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03 March 2011 | Volume 113

AUTOMATIC Transmission for the Opel Insignia

VIDEO-BASED Driver Assistance Systems

CONCEPT for Maneuver-based Driver Assistance

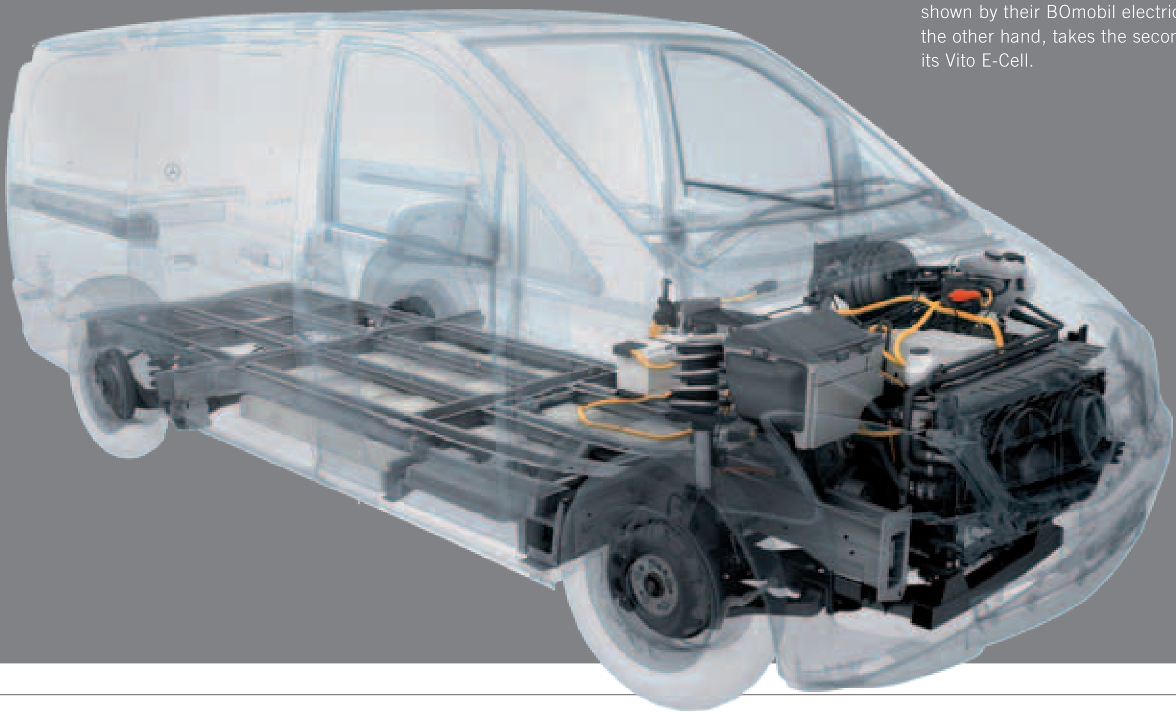
INNOVATIVE VEHICLE CONCEPTS

CONTENTS

COVER STORY

INNOVATIVE VEHICLE CONCEPTS

4, 10 I Electric vehicles for urban and delivery applications can be developed in two different ways. One can either design them from scratch and build an optimally adapted vehicle around an electric powertrain, or one can use a conventional vehicle with an internal combustion engine with a high level of maturity and integrate an electric drive system into it. The supplier Delphi and the University of Bochum chose the first way, as shown by their BOmobil electric van. Daimler, on the other hand, takes the second approach with its Vito E-Cell.



COