehicle derivatives, **Figure 2**.

Reliable simulation data processes as well as tailor-made software solutions are required to cope with the huge variety of vehicles and driving tasks. Only in such a way it is possible, on the one hand, to provide the calculation engineers with the latest model developments and, on the other hand, to guarantee that all simulations are reproducibly performed with the currently valid boundary conditions.

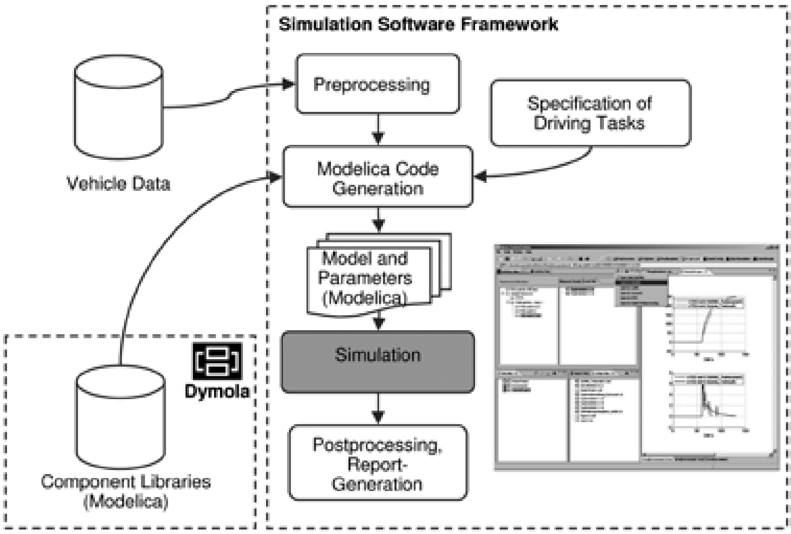

Figure 2: Simulation process and software framework

3.1 Variety of Driving Tasks

With a complete vehicle model, various driving tasks can be simulated. These are:

- legally prescribed fuel consumption cycles from different markets such as Europe, USA or Japan
- driving performance tasks such as acceleration from 0 km/h to 100 km/h or elasticity tasks
- special cycles defined by BMW, which are used for the component layout (lifetime) or for the calculation of the fuel economy of the average customer.

In all of these driving tasks, special boundary conditions have to be taken into account. These include:

- environmental conditions such as air pressure and temperature
- pre-conditioning of the vehicle for the individual cycles (for example legally defined vehicle standstill periods before performing the actual test) and the initial system states arising from it (for example cooling media temperatures)
- legally or otherwise prescribed boundary conditions, such as operation of the air conditioning, gear profile, clutch actuation.

The boundary conditions significantly differ for different vehicles, for example manual or automated transmission, hybrid or conventional vehicle. It is also of great importance whether a driving task is performed on the road or on a vehicle test bed. For the simulation of driving tasks on a chassis dynamometer, the driving resistance must be calculated using the so-called ABC factors.

3.2 Large Amounts of Input Data

As mentioned above, numerous data sets are needed for a complete vehicle model. Every relevant component of the vehicle model must be provided with the appropriate data in a fast and secure process. The data for the individual vehicle components are therefore filed in a central database. A single person cannot possibly oversee the validity of all data sets and the change history. It must therefore be clearly defined who is allowed to change which data and what the data are approved for.

A graphical database front-end makes it easy for the development and calculation engineers to view and change the data. Besides component data sets, the database also contains tables that describe the composition of a complete vehicle data set from the component data. The definitions of the driving tasks and the respective boundary conditions are also centrally managed. Updates of these boundary conditions can therefore be immediately provided to all users without them having to take care of it themselves.

Most raw data sets are obtained from measurements. To prepare this data for simulation, it must be pre-processed. Characteristic maps, for example, are extrapolated in areas in which no measuring is possible.

3.3 Approval Process for Models and Data Sets

The “Modelica” component libraries are being continuously improved and extended. In order to ensure high quality and reliability of the models, it is important to strictly comply with model approval processes. All model changes are documented and subjected to regular tests. Only if these tests are passed successfully the models are approved for general usage within the simulation framework.

Data sets also have to be approved for the individual simulation tasks. Sometimes, data sets are only validated in certain areas of operation. It may be the case, on the other hand, that the output of a map is not significant for a certain simulation task and that dummy data would be sufficient. For example, the fuel consumption is not important for calculating the 0 km/h to 100 km/h value.

3.4 Simulation Execution and Automation

A graphical user interface is available to allow the calculation engineer to choose the vehicle data and component models approved for a certain simulation task. He can thus define a test procedure suitable for his application. The engineer can vary parameters, switch between submodels or even arrange a test of any number of vehicles in any number of driving tasks in the batch mode. The Java-based framework is created using Eclipse Rich Client Platform. The configuration mechanism for the possible selections available to the user is based on xml files and can thus be easily adapted.

To execute a simulation, the compliable “Modelica” code must be generated from the vehicle data and the component libraries. The code generation is based on

- the generation of data objects containing the numerical data (Records)
- the generation of models that are derived from existing models via inheritance mechanisms (“Modelica” language elements “extends”, “replaceable”, “redeclare”).

The exploitation of the object orientation of “Modelica” makes the code generation very efficient, and relatively little code needs to be generated.

The simulation of many vehicles and driving tasks produces very large amounts

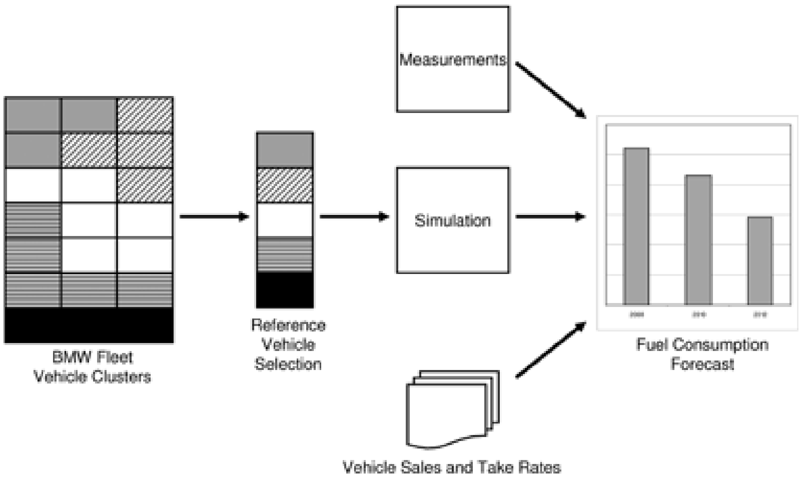

Figure 3: Fuel consumption forecast for the vehicle fleet

of data. The result files cannot only be managed and archived but also be evaluated with the simulation framework. Important features are:

- a fully integrated "MATLAB"-based plot tool
- pdf report generation
- "MATLAB" application programming interface (API) for the programming of pre- and post-processing routines.

All these steps are capable of being automated. Scripts can be easily written, thus automating all steps from data pre-processing up to report generation. One can define a test procedure that can be applied to a new version of the component libraries overnight. All relevant time series and characteristic quantities (for example speed deviation, fuel consumption, loss energies) are written to a pdf document and can be reviewed and filed conveniently.

"MATLAB" was chosen for the pre- and post-processing interface because it is widely known and well-suited for numerical data analysis and visualisation. For example, comparisons with previous versions of the component libraries can be easily implemented. All vehicle data and time series are easily accessible via the API.

4 Application: Analysing Measures to Reduce CO_2 Emissions in the Vehicle Fleet

The model-based analysis of energy flows leads to ideas for functions that reduce CO_2 emissions. The functions are designed in the "Dymola" model environment and then implemented on rapid prototyping platforms to validate the effectiveness of the measures in legal cycles as well as in customer use cases.

Examples are the automatic engine start/stop system, which stops the engine during standstill when it is not needed, and the intelligent control for the electric generator that charges the battery in deceleration phases and thus regenerates braking energy.

For the analysis of measures in the BMW vehicle fleet, the software framework is used to simulate large amounts of vehicles in different driving tasks. The vehicle fleet consists of several hundred variants, not all of which have to be simulated. Vehicle clusters are set up, considering weight, power, gearbox type and other properties. Afterwards, reference vehicles for these clusters are selected for simulation. The simulations, together with the detailed analysis of measurements, form the basis for extrapolating the results to the entire vehicle fleet. Expected vehicle sales and take-rates of optional extras are then taken into account to forecast the fuel consumption of the vehicle fleet in future model years, **Figure 3**.

5 Summary and Future Prospects

The model described reproduces the energy flows in the vehicle. All current and planned vehicles in the BMW fleet can be simulated using the developed model structures and parameter sets. As seen above, all important steps of the simulation process are supported by easy-to-use software solutions. The software framework alleviates the calculation engineer of many working steps that would be extremely time-consuming and error-prone if performed manually. The evaluation process described essentially contributed to the successful introduction of the "EfficientDynamics" package in 2008.

Vehicle simulation enables energy analysis to be performed in all development phases. It allows complex problems and interactions in the vehicle to be understood, analysed and solved. In this way, the energy flows can be optimised and the fuel consumption can be lowered. Thus, vehicle simulation is an important tool in the product development process. ■

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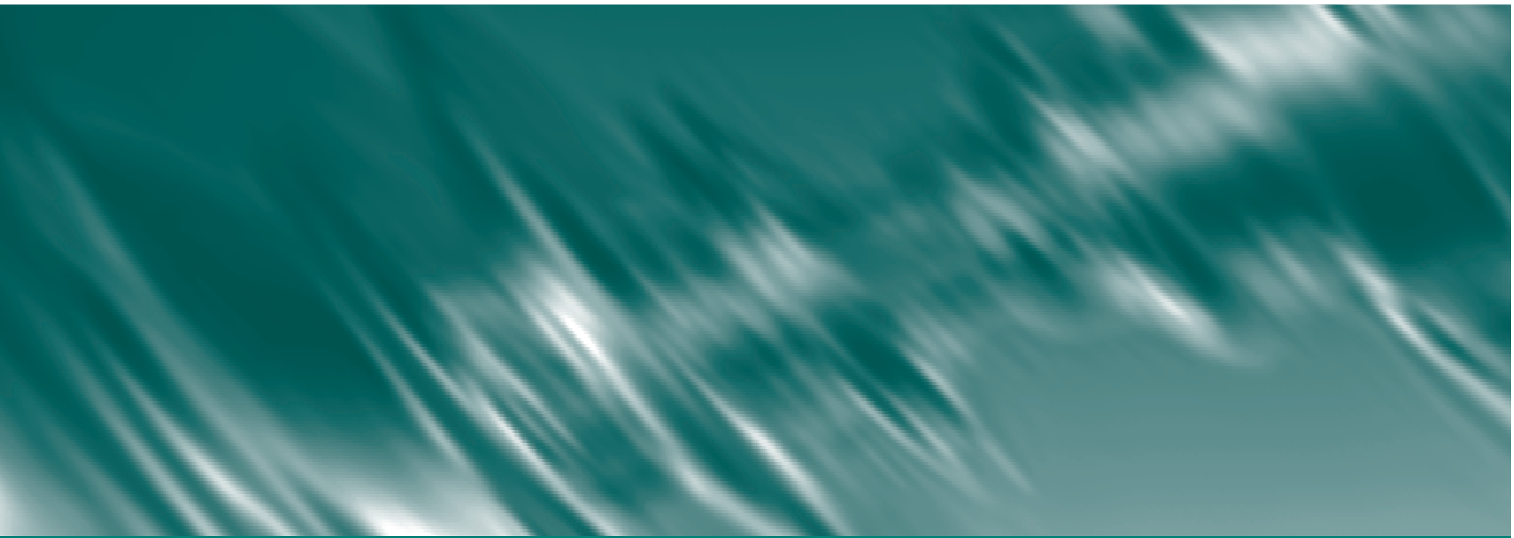

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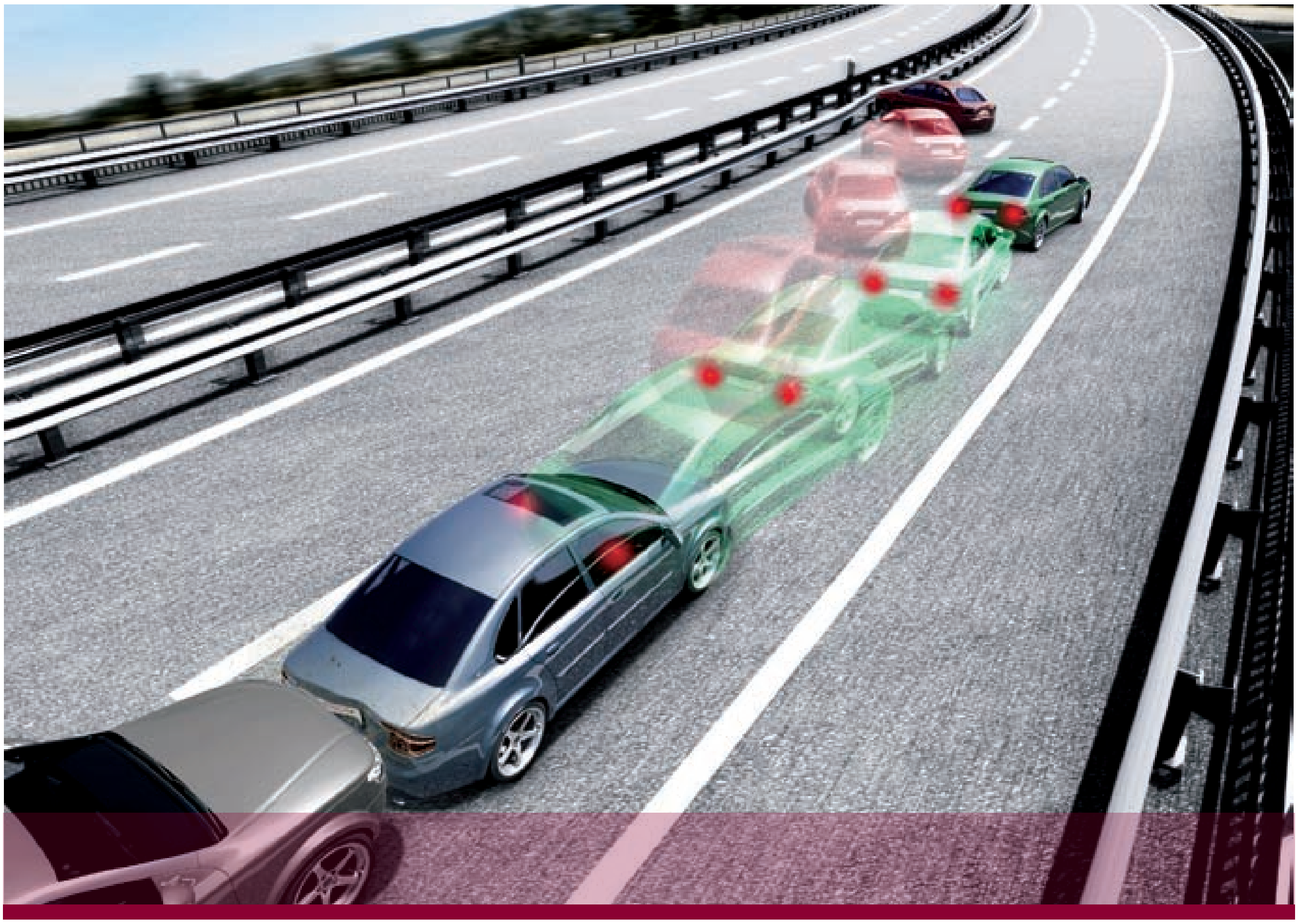

Development Strategy for Collision Warning Systems in the Low Price Segment

In the field of safety oriented driver assistance systems, there is the tendency to reduce accidents and their consequences by autonomous interventions in the driving process which are getting stronger and stronger. But this increase of the "effectiveness" also increases the danger emanating from such a system in case of a malfunction. This increases the effort of development and safeguarding and with it also severely the costs of such functions. It is possible however to develop systems with comparable effectiveness without using strong autonomous interventions. For this, Bosch combined very early collision warning with driver assisting functions. This provides the driver with sufficient time to assess the situation and assists in initiating measures for accident prevention in the best possible way. The technical challenge is the realization of an early and at the same time reliable criticality assessment of the traffic situation.

1 Risk and Benefit Assessment

The German product liability act as well as ISO 26262 and further legal and normative constraints require that a driver assistance system must not represent a danger to the user or a third party. To guarantee this requirement, a fully specified system is subjected to a danger and risk analysis which determines the danger emanating from the system in a situation of benefit and of malfunction. Systems with a high damage potential in cases of malfunction have to compensate by having a low probability of malfunctions or by the state of malfunction being highly controllable.

The approach for an autonomous emergency braking function used at Bosch is a model-based so-called objectified danger and risk analysis. In this, the effect of a false triggering of a specified autonomous emergency braking function is simulated on the basis of real traffic data, i.e. distances and relative velocities between vehicles. This has the intuitively expected result: The more velocity to the following vehicle is reduced by an automated emergency braking function, the more often rear-end accidents of higher severity are caused. Therefore, a strongly decelerating autonomous brake intervention has a higher damage potential than a weakly decelerating intervention.

The higher damage potential must therefore be responded to with a lower rate of malfunction. This is possible by means of the following measures:

- The environment sensors must have the potential to comply with the required rates of false triggering. That is, that the sensors must have sufficient rates of error detection. The low rates of false triggering needed for strongly intervening functions therefore require reliable and therefore in tendency expensive sensors.
- The process of development must be designed so that errors during product development are avoided. For example, for functionalities rated aSIL A or higher, ISO 26262 requires a continuous design and increased test expenditures.
- The false triggering rate of the product has to be proven by extensive endurance test drives. For this, the principle is valid that the proof of significantly low false triggering rates requires a sufficiently long safeguarding distance.

In the benefit scenario of a front accident, an autonomously braking driver assistance function reduces the relative velocity and thereby the severity of the accident. If the autonomous intervention is combined with a previous warning of the driver, two cases have to be distinguished in the discussion of benefit:

- The autonomous intervention takes place before the driver reaction time is over. During this period of time, the previously inattentive driver can only be assisted autonomously. Autonomous interventions are especially important if the accident occurs within the reaction time or cannot be prevented by interventions anymore after the reaction time is over.
- The autonomous intervention takes place after the driver reaction time has passed if the driver does not react. After expiration of the reaction time, a reaction by the driver to the escalated traffic situation is to be expected though, as the result of a warning. If the driver reacts, he can be assisted for example by steering or brake assistants. Crucial for the category of the functions which assist the driver is that they are only activated if besides the environment sensors the activities of the driver also indicate a critical situation.

This reduces the requirements to the reliability of situation interpretation by the environment sensors. If however the driver does not react to a previous warning, a fully autonomous intervention is initiated. For the lack of reaction there can be only two causes: First, the driver does not react by mistake and therefore the autonomous intervention is legitimate. Second, the driver assistance function is mistaken in its estimation of the situation, mistakenly intervenes and therefore endangers the driver.

From the requirement to gain more cases of benefit than false triggering rates with autonomous interventions after expiration of the driver reaction time, results the following requirement: driver assistance systems with autonomous interventions which are not made plausible via the driver and which exceed the reaction time of the driver have to analyze the situation more reliable than the driver. The result of this is a high requirement on quality and with this on the development of the criticality assessment for driver assistance systems which are autonomously intervening outside of the driver reaction time.

Alternatively to autonomous intervention it is also possible to achieve an improvement of the effectiveness in both cases described if the warning is set to an earlier point in time and is only supplemented by low-risk assistance functions supporting the driver. The part of the accidents which require intervention within the reaction time is reduced by this, and the driver has more time to deescalate the situ-

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ation. In these cases, the effectiveness of the function increases greatly, especially since, because of the possibility of evading or a full stop, the driver has more effective methods for accident prevention than an autonomously braking system with restricted deceleration. The remaining cases which necessitate a reaction within the reaction time are not supported by such a system though.

In a generalized manner it can be summed up: The stronger and potentially more risky the intervention of an autonomous function, the more expensive the development, safeguarding and hardware of the function. In most situations though an early warning with driver assisting functions without risky autonomous interventions is similarly effective and can be realized on the basis of a cheaper sensor. By means of such economical systems, so the vision, access to a safety-oriented driver assistance is to be made possible for every road-user.

2 The Restrictions of Target Object Based Approaches

Many driver assistance systems essentially take regard of a single "target object". Based on data from the environment and the own vehicle, the probability of a collision is constantly calculated for this object. Without knowledge of the intentions of the drivers in the own and the other vehicle, the driver assistance system may be in unclear decisive situations about the criticality of the traffic situation. This is illustrated by the following simple modeling.

In the first case, the systems looked at are to effect a driver reaction to a critical approach by means of a warning. If the driver is aware of the traffic situation, he, independent from the warning, will initiate a braking process with a moderate deceleration of $a_{ATTENTIVE}$ so that he will have adjusted the relative velocity to the obstacle. With this, a braking time $t_{ATTENTIVE}$ can be calculated at which the driver who does not require support by a driver assistance system typically starts his braking process. If the driver is inattentive however, he requires support by a driver assistance function. The latest time t_{WARN} for a warning is calculated according to the following model: After triggering of the warning at the time t_{WARN}, the driver needs a reaction time after which he will react with a strong emergency braking-deceleration $a_{EMERGENCY}$ so that he will come to a standstill before the rear-end of the obstacle. A formal analysis of the described models shows that, dependent on the relative velocity, the time of decision t_{WARN} for the triggering of the warning is earlier (!) than the typical braking time $t_{ATTENTIVE}$ of the attentive driver. At the time of decision for triggering of the warning t_{WARN} it therefore cannot be deduced without doubt from the activities of the driver whether the driver is aware of the situation and will sufficiently react with a braking with $a_{ATTENTIVE}$. For the time $t_{WARN} < t < t_{ATTENTIVE}$, the driver assistance system therefore is in the dilemma of not sufficiently assisting the inattentive driver when suppressing the warning or of distracting the attentive driver with an unnecessary warning. This first dilemma of decision occurs in the lower respectively middle velocity range.

A second dilemma of decision concerns autonomously intervening systems also. A look is again taken at the case of a critical approach. The approach can be deescalated by braking or evading. These processes are initiated by an attentive driver at different points in time: when a braking process is no longer possible for deescalating, it is still possible to easily complete the evading process. At the time when an intervention by a driver assistance system could still prevent the accident by brake intervention, it is still possible to comfortably evade.

2.1 Warning Dilemma

In the following, the described decision problems are called "warning dilemma". The warning dilemma does not only affect the electronic, but also the human passenger. Human passengers react, dependent on their frame of mind, sometimes more nervous, sometimes more relaxed to the driving behavior of the driver. The assessment of a passenger that the driver will for example drive past the next traffic island and not straight into it is based on the situational context and assumptions about the driving behavior which is to be expected. The course of the lane markings alone leads the passenger to the assessment that in front of the traffic island the driver will choose the option "evade" and not the option "brake". If the driver deviates from this assessment, a human passenger also will not be able to prevent the accident by means of a sufficiently early warning of the driver.

This example shows that the warning dilemma is of a fundamental nature and not restricted to electronic driver assistance functions. So aside from the raw physical data between target object and the own vehicle, the human passenger uses additional model knowledge and environment information to generate a-priori probabilities for the individual options for action of the driver. These help reducing the warning dilemma.

2.2 Additional Information for Situational Interpretation

Besides the described "warning dilemma" scenes, additional information for situational interpretation arises from the observation of the traffic situation of third party road-users. If critical situations are detected for third party vehicles, a behavior deviating from the normal case is to be expected from them. For example, if a faster vehicle approaches a slower vehicle on the left lane, the probability increases that the fast vehicle will pull out onto the lane of the own vehicle and that as a result there will be a critical situation for a third party vehicle.

If the human passenger is accepted as a "benchmark" for a best possible situational interpretation, the following hypothesis can be made: Including additional information like multi-object constellations and lane information aids in the reduction of the warning dilemma problem and so in the improvement of the false triggering to benefit ratio. Functions which only use one target object are restricted in the quality of the criticality assessment as a result of their principle.

3 Situation Analysis in Multi-object Scenarios

Basis of the analysis of the benefit of multi-object scenarios is a detailed accident analysis of the GIDAS-accident database in individual case representation. Observed are accidents in longitudinal traffic (GIDAS-accident type 6) and accidents while turning off (GIDAS-accident type 2). In detail, they are the following subtypes:

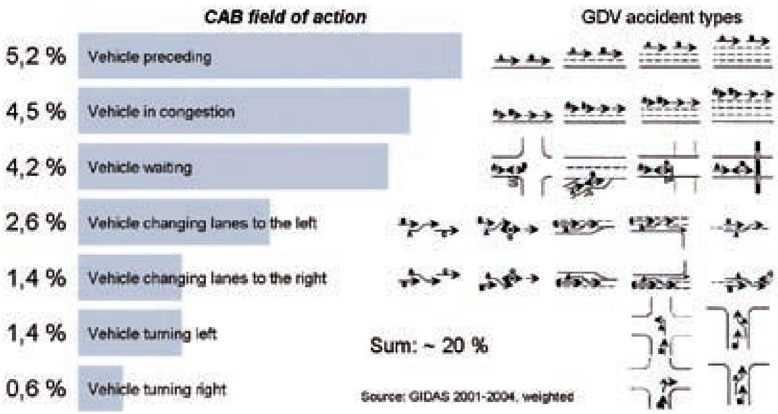

Figure 1: Percentages of the essential accident types in the complete incidence of accidents and area of effect of a CAB function (Collision Avoidance Braking)

Figure 2: Critical situation "oncoming traffic on opposite lane" in which excluding the intention of overtaking as a permissible option for action is possible at the warning time

GIDAS-accident type 6 (60: 601, 602, 603, 604, 609), (61: 611, 612, 613, 614, 619), (62: 621, 622, 623, 624, 629), (63: 631, 632, 633, 634, 635), (64: 641, 642, 643, 644, 645, 646, 649); GIDAS-accident type 2 (20: 201, 204), (23: 231, 233). The percentages of the essential accident types in the complete incidence of accidents are itemized in **Figure 1**.

Altogether, the area of effect of a driver assistance function reacting to frontal and parallel traffic therefore is approximately 20% of the complete incidence of accidents. The accidents within this area of effect were analyzed according to the additional information available by additional objects. This results in a new typecasting of the accidents which deviates from the one in Figure 1. For two of these types, the additional benefit by evaluation of the multi-object information is discussed in the following. The information in percentages relates to the area of effect of approximately 20 %.

Case 1: In 9.3 % of the accidents, the preceding vehicle brakes strongly while there is oncoming traffic on the left lane. A similar scene is shown in **Figure 2**. If only the "target object" is observed, the driver assistance system as a matter of principle has the problem of the decision between evading and braking. This is correspondent to the second problem of decision (warning dilemma) discussed in section 2. But when there is oncoming traffic, overtaking respectively evading can be excluded as a sensible option for action for the driver at the time of warning. By reducing the warning dilemma problem, an earlier and more reliable system reaction is possible.

Case 2: In 10.5 % of the accidents, the preceding vehicle drives against a slower object and brakes strongly. In principle, radar based driver assistance systems can detect pre-preceding vehicles.

Before the actual target object becomes "a problem" in this example because of its strong braking, it is possible to discern a critical traffic situation for the preceding vehicle by observing its fast approach to the vehicle in front of it. The hypothesis that the preceding vehicle will brake or evade to prevent the accident is self-evident. On the basis of this interpretation, the behavior modeling for the preceding vehicle can be adjusted to already warn the driver with this before it is even possible to detect the danger by means of the state of the "target object", concerning this see also [1]. Here, the principle discussed in section 2, to observe the traffic situation of a third party road-user and deduce possible danger for the own vehicle from it early, is used.

The described situation is especially important for a driver, because his view on the pre-preceding vehicle is obstructed. The driver assistance system however has its radar measurement and therefore an advantage in information compared to the driver.

4 Conclusion

By the assessment of multi-object scenarios, an earlier and more reliable criticality assessment of a traffic situation is possible for many frontal accidents. This can be used to distinctly increase the effectiveness of low-risk driver assistance functions. By combining early driver warning with driver assisting functions, it is possible to reach, relating to the total number of frontal accidents, the effectiveness of functions with strong autonomous intervention. The argument is essentially based on the experience that with "target object based" driver assistance systems, the obscurity about how a situation will progress increases drastically with growing temporal range of prediction, and that this can be moderated by the additional involvement of multi-object information.

The early warning approach illustrated by Bosch offers the advantage that it is possible to forego the use of complex, expensive and strongly autonomously intervening systems. The great benefit combined with the low price is the basis of the vision to make safety oriented driver assistance functions with high effectiveness available to the mass market.

Reference

[1] Branz, W.; Stämpfle, M.: Kollisionsvermeidung im Längsverkehr – die Vision vom unfallfreien Fahren rückt näher. Vortrag, 3. Tagung aktive Sicherheit durch Fahrerassistenz, 7. und 8. April 2008, TU München, Garching

From Real to Virtual Tyre
Tyre Model Parameterisation

The simulation of driving dynamics has to meet highest demands regarding model accuracy and reliability of the prediction results. Hence complex handling tyre models are used, which must be parameterised based on highly accurate tyre measurements. At IABG, a modern flat track tyre test stand is methodically integrated into the parameter generation process, from the creation of the test procedure up to model parameter update.

1 Introduction

An integral component of the modern tyre development is the highly precise measurement of tyre characteristics and the enhancement of test methods on tyre test stands. Compared to conventional tyre measurement, modern flat track tyre test stands offer significant advantages regarding the reproduction accuracy of the tyre-surface contact, the potential operational range and the flexibility during the test procedure preparation.

In the vehicle and tyre manufacturing industry the trend to shift complex tyre development loops from the real on-the-road testing to virtual prototypes and simulation can be observed at an increasing level. High model accuracy in particular of the tyre model, required for the analysis of the tyre effect on driving dynamics and comfort, is presupposed and can so far not be sufficiently guaranteed by the conventional tyre measuring methods. Thus roller drum test facilities possibly offer costs advantages; however, the changed shuffle geometry can only insufficiently represent the conditions between tyre and road. Measurement trailers, however, reveal deficits concerning the reproducibility due to constantly changing environmental conditions such as temperature and friction values. However, by integrating the flat track tyre test stand, driving dynamic parameters of the tyre can be obtained reproducibly and correlations between subjective and objective model criteria can be identified.

As substantial part of the tyre development process for various vehicle and tyre manufacturers a consistent process for tyre characterisation was established by IABG, with which tyre data for driving dynamics related applications are generated and consistently tailored to the requirements of the driving dynamics simulation. This article provides an overview of the test stand design, the measuring method, the data preparation and the parameter fitting of a Magic Formula [1] tyre data record using the parameter fitting programme MF-Tool [2].

2 Tyre Data Generation Process at the Flat Track Tyre Test Stand

The schematic view in **Figure 1** is supposed to illustrate the process described, based on flat track tyre test stand measurements. The measurement data are processed and used as an input to the parameter fitting procedure. The parameter fitting routine generates a tyre parameter dataset, which is used in offline and real time simulation models.

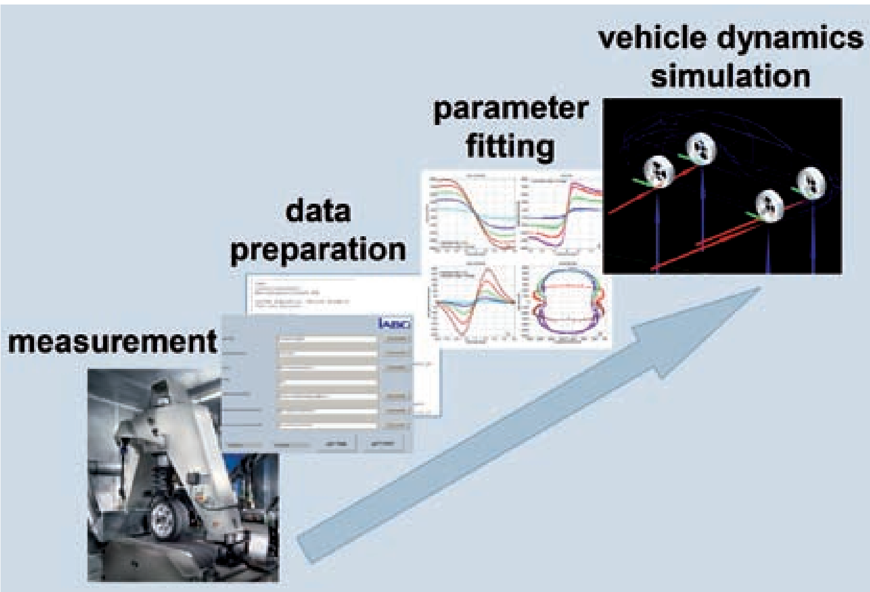

Figure 1: Schematic view of tyre data generation process for driving dynamics simulation purposes

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Table 1: Specifications flat track tyre test stand [3]

Maximum settings	Quantity	Accuracy	Unit
Tyre outside diameter	910	± 0,25	mm
Tyre width	450	± 0,25	mm
Speed capacity	250	± 1	km/h
Spindelspeed speed	3500	± 12,5	rpm
Wheel torque	2800	± 20	Nm
Slip angle	± 30	± 0.01	deg
Sweep rate	50	± 1	deg/s
Inclination angle	-12 to 45	± 0.01	deg
Sweep rate	5	± 0.1	deg/s
Vertical load	25000	± 1 %	N
Movement speed	300	± 3	mm/s
Tyre inflation pressure	700	± 3	kPa
Maximum measured values	**Quantity**	**Accuracy**	**Unit**
Longitudinal force Fx	10000	± 1 %	N
Lateral force Fy	15000	± 1 %	N
Overturning moment Mx	10000	± 1 %	Nm
Aligning torque Mz	3000	± 5	Nm
Wheel torque Tw	2800	± 20	Nm

water reservoir, which absorbs the wheel loads and thus guarantees a plane contact area kept at a moderate temperature. The tyre pressure is controlled during the tests. By using adapter systems positioning off sets are compensated. Thus all standard vehicle rims can be used. The tyre forces and moments are obtained via a multi-component load cell. A separate engine powers and brakes the wheel.

The measurements are obtained under laboratory conditions. Interfering factors such as fluctuations in friction and temperature are hence minimised. The air temperature in the test chamber is held at 23 °C. The test chamber is also used for the preconditioning of the tyres. The metal band bonding has to meet highest qualitative demands (macro and micro roughness, tyre wear, speed resistance). The required roughness of a dry road is guaranteed with a special finishing procedure, which was validated in pre-tests with a friction value measuring method. Thereby the prerequisites for reproducible measurements are fulfilled, which are required for a continuous development process.

3 Design of the Flat Track Tyre Test Stand

The modern flat track tyre test stand [3] operated by IABG allows the measurement of passenger car tyres, motorcycle and motoring tyres, respectively. The test stand enables operation up to a speed of 250 km/h and copies driving manoeuvres (wheel load, slip angle, camber angle, driving/braking) high-dynamically, **Table 1**. Apart from the kinematical tyre control the test stand offers the possibility of exerting forces and moments in a force-controlled manner as target data during test runs, which are obtained via six degrees-of-freedom force test hubs.

The tyre runs on an about 0.7 mm thick stainless steel strap, which can be coated with varyingly rough surfaces. Under the strap there is a hydrodynamic

4 Measuring Method and Measurement Procedures

The following aspects are to be considered during the preparation of measurement procedures:

- development objectives (traction, braking distance, directional stability, etc.)
- tyre model
- measured variables

Table 2: Measurement plan for the determination of the Magic Formula parameters

Test Programme Passenger Car				
Spindeldrive attached			Free rolling	
Driving	**Braking**	**Driving/Braking**		
Tyre 1	Tyre 2	Tyre 3	Tyre 4	Tyre 5
Warm up/Tyre conditioning				
Setup Tuning Set				
Pure longitudinal	Pure longitudinal	Pure longitudinal braking FZ,max	Sideforce	Springrate
Longitudinal/lateral FZ,1	Longitudinal/lateral FZ,1	Longitudinal/lateral FZ,max	Sinsweep	
Longitudinal/lateral FZ,2	Longitudinal/lateral FZ,2	Pure longitudinal driving FZ,max	Vertical Stiffness	
Longitudinal/lateral FZ,3	Longitudinal/lateral FZ,3	Longitudinal/lateral FZ,max		

Table 3: Input data for the Magic Formula parameter fitting

Measured channels for Magic Formula		
Channel	**Description**	**Unit**
MEASNUMB	Measurement point number	–
SLIPANGL	SA Slip angle	rad
INCLANGL	IA Inclination angle	rad
LONGSLIP	SR Longitudinal slip	%
FX	FX Longitudinal force	N
FYW	FY Lateral force_ISOW	N
FZW	FZ Vertical force_ISOW	N
MZW	MZ Aligning torque_ISOW	Nm
MXW	MX Overturning torque_ISOW	Nm

- range of capacity of the test stand
- tyre temperature
- tyre wear
- test sequence.

From this a measurement plan can be generated as a sequence of specified operational conditions. The actual test sequence is foregone or followed by conditioning sequences (for example warm up or cool down). With the Magic Formula measurement procedure particular attention must be paid for example to keeping constant the factors of influence tyre wear and tyre temperature.

In **Table 2** a standardised Magic Formula measurement plan is displayed. For the total measurement campaign five tyres are required. The tyres one to three are applied for manoeuvres with driving and braking slip. Tyres four and five are provided for free rolling measurements.

In the single measurement routines the respectively operational conditions (wheel loads, speed, slip angle and camber angle, longitudinal slip, pressure) are initiated. The measurement routine "pure longitudinal" for example records the dependency of these quantities upon the longitudinal slip. For one pressure and one speed thereby 15 various operational conditions are necessary. The total measurement for a tyre parameter record requires altogether about 200 individual measuring processes.

Four various normal force levels are also evident in Table 2. The first three vertical force levels are typically determined (for example 800 N, 3200 N and 4800 N), in order to guarantee a direct comparability between various measurement procedures and measurement campaigns. The fourth vertical force level, marked "max", is variable and related to the type of tyre. It is obtained prior to the determination of the measurement procedure iteratively at the test stand. The objective is to collect working range data of the tyre as completely as possible.

Despite extensive elimination of factors of influence in view of a reproducible fitting process it became clear that repeated measurements are essential for parts of the measurement campaign. This particularly applies for complex operational ranges (for example transition adhesion, sliding).

The selection of the measuring channels which can be recorded and their sampling rate is adapted individually in view of the dynamic effects of interest and the handling of the resulting file sizes. Normally 32 measured variables are currently recorded at a sampling rate of up to 1 ms. **Table 3** displays the channels necessary for the parameter fitting.

5 Conversion and Evaluation Software

Only by applying suitable conversion and evaluation software the flat track tyre test stand turns into a high-power development platform. It represents the link between measurement raw data, simulation and tyre development. For this purpose IABG has developed a modular programme environment under "MATLAB", which is provided with a graphical user interface. The software accesses both the test control files (inputs) and the created measuring data files (output). Thus a comprehensive interpretation and documentation of test results is ensured.

Flexible adaption and standardisation of recurrent functions is provided. Further functionalities are also available, from automated measuring data storage up to the measurement report preparation. As a result for example "TYDEX" compatible data [4] are available.

The total data conversion process is recorded and documented by the evaluation software. From this results a transparent documentation of the time raw data post-processing. User entries are recorded amongst other data applied sequencing programmes as well as all control parameters and filter settings.

The functionalities of the IABG data converter regarding the parameter fitting process with MF-Tool are represented as follows:

- conversion and export of the individual measurement in "TYDEX" format (header, data and parameter range)
- digital filtering of the measured variables
- detecting and cutting of analysis-relevant measuring ranges
- separating and combining of individual measurements
- measurement analysis of special parameters (vertical tyre stiffness, kinematical rolling radius, "pre"-relaxation lengths)
- transformation of coordinates
- selection of measuring channel
- control and result plot preparation
- conversion report.

The conversion and evaluation process is represented in **Figure 2**.

6 Aspects to be Considered in the Fitting of a Magic Formula Dataset

Using individual data preparation steps it is shown, how the parameter fitting programme MF-Tool is embedded into the parameter fitting process, Figure 2.

At the beginning the prepared measuring data need to be validated; each measurement is checked regarding its usability as well as its range of validity. If

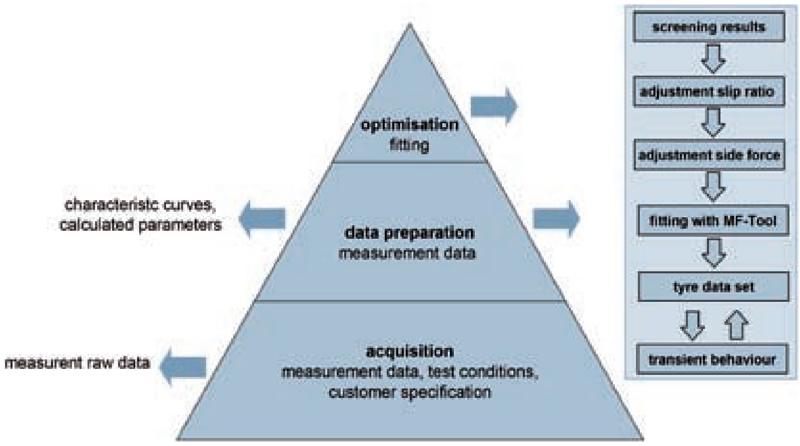

Figure 2: Sequence measurement data recording, processing and parameter optimisation

necessary individual measurements are not being used and/or their range of validity is limited. The classification of measurement data is carried out on a half-automated basis, that is the analysis programme obtains a proposal for the measurement preparation. This must be acknowledged or corrected by the user in each case, **Figure 3** a and b.

The base factor for the filtering and representation of the measured variables (forces, moments) is the longitudinal slip of the tyre. The indirect determination procedure [5] of the longitudinal slip at the test stand bears a systematic inconsistency, that is slip-dependant measured variables do not indicate their origin at longitudinal slip zero. According to the model concept that longitudinal slip equivalent parameters, that is the longitudinal force also show zero values, vertical-force-dependant offset adjustments are being made, Figure 3 b and c. The required adjustments typically lie in a range of up to 3 %.

Additionally the measured lateral forces affecting the wheel must be adapted in the view of a consistent data evaluation: Adaption of the measured lateral forces in case of combined slip on the lateral forces with pure slip angle. This is due to the model concept that the combined load case can be transferred to the non-combined load case in each case. This procedure guarantees a consistent data collection of the drop in lateral force dependent on the longitudinal force and thereby provides more accurate longitudinal force sensitivity in the vehicle model simulation. The necessary lateral force adjustments lie in the range of up to 4 % of the respective normal force level, Figure 3 d and e.

Beyond the fitting of the quasi-stationary tyre parameters a precise alignment of the dynamic force response is important in longitudinal and lateral direction. Magic Formula contains a dynamic analogous model in form of a first-order (PT1) lag of deformations, which requires a special weighting of the measurements for the relevant operational range of the tyre. Decisive factors here are speed, vertical force, steering angle frequency and steering angle amplitude. The determination of these parameters is achieved via simulation of the tyre parameters set generated up to this point. The optimisation of the lateral force behaviour is for example affected using the sinus steering manoeuvre (Table 2: sine sweep) under specification of the steering angle, Figure 3 f.

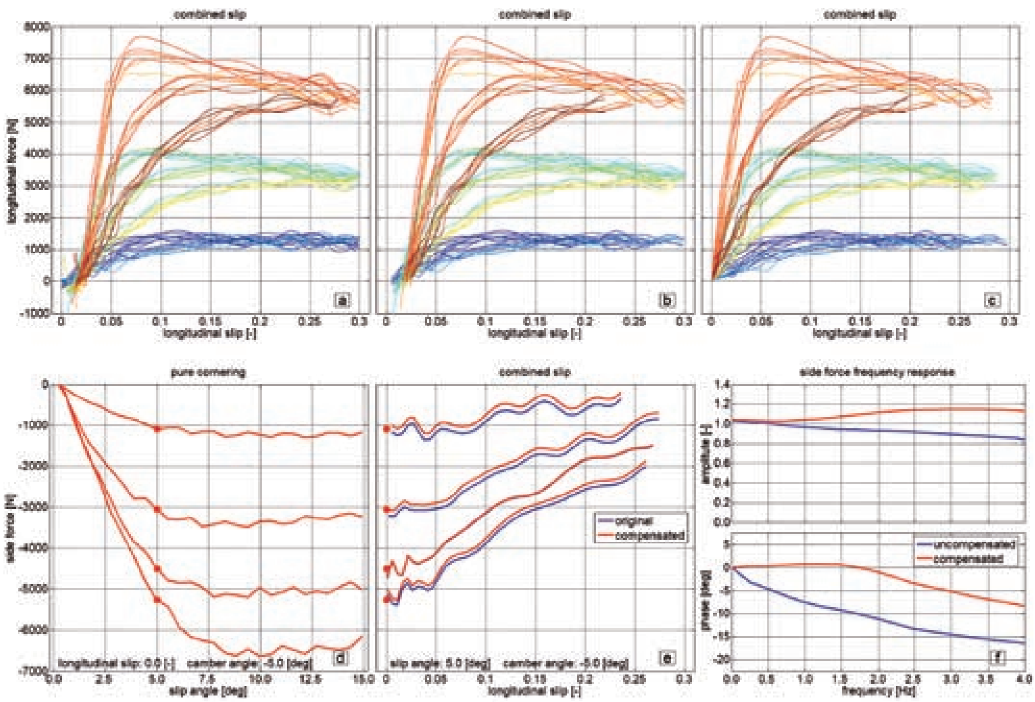

Figure 3: Schematic view of the measuring data preparation for the parameter fitting

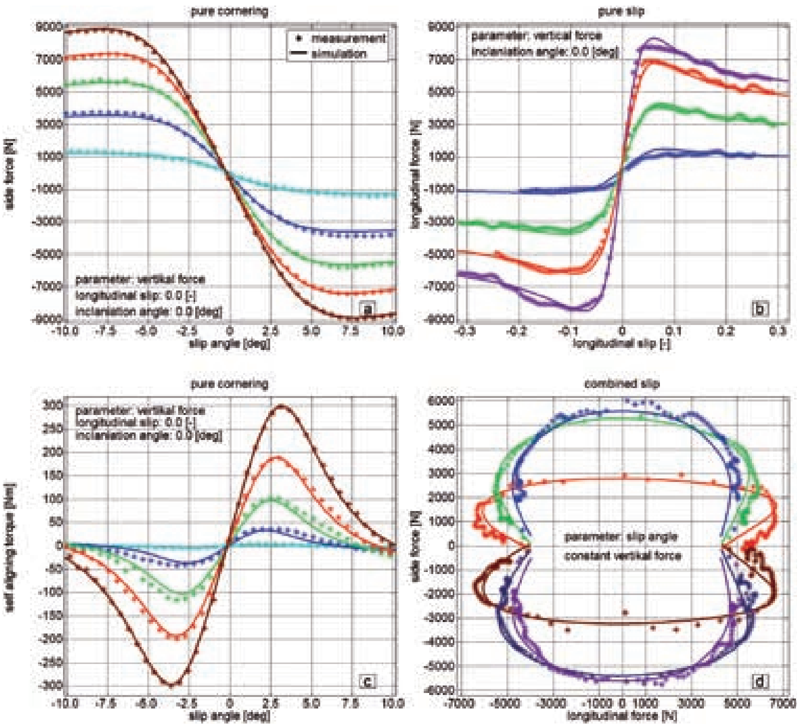

Figure 4: Exemplary result representation of a fitted dataset

7 Summary

The use of the ultra-modern flat track tyre test stand includes the vision to promptly provide the vehicle development process with a tyre which is already "fit for operation" with the required driving and handling characteristics. With the test stand qualitatively and quantitatively tyre measurements can be carried out under reproducible conditions, which form the starting point for the generation of tyre model datasets for the driving dynamics simulation.

Apart from the measurement equipment the measurement and evaluation methodology is of crucial importance for the generation of Magic Formula parameters. In the measurements for example abrasion and temperature influences are compensated and relevant operational driving dynamics conditions are covered.

Comprehensive evaluation software is used for the processing of the measuring data. It guarantees the preparation and optimisation of measuring data for the fitting. Using the example of the commercial programme MF-Tool [2] the parameters for the Magic Formula tyre model [1] are determined from the preprocessed measurement data, **Figure 4**.

8 Future Prospects

In the future tyre development it must be assumed that the tyre parameter identification procedure (for example also fitting and analysis) will increasingly be outsourced to tyre manufacturers or service partners after validation and standardisation of the test procedures. That means that in addition to the actual tyre, the tyre manufacturers have to provide the respective tyre model data or tyre parameters.

By using the flat track tyre test stand in the evaluation environment described, tyre and vehicle manufacturers and engineering partners can save costs and above all development time. Tyre measurements on a flat track tyre test stand will be standard in the future, to make results of measurement and tyre model parameters comparable. Apart from the determination of data for the simulation, tyres can be characterised and compared. Beyond that driving dynamics manoeuvres can be copied and the capacity of tyres in threshold ranges can be analysed.

In the context of a consistent development of the application range blow bar tests and footprint measurements are already accomplished at the flat track tyre test stand. These fulfil – amongst other things – the purpose to determine parameters for tyre models from the comfort division as for example "RMOD-K" [6] or "FTire" [7]. The conversion and evaluation software is enhanced with the target to supply consistent parameter datasets also for comfort tyre models at the push of a button.

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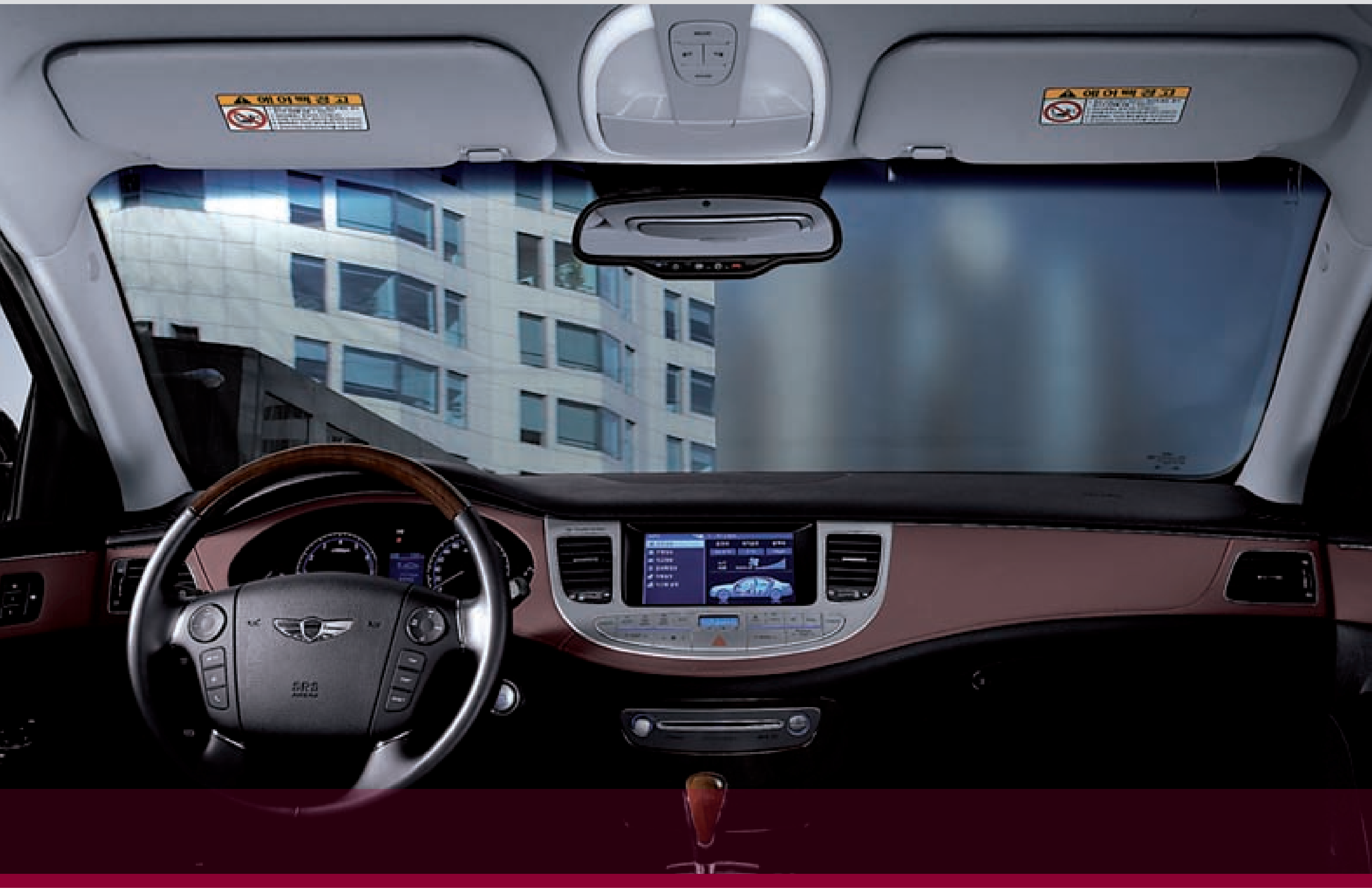

Hyundai Genesis with Automatic Windshield Defogging System

Excessive windshield fogging is not only a safety hazard but is also a major consumer concern in the automotive industry. One of the key features of an automated system is its ability to maintain a pleasant in-cabin atmosphere and provide an unobstructed forward visibility for the driver. Hyundai has developed an automatic defogging system by integrating a sensor that detects fogging into the conventional climate control and embedding a defogging control logic in the controller's microprocessor.

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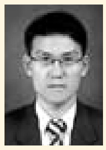

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1 Introduction

The fogging of the car's windshield obstructs the forward visibility of both the driver and the front passenger and is widely considered by many as a major motoring safety hazard while driving or changing lanes. In addition, "excessive windshield fogging" tops the Initial Quality Study list, indicating that the problem is not only a safety hazard but is also a major consumer concern. Windshield-fogging-related consumer complaints are attributed more, however, to the consumers' unfamiliarity with defogging systems than to the actual performance of the systems themselves. In fact, surveys have shown that a vast majority of motorists either never use their cars' defogging systems or use them inappropriately. It stands to reason then that if the automated defogging system is properly operated before the driver attempts manual control, both the driver's safety and the passenger's comfort would be further promoted.

2 Auto Defog System Design

The Fully Automatic Temperature Control (FATC) Heating, Ventilating, and Air Conditioning (HVAC) system in most vehicles on the road today was designed to maintain the interior temperature at the user-selected level and is incapable of providing an effective solution to defogging the windshield. For this reason, the driver constantly manually adjusts the HVAC system to defog the windshield. As a solution, an automatic defogging system can be devised and implemented if the HVAC functions are properly operated by integrating a sensor that detects fogging into the conventional FATC HVAC controller and embedding a defogging control logic in the FATC controller's microprocessor.

The key feature of this automated system is its ability to simultaneously maintain a pleasant in-cabin atmosphere and provide an unobstructed forward visibility for the driver. Even if a defogging system were capable of detecting fog build-up in advance and automatically start to defog the windshield, all would be for naught if the system were incapable of providing similar levels of interior-temperature comfort as the conventional, non-automated defogging HVAC systems can perform. This means that the development of an actuator that would independently open and close the defrost door without sacrificing the HVAC system functionalities was needed, as well as the detail tuning of outdoor conditions (specific dehumidification factor algorithms) in connection with door opening level.

This was the result of the efforts to minimise the structural changes to the HVAC and to achieve the independent control of the defrost door. The defrost door shaft was separated from the existing operational structure of a cam operated mode door actuator. The separate actuator was added to the door shaft in order to enable the automatic defogging system to independently control the defrost door.

The basic concept and mechanism of the automatic defogging system presented herein are shown in **Figure 1**. The system is made up of a sensor that measures

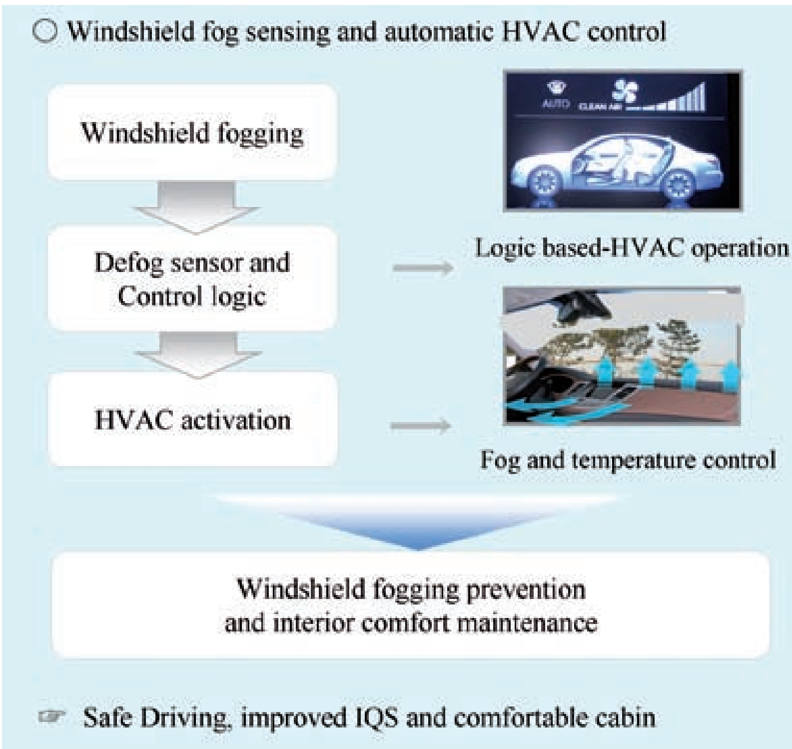

Figure 1: Auto defog system concept

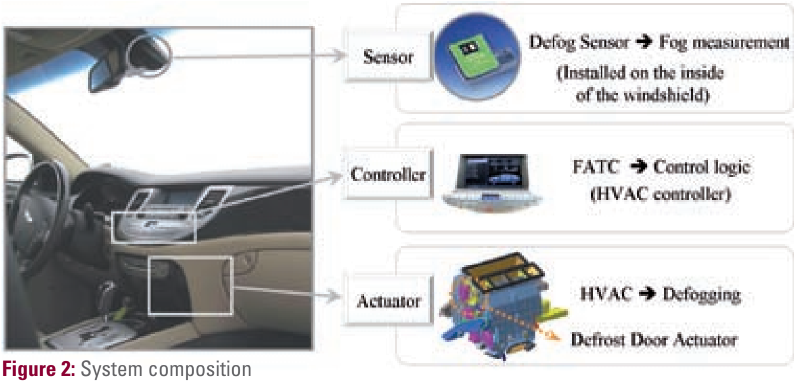

Figure 2: System composition

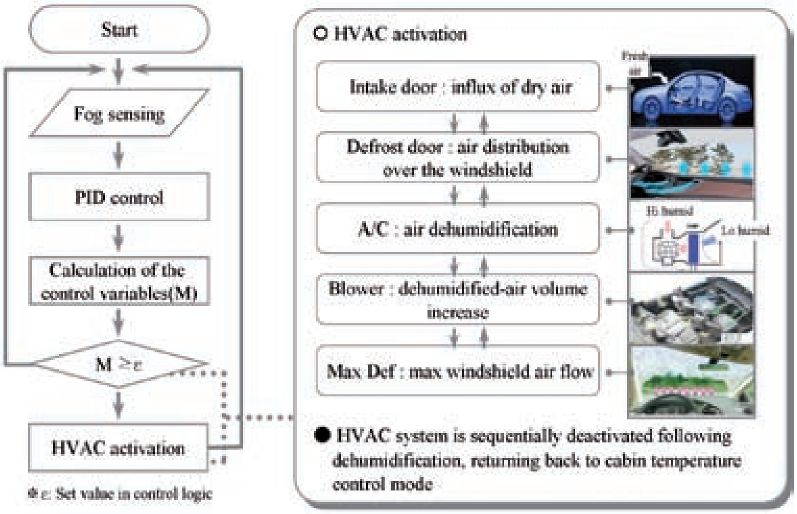

Figure 3: Windshield defogging strategy

the surface humidity of the windshield, a controller that analyses the obtained data to determine the presence of fog on the windshield and an actuator that activates the HVAC defrost door, **Figure 2**.

2.1 Defog Sensor

The standard method of measuring windshield condensation involves taking humidity and temperature readings from the air near the windshield to derive the dew point on the windshield surface. In contrast, the presented system utilises a sensor that takes direct readings of the windshield surface condensation and calculates the relative humidity based on the lead electrode capacitance change. This sensor detects windshield fogging much quicker and features a Proportional Integral Derivative (PID) control algorithm that adjusts the measurement basis points for accurate sensing when sudden changes in humidity occur.

As interior-air stream, air discharge direction, temperature, passengers, and various other elements affect windshield condensation, different readings may result, depending on the position of the sensor. This requires the configuration of the sensor position and a baseline windshield condensation level that will trigger the HVAC. The defog sensor in the developed system was positioned behind the rear-view mirror, on the cabin side of the windshield, considering the driver's view, solar radiation, and interior aesthetics.

3 Control Logic Calibration

3.1 Automatic Windshield Defogging Strategy

During normal operation, FATC HVAC systems with an automatic defogging feature control the cabin temperature using only the panel or floor ventilation and not the defrost feature, as controlled by an automatic cabin temperature control logic.

When an increase in windshield humidity is detected, the system initiates a defogging strategy, **Figure 3**, and then returns to cabin temperature control logic when the targeted windshield humidity level is reached. This process is repeatedly done according to the varying circumstance. Once a defogging strategy was established, the following criteria were optimised considering the environmental conditions, weather, number of passengers in the vehicle, and HVAC operation:

1. baseline humidity levels for defogging initiation and termination
   - initiation: maximum humidity, at which point the windshield condensation cannot be read
   - termination: considering fuel efficiency and comfortable temperature maintenance
2. intake door moves from recirculation (inside air) to fresh (outside air)
3. air/conditioning (A/C) activation point and level
   - considering the defogging duration (efficiency) and fuel efficiency
4. blower speed adjustment
   - considering the noise and passenger comfort
5. max defrost
   - high defogging efficiency.

3.2 Independent Defrost Control and Linked Airflow Control

Independent defrost control opens and closes the defrost door independently while maintaining the panel and floor doors as they are, variably controlling the air flow at the windshield to control both windshield defogging and passenger comfort. The feature increases the defrost door opening as the windshield humidity level rises, thereby increasing the airflow at the windshield. The relative decrease in panel and floor airflow that results from this increase in the airflow at the windshield is compensated with increased blower output to further ensure passenger comfort and windshield fogging prevention, **Figure 4** a.

3.3 Variable Compressor Control and Linked Temp Door Control

The variable control of the compressor based on the windshield humidity level

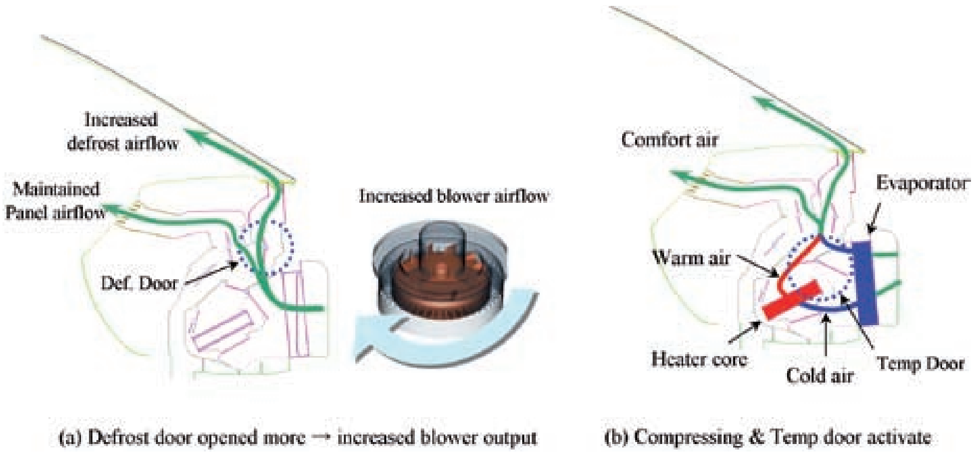

Figure 4: Defrost door and blower air flow control

minimises fuel consumption. In addition, the compressor is linked to the temperature door operation to prevent an excessive drop in discharge air temperature during compressor operation, thereby preventing secondary frost/mist formation on the windshield's exterior, Figure 4 b.

4 Performance Tests

The performance of the presented automatic defogging system was tested under various weather conditions and HVAC operation in both laboratory (rain climatic wind tunnel and cold ambient climatic wind tunnel lab) and field.

4.1 Rain Conditions at the Seasonal Transitions (Rain Climatic Wind Tunnel)

Figure 5 shows the results of the defogging and interior temperature control performance comparison tests conducted on the vehicle with the automatic defogging system and the vehicle without the automatic defogging system under rainy conditions at seasonal transitions.

The activation of the HVAC system as the windshield started to fog up resulted in quicker defogging in the vehicle equipped with the automatic defogging system than in the vehicle without an automatic defogging system. A/C operation alone, however, prevented windshield fogging in both vehicles, indicating that interior dehumidification alone is capable of suppressing windshield fogging with mild ambient temperature (outside temperature: 20 °C) conditions.

When the driver deliberately turned off the A/C (to reduce fuel consumption) and when the outside temperature was decreased from 20 °C to 0 °C, the vehicle that was not equipped with the automatic defogging system experienced an increase in windshield condensation to the point of obstructing the forward visibility for the driver. In the vehicle equipped with the automatic defogging system, on the other hand, the automatic control of the A/C compressor according to defogging logic prevented windshield fogging and thus maintained clear and unobstructed forward visibility for the driver.

A drop in the outside temperature results in a sudden increase in windshield condensation, even if the absolute humidity inside the cabin remains constant. In the test vehicle equipped with the automatic defogging system, however, the defrost air flow and temperature control were able to prevent windshield fogging.

The continued operation of the automatic defogging system was able to constantly maintain the driver-configured temperature level inside the cabin and thereby maintain a pleasant cabin environment, Figure 5.

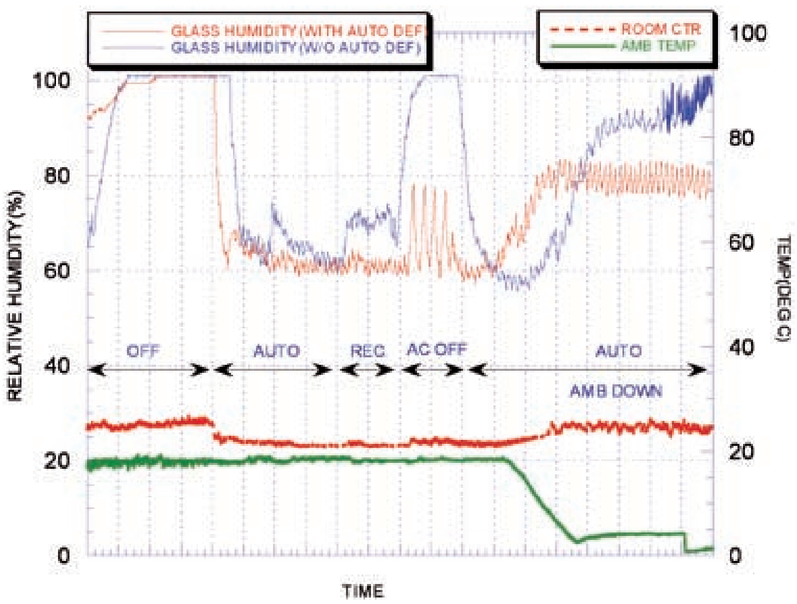

Figure 5: Performance comparison under seasonal transition rain conditions (rain wind tunnel)

4.2 Winter Conditions (Cold Climatic Wind Tunnel)

Figure 6 shows the results of the dehumidification and interior-temperature control performance comparisons that were conducted under winter conditions. Typically, in winter conditions custom-

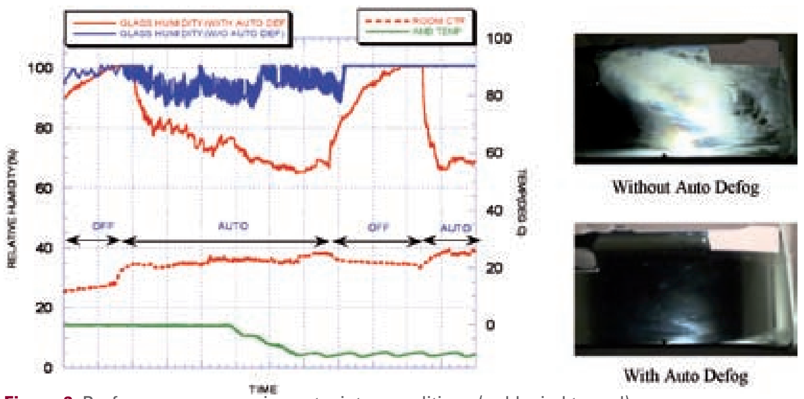

Figure 6: Performance comparison at winter conditions (cold wind tunnel)

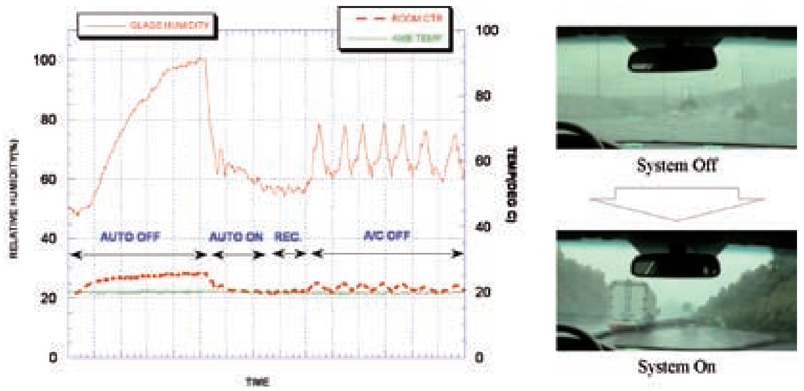

Figure 7: Field test on Korean roads (rain conditions)

ers use Fresh Mode and Air Conditioner Off. To simulate these conditions the system was evaluated in the Fresh Mode with the Air Conditioner Off and only the performance in Auto mode was used for the comparison.

The vehicle equipped with the automatic defogging system was able to remove the windshield condensation and to maintain unobstructed forward visibility for the driver at the 0 °C and -10 °C outside-temperature. The vehicle without an automatic defogging system, on the other hand, was unable to defog the windshield.

When the auto defogging system was activated with frost formed on the window (outside temperature: -20 °C), partial frost remained along the edges of the window but the system did provide sufficient forward visibility. The automatic system was able to appropriately control the HVAC system in the defogging and defrost sections so that it can sufficiently maintain the cabin temperature.

4.3 Field Test : Rain Conditions at the Seasonal Transitions on Korean Roads

Upon the completion of the automatic defogging system's primary development using a climate wind tunnel, the vehicle was tested under real-world conditions on Korean roads (highways and local) and in the rain. The results of the field test confirmed the wind tunnel findings: The system was able to prevent windshield fogging well in advance, even with the A/C unit turned off, and was able to provide unobstructed forward visibility to the driver, **Figure 7**. In addition, passenger comfort was superior with the automatic defogging system activated.

4.4 Field Test : Winter Conditions on Californian Roads

A test was conducted along the Californian roads to verify the system's performance and whether it meets the strict standards for different weather conditions around the world. As shown in **Figure 8**, the system faired well both in terms of windshield fogging prevention and passenger comfort maintenance.

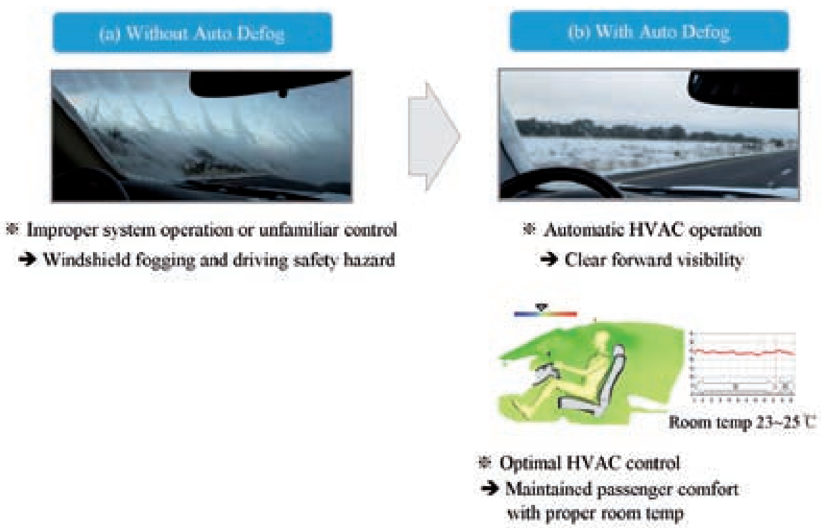

Figure 8: North American testing (outside temperature: -5 °C to 5 °C)

5 Conclusion

An automatic defogging system was developed by minimising the changes to the HVAC, incorporating a windshield surface humidity sensor, and creating an automatic defogging strategy. This system is capable of providing unobstructed forward visibility to the driver and of maintaining passenger comfort. The system's excellent performance was confirmed via field tests in Korea and America. Once proven, the system was incorporated into Hyundai's Genesis. ■

Modified Dang Van Approach for Fatigue Estimation of Exhaust Systems

For the estimation of the service life of an automotive component like the exhaust system suffering high cycle fatigue in the case of multiaxial stress a simple calculation approach was developed by Tenneco. The generally used Dang Van fatigue model is modified so that it can be used for the prediction of the high cycle fatigue life with the help of stress solution from FEM simulation. The proposed approach is successfully applied at Tenneco.

1 A Brief Outline of the Dang Van Life-cycle Criterion

Fatigue life estimation is one of the main tasks in designing of an automotive structure under cyclic loading. In the past decades, the stress-life method and strain-life method have been widely adopted in engineering practice. The first one is based on the SN-curve and the second one on EN-curve.

When a structure undergoes high cycle fatigue (HCF) that means, the amplitude of the load is low and number of loading cycles is very large; the stress level in the structure is low and the deformation is elastic. When the amplitude of loading is so large that the material is in plastification, a structure may fail after few thousands of loading cycles. In this case the structure undergoes Low Cycle Fatigue (LCF) and the strain-life method is used for the life estimation. These methods are simple and the SN-curve and EN-curve can be easily obtained from cyclic tension-compression and cyclic torsion tests. However, because these curves are of uniaxial in nature, these methods must be extended for the multiaxial stress state.

Several models were proposed for the judgement of fatigue occurrence in the material in the case of multiaxial cyclic stress, for example, Crossland model, Sines model and Dang Van model, etc. These models are based on the concept of critical plane, which represents the critical site in the material for the onset of damage based on some criteria [1]. The basic idea of Dang Van model is that fatigue damage in the material occurs, when a linear combination of shear stress and the instantaneous hydrostatic pressure excesses a certain value. During the first loading cycles, some misoriented grains in the material undergo plastic deformation. Consequently these grains workharden and a stabilized stress state is reached after a while. If this stabilised stress is below a threshold, no fatigue occurs. The Dang Van model can be represented by the equation:

$$\tau + \alpha p \leq \beta \qquad \text{Eq. (1)}$$

Here, τ is the maximum shear stress and p is the instantaneous acting hydrostatic stress. Both of them are determined by local stress or microscopic stress analysis, α and β are parameters [2]. The local stress is determined by Eq. (2):

$$\sigma_{ij} = A_{ijkl}\,\Sigma_{kl} + \rho_{ij} \qquad \text{Eq. (2)}$$

Here, σ_{ij} and Σ_{kl} are microscopic stress and macroscopic stress (engineering stress) respectively, and A_{ijkl} is the localisation tensor correlated to the microstructure, ρ_{ij} is the residual stress in grains in the material.

Obviously, it is very difficult to determine the microscopic stress. In engineering practice, FEM calculations are standard procedure for the determination of the stress in a structure. Because of time pressure and budget limit, no one in the industry can (normally) afford the luxury to find out the microscopic stress between grains in the materials through complicated and time consuming calculations. Therefore, instead of microscopic stress, engineering stress was used to formulate the Dang Van model [3]. In present paper we use macroscopic stress to formulate a modified Dang Van model. Below, we do not distinguish microscopic and macroscopic stress any more.

2 Modification of the Dang Van Model

The SN-curve for cyclic tension-compression gives:

$$\sigma = \sigma'_f \left(N_f\right)^{b_\sigma} \qquad \text{Eq. (3)}$$

σ is the normal stress amplitude, N_f is the number of loading cycles to failure. σ'_f and b_σ are the fatigue strength coefficient and the fatigue strength exponent respectively. Similarly, the SN-curve for cyclic torsion is written as Eq. (4):

$$\tau = \tau'_f \left(N_f\right)^{b_\tau} \qquad \text{Eq. (4)}$$

where τ is the shear stress amplitude, τ'_f and b_τ are shearing fatigue strength coefficient and the fatigue strength exponent respectively. Normally, the fatigue

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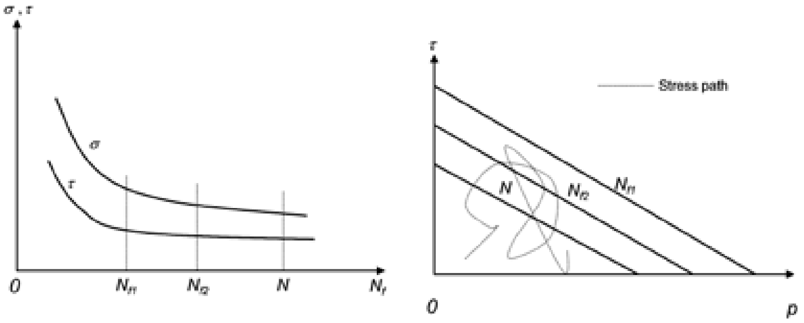

Figure 1: Schematic representation of the modification. Left: typical SN-curves for cyclic tension-compression test (σ) and cyclic torsion test (τ); right: Modified Dang Van limits corresponding different number of loading cycles

strength is defined as the stress level σ_f, below which the material can withstand a certain number of loading cycles N, for instance, 5×10^6. When the normal stress level is σ, the fatigue life $N_f(\sigma)$ can be calculated from Eq. (3) to Eq. (5):

$$N_f(\sigma) = N\left(\frac{\sigma}{\sigma_f}\right)^{\frac{1}{b_\sigma}} \quad \text{Eq. (5)}$$

Similarly, we get Eq. (6) from Eq. (4):

$$N_f(\tau) = N\left(\frac{\tau}{\tau_f}\right)^{\frac{1}{b_\tau}} \quad \text{Eq. (6)}$$

The parameters in Dang Van criterion are determined by [3] to Eq. (7):

$$\alpha = \frac{3\tau_f}{\sigma_f} - \frac{3}{2}, \ \beta = \tau_f \quad \text{Eq. (7)}$$

The fatigue strength σ_f and τ_f are determined by cyclic tension-compression and torsion tests. Thus, they are of macroscopic in nature. The Dang Van criterion,

$$\tau + \alpha p = \beta, \quad \text{Eq. (8)}$$

can only be used to judge whether fatigue occurs in the material. However it cannot be used to calculate the service life of a structure if fatigue occurs. In order that Dang Van criterion can be used to estimate the fatigue life of a structure, it can be modified as following.

For a certain number of loading cycles N_f, above which the material fails, the corresponding stress level can be calculated from Eq. (5) for cyclic tension-compression test and from Eq. (6) for cyclic tension test respectively. If these stress levels are used to determine the parameters α and β in Eq. (8), they can be written as functions of the number of loading cycles with regard to fatigue failure:

$$\alpha(N_f) = \frac{3\tau_f}{\sigma_f}\left(\frac{N_f}{N}\right)^{b_\tau - b_\sigma} - \frac{3}{2},$$

$$\beta(N_f) = \tau_f\left(\frac{N_f}{N}\right)^{b_\tau} \quad \text{Eq. (9)}$$

Substituting Eq. (9) into Eq. (8) we get the modified Dang Van model with Eq. (10):

$$\tau + \left[\frac{3\tau_f}{\sigma_f}\left(\frac{N_f}{N}\right)^{b_\tau - b_\sigma} - \frac{3}{2}\right] p = \tau_f\left(\frac{N_f}{N}\right)^{b_\tau} \quad \text{Eq. (10)}$$

The FEM solution of a structure gives the stress field σ_{ij}, from which we can easily get the Eq. (11):

$$\tau = \frac{1}{2}(\sigma_1 - \sigma_3), \ p = \frac{1}{3}(\sigma_1 + \sigma_2 + \sigma_3) \quad \text{Eq. (11)}$$

Here, σ_1, σ_2 and σ_3 are the principal stress components. Substituting Eq. (11) into Eq. (10) and solving for N_f, we get the fatigue life of a structure in multiaxial stress state. If $b_\tau = b_\sigma = b$, we can easily get Eq. (12):

$$N_f = N\left[\frac{\tau + \alpha p}{\tau_f}\right]^{\frac{1}{b}} \quad \text{Eq. (12)}$$

Figure 1 is a schematic representation of the modification. The left panel of figure 1 represents the typical SN-curves for cyclic compression-tension test and cyclic torsion test. The stress levels, below which the material can survive a predefined number of loading cycles N, are defined as the fatigue strength σ_f and τ_f. From Eq. (7) and Eq. (8) the Dang Van limit can be determined, as shown by line N in the right panel. For two arbitrary numbers of loading cycles N_{f1} and N_{f2}, Eq. (10) can be used to calculate the corresponding Dang Van limits, as shown by lines N_{f1} and N_{f2} in the right panel of Figure 1. For a loading path shown in the right panel of figure 1, the service life of the material is between N_{f1} and N_{f2}.

3 Example of Application

A user subroutine is developed for the commercial FEM solver Abaqus so that it is able to estimate the fatigue life of a structure by using the modified Dang Van model presented in this paper. In order to investigate the fatigue behaviour of a structure experimentally, component tests are usually performed in automotive industry. **Figure 2** shows the finite element model, which simulate the com-

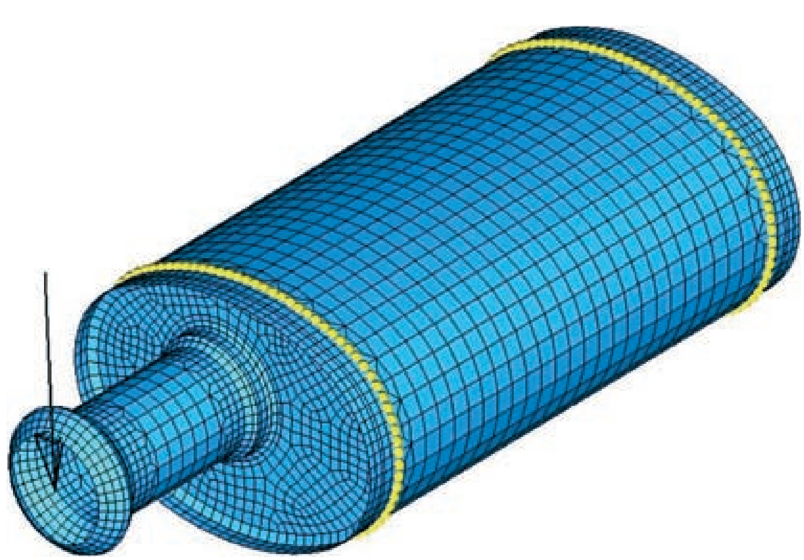

Figure 2: Setup of the component test of a front muffler and FE model

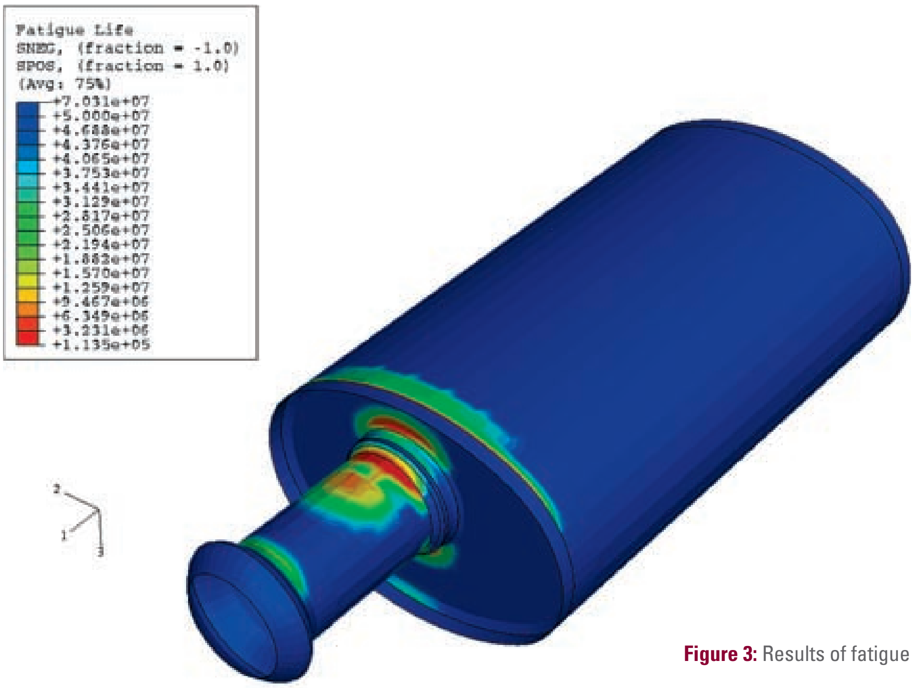

Figure 3: Results of fatigue life by using modified Dang Van model in FEA

ponent test of a front muffler in the exhaust system of a car. The muffler is clamped on outer shell at positions marked by the yellow nodes. A cyclic force of 3000 N in amplitude is applied at the end of inlet pipe.

The muffler is made of ferritic stainless steel. It is widely known that fatigue failure occurs most probably in welding area. According to fatigue test results by using welded samples of this material, the fatigue strength of welding area at room temperature is σ_f = 89.7 MPa and τ_f = 67.6 MPa, under which the material can withstand $N = 5 \times 10^6$ loading cycles. Corresponding parameters b_σ and b_τ are specified to -0.219 for the FE analysis. The resultant parameter a in Eq. (12) is 0.76.

The results by using the modified Dang Van model are illustrated in **Figure 3**, which present the calculated fatigue life of the front muffler. Based on the FEA, the earliest incipient crack occurs at the intersection area between the outer shell and the inlet plate after 1.135×10^5 cycles. The other critical areas, for example the intersection between inlet pipe and weld seam as well as the fillet of inlet plate, can withstand 3.2×10^6 cycles approximately. The areas, where the fatigue-life is greater than $N = 5 \times 10^6$, can be regarded as fatigue endurable.

4 Concluding Remarks and Outlook

The Dang Van model can only determine whether fatigue occurs in a material under certain loading. Nevertheless it is not able to predict the fatigue life of the material. In this work by Tenneco, the Dang Van model is extended by using the formulation of SN curve, so that the prediction of fatigue life is available.

Additionally, the modified Dang Van model is applied together with commercial FEA software to predict the fatigue life of real mechanical components regarding HCF component tests at Tenneco. In future work, this model will be further improved to estimate the fatigue life of an exhaust system under dynamic loading in the frequency domain.

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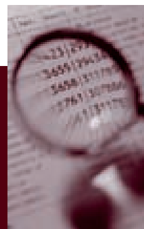

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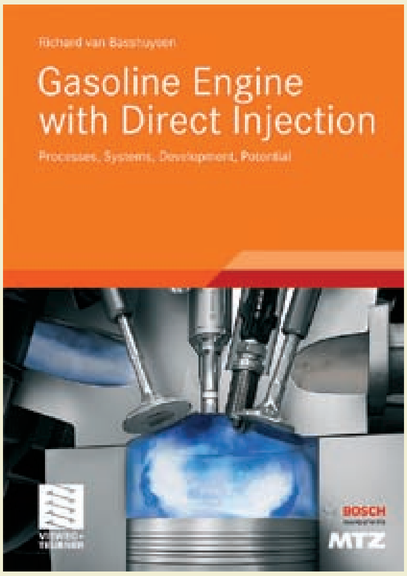

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3D Simulation Environment for Haptic Sensor and Actor Components in the Cockpit

Can automobiles forewarn the driver of dangerous situations and how could that information be communicated? How intuitive are control elements with integrated tactile feedback compared to visual and acoustic signals? To test deployability, acceptance and road capability of actuators designed for driver assistant systems or as control elements during driving situations, a modularly configurable 3D simulation and visualization environment with integrated automotive cockpit has been developed by the Institute of Computational Engineering at the Karlsruhe University of Applied Sciences (Germany).

1 Introduction

In modern automobiles, the driver is exposed to a multitude of visual and acoustical signals, which are emitted by signal lights, control elements and displays fitted in the dashboard or the centre console. This helps the driver to cope with difficult traffic situations as safely as possible. Additionally, vehicles are equipped with more and more functionality, as drivers demand more and more comfort. Thus, the flood of information, the driver is exposed to, steadily increases and due to excessive demands from the human perception; the risk potential during driving is raised.

New ground is broken in the area of automotive development by communicating signals and information via haptical sensations like vibration, temperature or counterforces [1–4]. The research project "HaptICS Haptical Interface Communication System", which is presented here by the Karlsruhe University of Applied Sciences, explores, in what ways the heavily burdened optical and acoustical senses can be relieved by means of haptical signals to further address safety and comfort issues.

2 Lab Environment

In addition to the analysis of concepts for driver assistant systems, the developed experimental platform provides a comfortable environment for integrating control elements with newly designed surface structures and materials or with special feedback signals in the vehicle cockpit and automatically evaluating its effect on groups of human test subjects. Examples of such controls are touchable surfaces combined with Peltier elements, which allow the user to feel the set temperature or knobs, which report the tuned in radio channel via vibrations. The relevance of the various controls is investigated through technical measurements and ascertainment of the human perception within preparatory studies, **Figure 1**. Driver assistance systems are designed to alert the driver to potential dangers such as tailgating or speeding through tactile feedback via the steering wheel, pedals or integrated into the seat.

The lab environment consists of the software environment with a configurable driving simulator, the three-screen projection environment (cave [5]) and an expandable cockpit. This setup allows the recording of changes in behaviour of the test subjects, resulting from use of varying actuators and signals. Thus, expensive and time-consuming experiments conducted with real vehicles in traffic, which bear higher safety risks and lower reproducibility, can be avoided.

A user-friendly interface enables the operator to conduct reproducible, freely configurable traffic experiments with the test subjects. The criteria for the evaluation of the driving behaviour can be configured and combined for, specific experimental requirements. It is investigated how fast and intensively signals lead to a change of behaviour of the test subject by conducting various test series. All required information, produced by automotive sensors like distance and position encoders, can be emulated. To increase the flexibility of tests, a software program was developed that facilitates actuating dashboard controls through

Figure 1: Test set-up of the „Effect Designer" for the generation of force profiles as input signals (1), which control actuators (3) via a computer (2); the feedback is measured and validated either through sensors (4, 5) or human perception (6)

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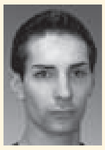

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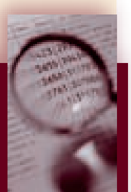

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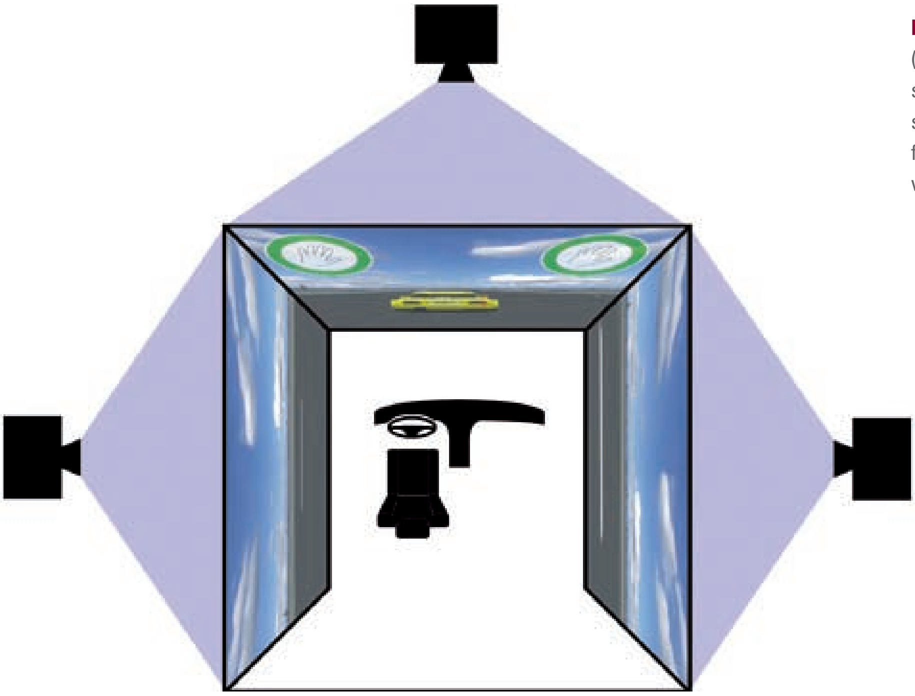

Figure 2: Schematic of the 3D projection room (cave) consisting of three back-projection screens with the dimensions 270 × 270 × 200 cm, six video projectors with circular polarization filters, six PCs, a surround sound system and the vehicle cockpit integrated in the centre

individual force profiles. The resulting reaction time of the driver in relation to the specific traffic situation and to the haptical output signals is then digitally recorded and evaluated.

2.1 Driving Simulator

The driving simulator visualizes various scenarios like city, highway or country road traffic with adjustable courses, traffic density, border conditions and landscape scenarios. To produce an accurate depiction of reality, the application is constantly extended with features like darkness and atmospheric conditions. The driving simulation is based on the open source car-racing simulator Torcs [6]. In addition to a realistic 3D visualization, the software models accurate vehicle physics as well as interactions with the simulated environment. During the evolution to a traffic simulation, a track generator was implemented, which allows modeling intersections. Basic traffic rules like right-of-way, priority roads, autonomously moving vehicles, traffic signals, multi-lane roads, grade-free crossings, night scenarios and speed limits were added.

The simulation environment includes a graphical display system, which facilitates delivering audiovisual signals to the test subjects. Thanks to the modular architecture, it becomes possible to carry out context-rich simulations and to produce situations like convoys of cars or the well-known lane change test by means of combining appropriate vehicles and audiovisual signals [7, 8]. The integration of the simulation environment into the layer-oriented software model permits coupling the sensor-actuator control elements mounted in the cockpit with the driving simulation. Within the driving simulation, events can be defined, which drive the actuators with pre-defined, freely selectable force profiles while following certain logical rules.

2.2 Three-screen Projection Environment

A projection environment consisting of three projection screens has been constructed to display images produced by the driving simulation software, **Figure 2**. Reverse projection and stereo view technology is utilized. Behind each screen, two video projectors are located. In front of the projector lenses, reversely polarized filters are installed, which allow producing different images for both eyes with the aid of special glasses. Due to the two images being constructed with a slightly displaced point of view, a 3D illusion is achieved.

With a camera system integrated in the cave and with the appropriate software, the individual position and direction of view of the test persons can be determined. The actual composition of the images is carried out by three powerful computers, which are interconnected to a single “display wall” via an X-server. This technology abstracts from the six projectors and thus hides the physical configuration from the simulation software.

The installation includes a six-channel audio amplifier that reproduces the sound characteristics of the simulation by means of five satellite speakers and a sub-woofer. The dedicated audio channels allow for audible reproduction of moving sound sources such as passing vehicles.

2.3 Expandable Cockpit

For the primary application of testing input and output devices, the expandable vehicle cockpit features a dashboard, a centre console, accelerator, brake and clutch pedals, a shift lever, a steering wheel and a display behind the steering wheel, **Figure 3**. At the driver’s side, a seat was installed obeying realistic dimensions.

The display shows the speedometer and tachometer gauges as well as an ar-

Figure 3: Cockpit design with steering wheel, dashboard and centre console featuring a vibrating, turnable knob (1) and a Peltier element with controllable temperature output (2); actuators can be connected to the components, which can be analyzed with respect to alteration of the driving behaviour within test series

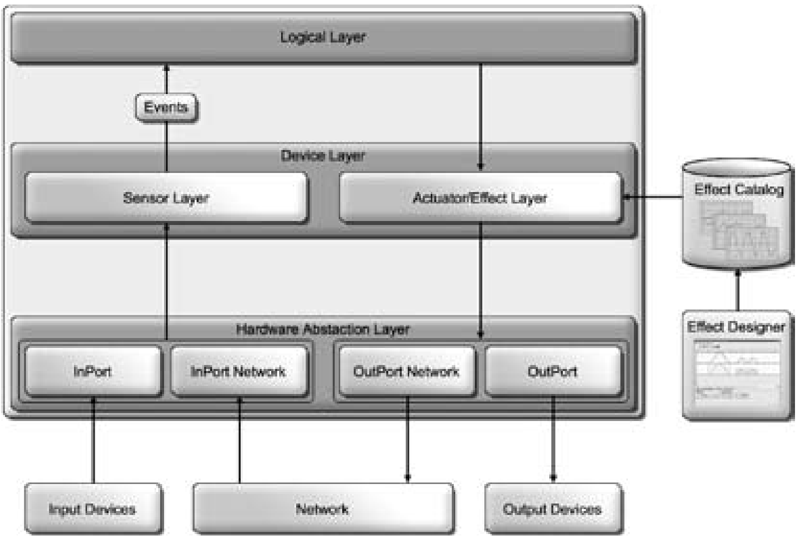

Figure 4: Software model: signals originating from input devices of the driving simulation are received via ports belonging to the hardware abstraction layer; the input data are pre-processed in the device layer, which also defines events used within the logical layer; the output devices are then controlled accordingly using force profiles from the effect catalogue

bitrary number of signal lamps, which can be controlled by the simulation environment. The centre console contains mounting system, which can be used to secure input and output devices utilized during test sessions.

3 Software Model

The software model facilitates a concerted design of test scenarios, traffic situations as well as combined events and allows adjusting requirement profiles for the implementation of test sessions for the evaluation of actuators with feedback. Input and output devices can be replaced or reconnected through the hardware abstraction layer [9]. Due to the layered design and the modular interface architecture, **Figure 4**, test scenarios can be devised.

The hardware abstraction layer prepares incoming signals for applications within the program. The sensor layer interprets the data within their context and detects changes, which are relayed as events. The logical layer reacts on these events and starts effects that are stored in an effect catalogue. An effect is defined through its force profile and the corresponding duration and intensity. The applications “Curve Editor” and “Timeline Editor” allow for a user-friendly design of force profiles. The signal output control is performed by the actuator/effect layer, which passes control commands on to the hardware abstraction layer. There, the commands are converted into corresponding control signals for the actuator device. The configuration of the software model is based on the XML format.

The hardware abstraction layer handles the communications between the software model and the connected sensors and actuators. To facilitate replacement of components, the hardware abstraction layer provides proxy objects for each sensor (InPort) and for each actuator (OutPort). **Figure 5** shows the class structure in the hardware abstraction layer. For network-transparent communications, it is possible to create network proxy objects that do not communicate directly with an actuator or sensor. Instead all data are sent to and are received from the control computer.

The sensor layer accepts analyze signals dependent on its origin. Context-dependent conversations like linearizations are performed and incoming data are tested for exceedance of defined upper and lower boundaries, which are responded to by the generation of events.

The logical layer is the head of the system. Here, all events (for example going below the safety distance) are received and are interrelated with actions (for example vibration of the steering wheel). With this scheme, events, variables and control commands can be linked to form

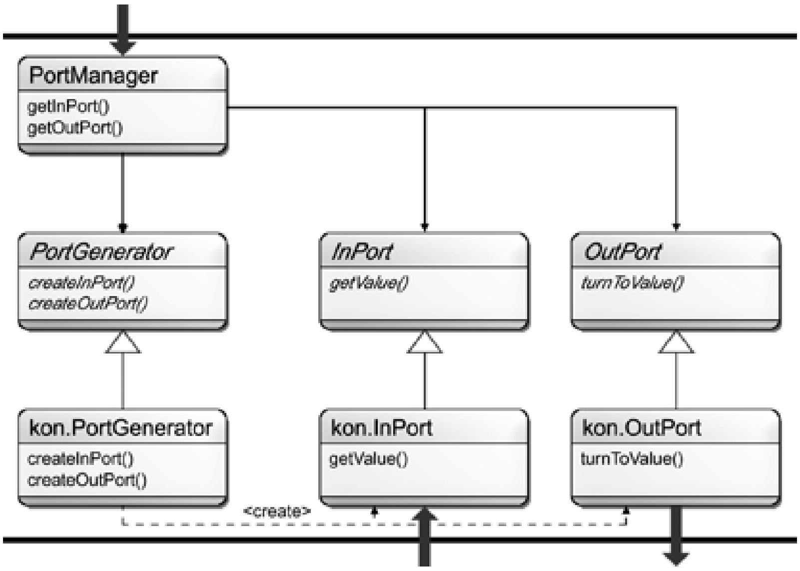

Figure 5: Class structure in the hardware abstraction layer

event chains, which allow for context-independent initiation of effects to analyze the reactions of the test subject.

An effect is a complex output sent to a device and can consist of a combination of superimposed force curves. With the help of the software "Curve Editor", **Figure 6**, effect curves can be created with the help of a graphical user interface as follows: A set of points is created and an approximation algorithm for interpolating the points is selected. This concept enables to generate arbitrary curves.

The application "Timeline Editor" provides the means to combine effect curves created earlier. Transformations like curve stretching or compression can be applied. A sequence generated in this manner can be assigned to an output device. An effect is a collection of an arbitrary number of sequences. The two applications "Timeline Editor" and "Curve Editor" constitute the software suite "Effect Designer". Each of the created effects is stored in the effect catalogue and is available within the software model. Thus, it is possible to start and stop effects as well as to modify the parameters such as intensity and duration.

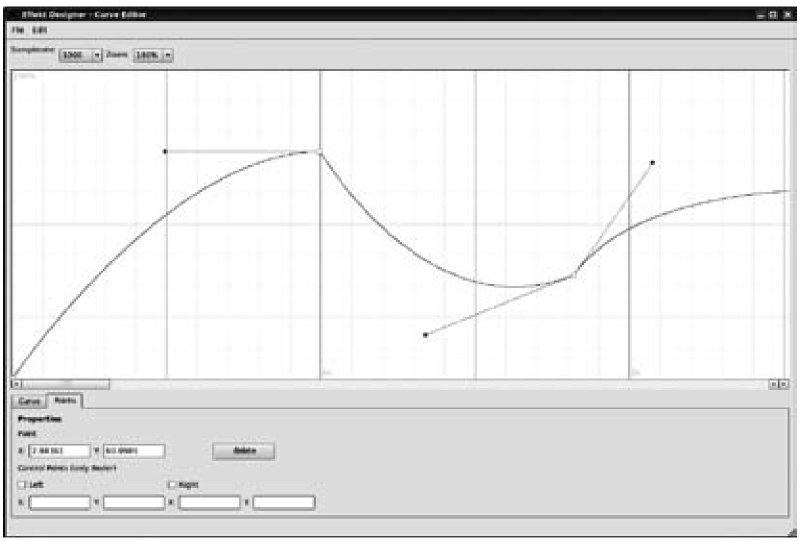

Figure 6: User interface of "Curve Editor" for the creation of force curves, which includes capabilities such as generation of additional points and modification of local curvatures

4 Typical Usage Scenarios

Typical usage scenarios include users of the software specifying criteria such as deviation from the ideal lane position, distance to the vehicle ahead, reaction time, curb distance, speed, acceleration, steering angle as well as accelerator and brake pedal usage. During test sessions with human subjects, indicators and static data covering the driving behaviour during operation of actuators can be collected and analyzed. With the aid of a graphical user interface, the scenarios can be prepared and configured to meet specific requirements. The evaluation of the driving performance can be derived from a single indicator or from a combination of several indicators.

All evaluation tools are collected in a software library and apply various defined operations such as smoothing, derivations, integrations, comparisons and detection of extrema to the recorded telemetry data. Due to the possibility of combining several of those tools to a filter chain, statistically relevant data can be derived easily. All evaluation processes use standardized file formats, which allow importing data into generic, well-known analysis tools.

As an example for a test series, a multi-lane circuit was created. The task was to recreate the arbitrary lane changes of a vehicle being pursued. Through a randomly triggered optical signal, the subject was instructed to operate a turnable knob. The deviation from the specified lane to drive on was used as the evaluation criterion.

Figure 7 depicts the statistically averaged comparison between a circuit driven with tactile (vibration) and one driven with optical feedback. The evaluation of the test series yielded a 36 % reduced deflection from the specified lane when using tactile feedback as opposed to optical feedback.

The current results of the test series for haptical components have been obtained in a statical cave environment. They do not account for vestibular properties.

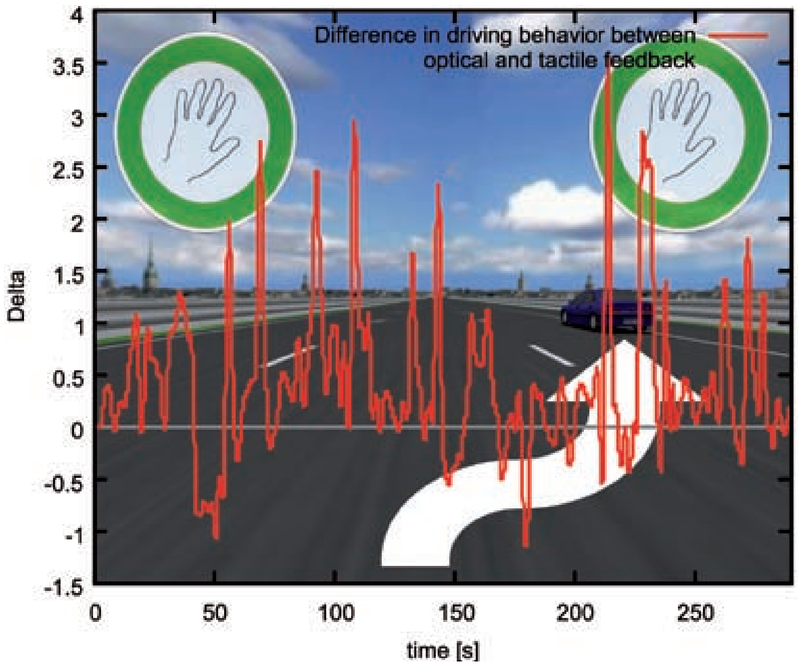

Figure 7: The difference of the amount deviation Δ = | dhapt | - | dopt | from the ideal lane specified by a vehicle being followed during random operation of a turnable knob with haptical and optical feedback, respectively, is plotted as a function of the driving time; the value dhapt, opt denotes the distance of the driven course with respect to the ideal lane for operating actuators with tactile or optical feedback

5 Future Prospects

The integration of multiple touch-screen displays into the centre console and behind the steering wheel is planned, which will provide a platform for the emulation of driver assistance systems. The 3D simulation and visualization environment as well as the software model will be made available to industrial as well as academic users to evaluate the use of actuators with acoustical, visual as well as tactile feedback as driver assistant systems or control elements [10, 11].

Furthermore the set-up will be used to investigate the effect of components with differing product designs such as surface materials on human subjects. Because of the very generalized and modular software model, the driving simulator can be replaced with other simulation software. Thus, the simulation and visualization laboratory at the Karlsruhe University of Applied Sciences provides a flexible and versatile environment, providing a wide potential into other fields of application, which are not limited to the field of automotive technology. Conceivable applications are, among others, home automation.

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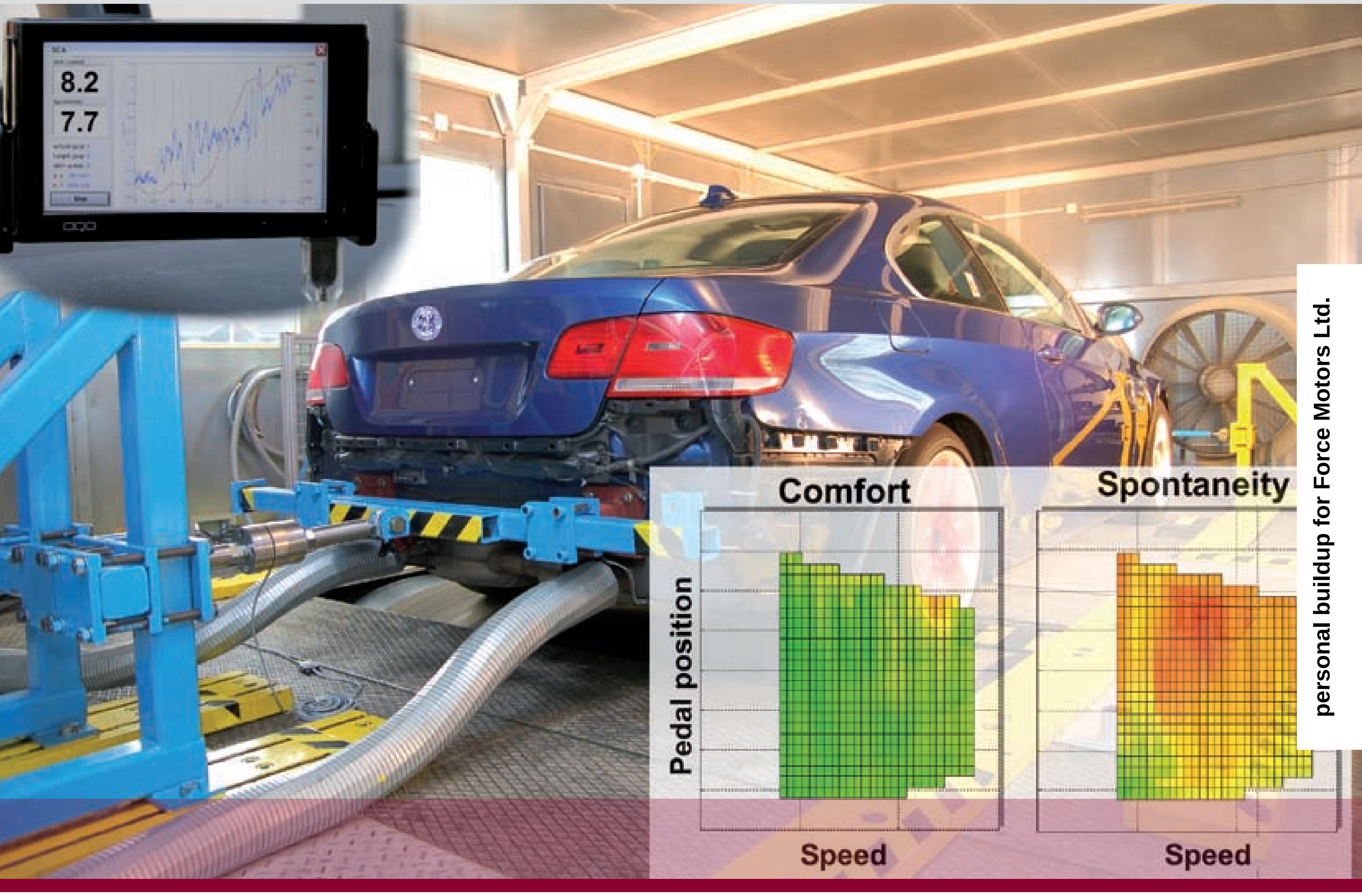

Efficient Calibration of Automatic Transmissions on the Roller Dynamometer

The transmission becomes more important in terms of evaluating emissions, drivability and comfort. These developments have caused an increase in the complexity of the transmission control units of automatically shifting transmissions (automatic transmissions, dual-clutch transmissions and automated manual transmissions) for more than twenty years. Additionally, the increasing popularity of these transmission concepts in all markets leads to more vehicle-engine-transmission combinations which have to be calibrated. The growing effort also means that more personnel and longer calibration times are required, which thus results in higher development costs. The Institute of Automotive Engineering of the Technische Universität Braunschweig (Germany) describes methods and tools to reduce the effort for TCU calibration in terms of shift comfort by means of efficient transmission calibration on a roller dynamometer.

1 Introduction and State of the Art of Shift Quality Optimisation

The state of the art of the parameter application of transmission control units (TCU) is characterised by road tests and the subjective evaluation of shift quality and measured variables recorded by the application engineer. 'Shift quality' here includes shift comfort and shift spontaneity, which significantly affect the subjective shift evaluation [1, 2]. Shift comfort mainly results from perceptible shift shocks, while shift spontaneity relates to the reaction time of the transmission and the shifting time. Both criteria can be evaluated with ratings from 1 to 10, for example with the ATZ scale [3].

At present, the so-called control parameters (CP) of the TCU, which determine the shifting process of the various types and operating conditions, are adjusted manually by means of an application laptop in accordance with the engineers' experience until an optimal parameter combination is found. **Figure 1** shows this "control loop" of transmission calibration.

Three points, which offer significant improvement potential in terms of an efficient calibration process and which have to be considered, can be identified in the control loop:

1. If a person evaluates shiftings, the evaluation is subjective and not reproducible; it is therefore essential to evaluate shiftings objectively.
2. Road tests do not provide the necessary requirements for reproducible shifting results. For this purpose, the tests have to be done in a lab on a roller dynamometer. This in addition to objective evaluation routines already allows the documentation of the shift quality at all operating points as well as manual transmission application on the roller dynamometer.
3. The manual optimisation of the control parameter adjustments requires a lot of time. The global optimum can hardly be achieved in the manual calibration process. The use of model-based processes and intelligent optimisation strategies ensures the determination of the global optimum in a short time.

The last point – automated transmission calibration on the roller dynamometer – requires the correct implementation of points 1 and 2. This means that the spread of subjective human evaluations has to be eliminated through an objectification of the shift quality. At the same time, it has to be guaranteed that approaching the operating conditions is reproducible. A software-controlled change in the TCU parameters is necessary here. **Figure 2** represents the four points of efficient transmission calibration on the roller dynamometer, which will be explained in the following sections.

2 Objectification of Shift Quality

Vehicles with automatic transmissions are considered as particularly critical in terms of shifting behaviour by the trade press as well as by the customer. The changes in longitudinal acceleration applied to the car seat are regarded as the main parameter which influences the subjectively perceived shift comfort. On the other hand, the shift spontaneity, which describes response time of the transmission as well as shifting time, is determined by speed developments at the transmission input and output. Various characteristic variables, so-called ob-

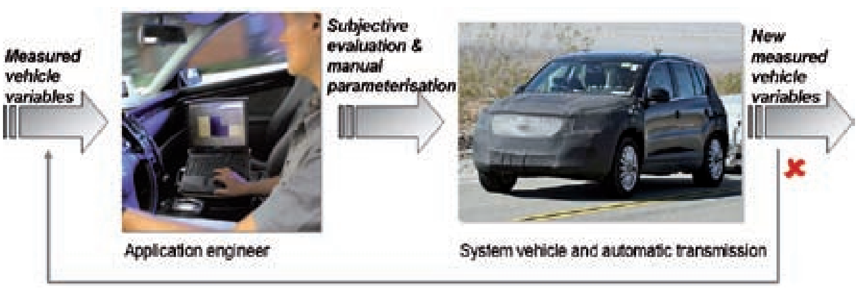

Figure 1: Control loop of transmission application

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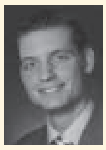
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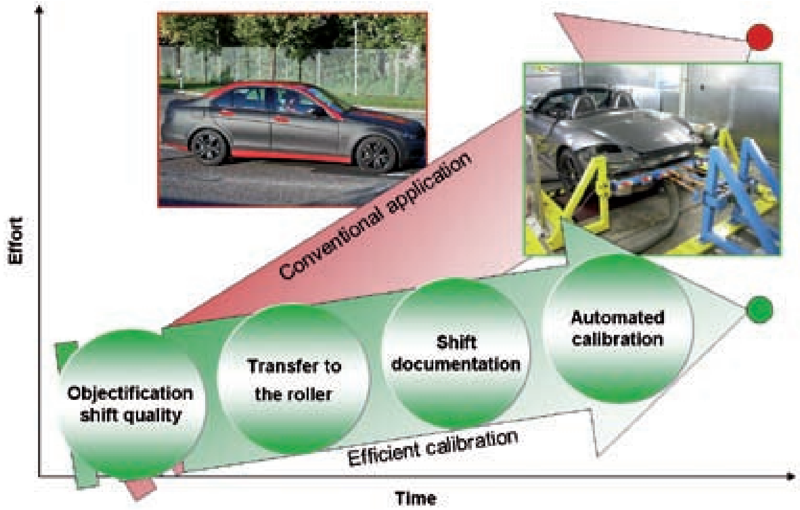

Figure 2: Four points of efficient transmission calibration

jective parameters, are derived in the first point "objectification of shift quality" from the measurement signals.

2.1 Longitudinal Vibration Feeling

In the scope of extensive studies at the Institute of Automotive Engineering of the Technische Universität Braunschweig (Germany), the human perception of longitudinal vibrations on the car seat was analysed with regard to the objectification of the shift comfort [1]. The frequencies can be perceived in particular range between 2 and 9 Hz. This detection allows low-pass filtering of the measurement signal to identify the objective parameters which are relevant for the shift comfort from the time and frequency range of the longitudinal vehicle acceleration. The vibration rates which are relevant for perception respectively shift comfort are also taken into account. The most important objective parameters determining the shift comfort include the acceleration gradients at the beginning and the end of the shifting process as well as the absolute acceleration difference, which is reflected in the peak-to-peak value.

Figure 3 represents the measured curves of longitudinal acceleration as well as some exemplified objective parameters for a traction upshift, both for a vehicle with automatic transmission (AT) and with automated manual transmission (AMT). Apart from the objective parameters generated from the acceleration signal, the deceleration time after electronic shift request as a spontaneity criteria and the shifting time are calculated by means of the speed signals [1, 4].

Correlation analyses of the objective parameters with experts' subjective evaluations of shift comfort and shift spontaneity [1] resulted in objective rating models of the following form of Eq. (1):

$$Objective\_rating = f(objective\_parameter_1, \ldots, objective\_parameter_n) \quad \text{Eq. (1)}$$

Robust identification of objective parameters is required for use in practice. The evaluation algorithms are required to be robust to detect objective parameters even in case of misapplications where signal courses deviate strongly from the optimum.

2.2 Shift Comfort Assistant

Based on the objective rating models in Eq. (1), the so-called shift comfort assistant (SCA) was developed, **Figure 4**. The SCA consists of a minicomputer with CAN port and analogue acceleration sensor. Shiftings are identified by means of measured CAN signals and are automatically rated objectively. The objective ratings for shift comfort and shift spontaneity are displayed in addition to the measurement signal curves for longitudinal acceleration and transmission input speed; the shift comfort rating is announced at the same time. The signals of an additional vertical acceleration sensor are used to detect shiftings where the recording was interrupted by road irregularities. The recorded measurement variables can be downloaded for offline analysis.

The SCA is the first step of efficient transmission calibration since it already supports the calibrating engineer during the manual calibration on the road by means of objective shift evaluations. The system at the same time allows the evaluation of the state of given applications: shiftings of the same type for different operating points which are recorded during test drives are used to generate a "fingerprint" of the transmission performance in accordance with a so-called shift documentation. For this purpose, a map for shift comfort and shift spontaneity is generated which displays the calibration status of the transmission at all operating points, Figure 6.

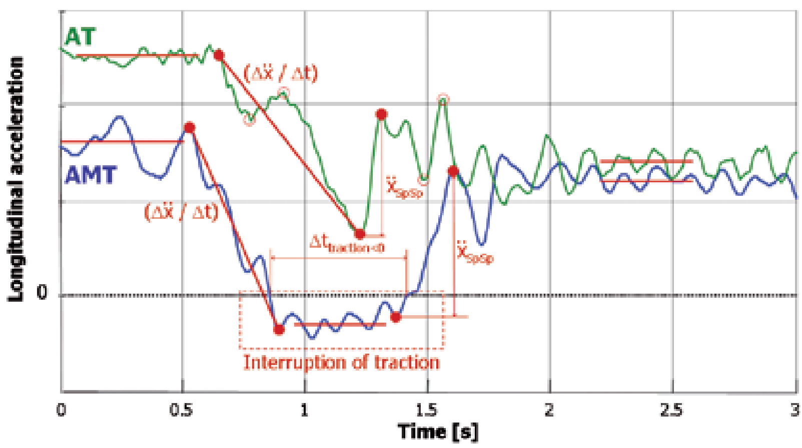

Figure 3: Examples of objective parameters from longitudinal acceleration for shift comfort objectification of a 1-2 traction upshift for vehicles with AT or AMT

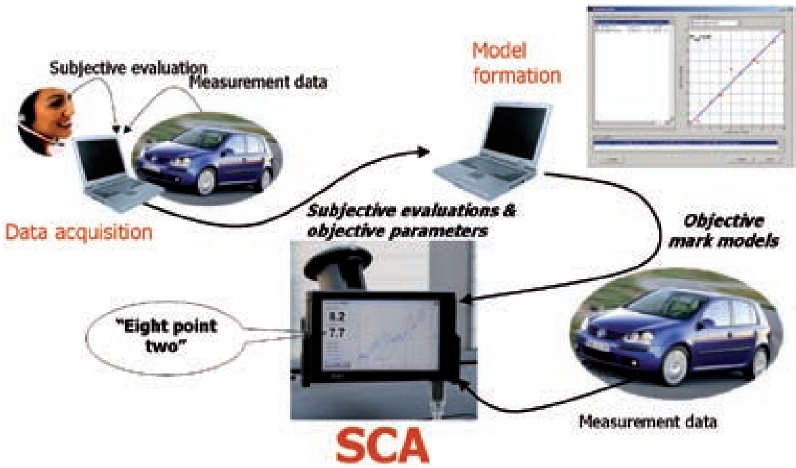

Figure 4: The shift comfort assistant (SCA)

3 Transfer to the Roller Dynamometer

In the following rig structure and periphery of the roller dynamometer but also the presentation of the operating points should be described.

3.1 Test Rig Structure and Periphery

The transfer of the calibration process from road to roller dynamometer (road to lab) is the essential step of automating the shift quality adjustment. Road resistance and road grip have to be reproduced realistically on the test rig. In addition, it is important to find an alternative signal for the longitudinal acceleration to evaluate the shift shock, which is not perceptible anymore due to the inevitable fixing of the vehicle in longitudinal direction.

The solution is the measurement of the traction force in a pendulum support with load cell, which connects the vehicle to the environment, **Figure 5**. The tire-drum contact (big drum diameters are advantageous) and the system dynamics for reproduction of the vibrations must be equivalent to road conditions. The traction force signal is converted into theoretical longitudinal acceleration as it can be measured in road tests (cf. [1]). Figure 5 shows the structure of roller dynamometer, peripheral devices and communication interfaces. The reproducibility of the shiftings was already proved in previous publications [1].

Another important part of the test rig structure is the application measurement system with the possibility of adjusting the CP of the TCU in real time that means without flashing, and during driving. Apart from varying the control parameters, the system is used to measure the TCU signals which are relevant for the shift quality. This for example includes transmission input and output speed, shift signals as well as the signal of the traction force for the objectification of shift comfort and shift spontaneity.

3.2 Operating Points

A shift robot developed at the Institute of Automotive Engineering is used to approach the desired operating points, which are defined by speed and accelerator position. The robot can control the accelerator position and activate the shift commands by means of vehicle state estimation and a learning algorithm. The vehicle state is estimated by connecting the robot directly to the vehicle CAN. This ensures that gears are changed at a defined vehicle speed respectively transmission input speed. The shift command can either be activated through digital commands to the TCU without delay or by pneumatic operation of the shift selector in manual mode. The learning algorithm ensures that possible deviations from the shift speed are compensated.

The driving robot additionally controls the roller dynamometer between the shiftings to support the change of operating points in terms of efficient test rig operation through test rig performance. A virtual uphill gradient for braking and downhill gradient for acceleration is used to add to the engine performance of the vehicle and the service brake or to replace them, which allows shiftings at intervals of 6 to 10 s, depending on the sequence of operating points. The gears are changed in the usual way with real road resistance on level track, but a gradient can be specified without any problems. The programming of the driving robot ensures that the operating modes are converted precisely, so the engine speed limits are not exceeded.

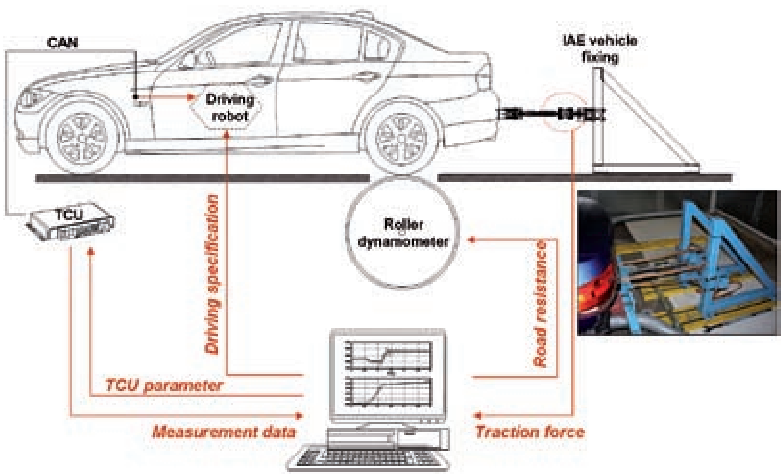

Figure 5: Test rig structure for transmission calibration on the roller dynamometer

4 Shift Documentation

The shift documentation is used to represent the transmission performance throughout the operating range of the

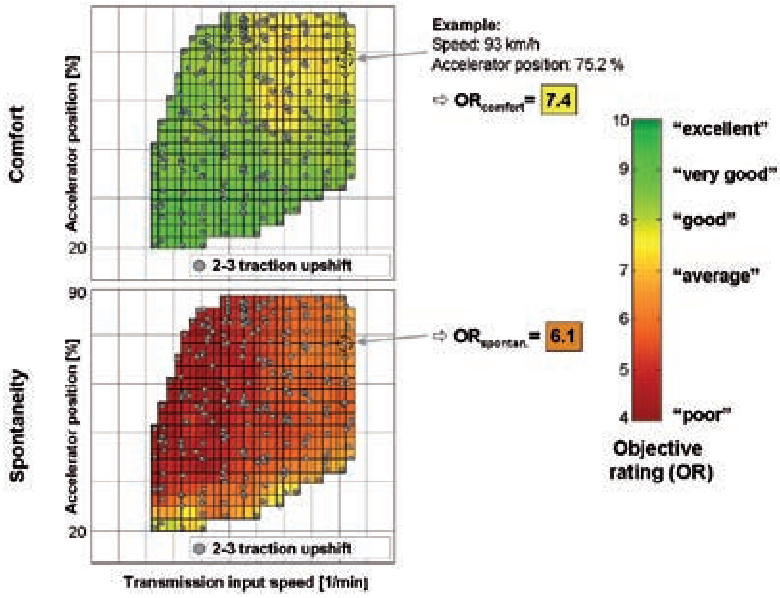

Figure 6: Shift documentation: illustration of shift comfort and spontaneity for a 2-3 traction upshift of a test vehicle, depending on speed and accelerator value

transmission. For this purpose, the driving robot covers a dense net of operating points for each type of shifting. The individual shifting processes are then analysed in terms of comfort and spontaneity by means of the objectification tool [5] mentioned before. **Figure 6** illustrates the approach and the result for the documentation of a 2-3 traction upshift of a test vehicle.

For the selected example shifting (speed 93 km/h and accelerator position 75.2 %), the objectification results in the objective rating (OR) $OR_{comf.}$ = 7.4 for the shift comfort and $OR_{spont.}$ = 6.1 for the shift spontaneity. Both criteria can be represented in the required form for the operating range through interpolation calculations. The shift documentation is thus used as a proof that the required aims were achieved with the application. It represents a tool which identifies possible strengths and weaknesses of the shift behaviour and can thus be used to compare the shift behaviour for different application datasets.

Shift documentations do not necessarily require access to internal calculation variables of the transmission control. This allows the benchmarking of the shift behaviour of vehicles by different car manufacturers.

Manual application of the TCU in the lab is already possible by means of the mentioned tools for objectifying the shift quality as well as the transfer of the tests to the roller dynamometer. Specified operating points are approached by the shift robot and evaluated through the objectification tool. The optimisation process is iterative and done by targeted, manual adjustment of the application parameters through an experienced application engineer.

5 Automated Application

The fourth and last point with improvement potential in the control loop of transmission application, Figure 2, is the time-efficient identification of the optimal transmission control parameter adjustment via automated application. This process is possible through the mentioned elements, model-based and automated.

The shift documentation already requires, as mentioned, planning of operating points, the system of roller dynamometer and driving robot as well as the objectification of the shift quality. These modules are marked blue in **Figure 7**. The automated application adds the effective design of experiments, a model formation, the optimisation and the dataset generation for the TCU as a final step to the tool chain. These elements will be described in the following.

5.1 Efficient Design of Experiments

Efficient design of experiments basically is a tool for obtaining as much information as possible from the system to be identified with as few tests as possible. With regard to the automated calibration of the shift quality, it is thus a challenge to adjust the control parameters of the transmission in a way that the transmission system performance can be identified in as large a space as possible while taking the constraints of the system into account. Every test thus represents a combination of different control

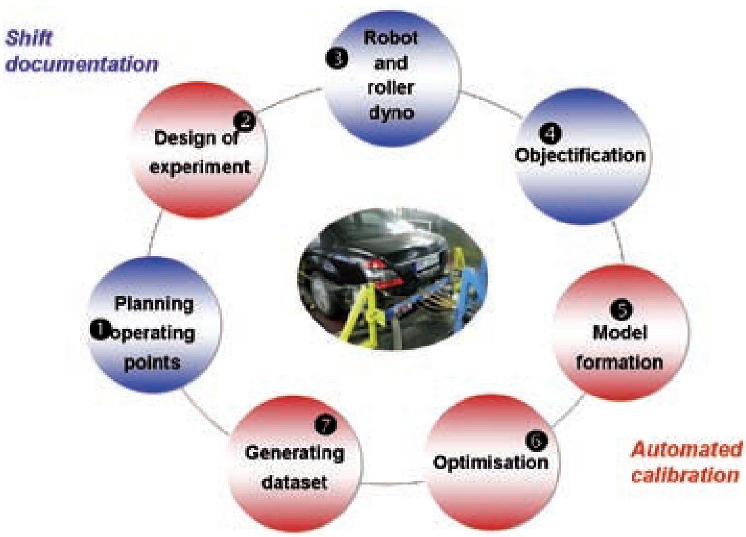

Figure 7: Modules of efficient transmission application

parameter adjustments; the system response is described in form of the objective parameter values resulting from approaching an operating point once or several times.

Due to the fact that the operation of roller dynamometers is comparatively expensive and the few existing test rigs are used to capacity, the time on the test rig has to be kept as short as possible. Several approaches of automated calibration of the shift comfort were analysed at the Institute of Automotive Engineering in the past years [1, 4]. The so-called offline approach will be explained in detail in the following.

5.2 Model Formation in the Offline Approach

In the offline approach, the transmission system performance is identified through intelligent design of experiment. Based on different optimisation criteria, the so-called design of experiments (DoE) generates the best possible test plans for different constraints. The selection of the appropriate DoE plans (for example D-optimal, V-optimal, A-optimal, space filling plans etc.) particularly depends on the required type of model formation. D-optimal test plans are well suited for model formation with polynomial models of higher order, while so-called space filling plans are rather used for the application of artificial neural nets [6]. The subsequent multidimensional, empirical model formation is typical of offline approaches to describe the general function mathematically:

$$Objective\_parameter_x = f(control\_parameter_1, \ldots, control\_parameter_n) \quad \text{Eq. (2)}$$

The approaches of empirical model formation for example include polynomial models of higher order and neural nets with different training algorithms.

Figure 8 illustrates the principle of the offline approach. It starts with completing a test plan on the test rig. The control parameters of the TCU are automatically adjusted in accordance with the test plan specification during the tests, the appropriate operating point is approached by the driving robot and the measurement data recorded during the gear changes. The work is transferred to the office after the tests. The objective parameters are determined from the measurements and functional connections between objective and control parameters are determined by means of the above mentioned approaches of model formation, see Eq. (2). This process is described with the generic term "transmission models" in Figure 8.

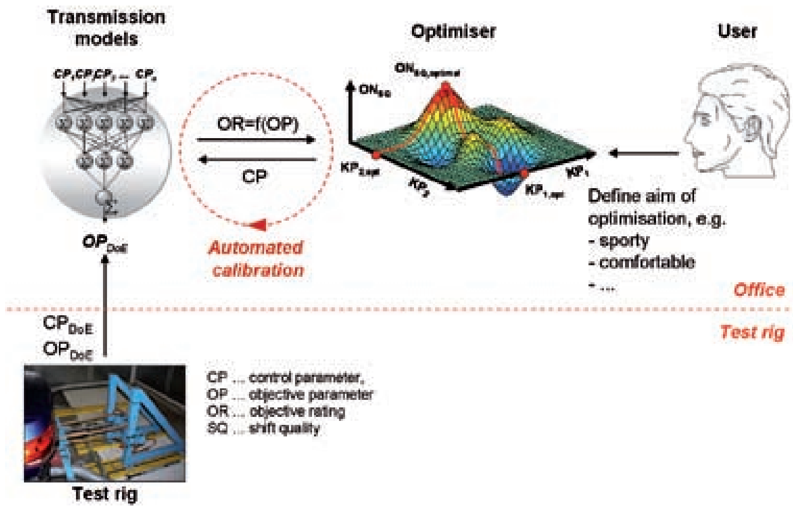

Figure 8: Basic representation of the offline approach for automated calibration of the shift comfort on the roller dynamometer

5.3 Optimisation

The crucial step of automated transmission calibration deals with the optimisation of the datasets that means the identification of the best possible control parameter combination in terms of the optimisation objectives specified by the user. A shift quality rating calculated from the weighting of objective shift comfort and spontaneity ratings can be the optimisation objective. Nevertheless, optimisation in terms of target time curves and objective parameters is also possible.

The optimisation process is done offline at the office; the roller dynamometer is not needed anymore after the transmission behaviour is identified. The main advantage of the offline approach becomes especially apparent when several calibration variants (more comfort or more spontaneity, compare with Chapter 5.5 and **Figure 9**) have to be generated since the created transmission models can still be used for this.

5.4 Generating Datasets for Control Units

The mentioned approach leads to optimal control parameter combinations for

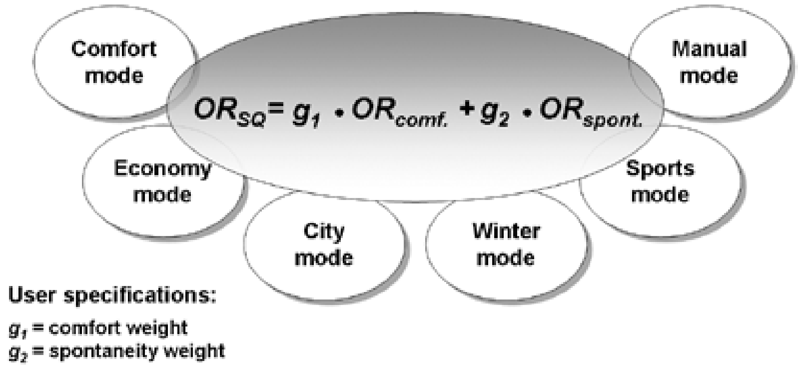

Figure 9: Different application datasets can be generated offline in a short time by means of the models of transmission performance – only by varying the weighting ratio of comfort and spontaneity

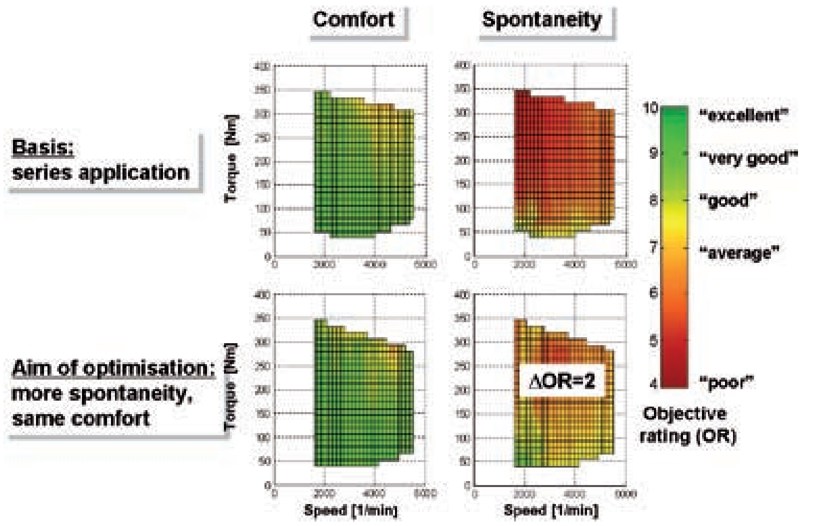

Figure 10: Result of optimisation

a number of considered operating points. Since some control parameters, however, cannot be adjusted individually in terms of operating points, the dependencies of some parameters have to be reduced. This usually means that a compromise is required. Due to restrictions in the software of the TCU, datasets may therefore be required which do not allow an optimal result in terms of shift comfort and shift spontaneity.

The abandonment of shift quality caused by the software restrictions can be quantified by means of the transmission model. Modification proposals for parameter dependencies can be derived from the results, for example introducing a characteristic curve or map instead of a scalar parameter.

5.5 Results

According to the weighting of the optimisation criteria comfort and spontaneity, different datasets can be generated, which are for example implemented as comfort mode, sports mode or manual mode in the control unit, Figure 9.

Another possible restriction is the use of only one optimisation objective (for example spontaneity) using the results of a shift documentation before optimisation (see Figure 6). **Figure 10** shows the results of the optimisation of a 2-3 shift for the optimisation target „maximum objective shift spontaneity with constant shift comfort" as a shift documentation after optimisation. This shift documentation has been created with an optimized dataset on the TCU. It becomes obvious, that with constant comfort rating, the spontaneity rating has been increased by up to two marks in each operation point. This improvement is clearly perceptible in test drives on the road.

6 Outlook

In the future, the extension of the method to more complex types of shifting as well as the consideration of further application constraints, for example shift energy, will be most important. The shift energy can approximately be obtained from measurement data of the shift documentation [7].

Another point, already being worked on, is the transfer of the method to software-in-the-loop systems. By means of this method, the user can already generate application datasets early in the development process and get a more profound insight into the shifting process.

7 Summary

The method of model-based, automatic transmission calibration, developed at the Institute of Automotive Engineering of the Technische Universität Braunschweig (Germany) since 1997, is an efficient tool to meet the challenges of an increasing application effort due to more complex transmission controls and an extended model variety. This method was already used successfully for automatic transmission, dual-clutch transmissions and automated manual transmissions and is also used by commercial companies [8, 9].

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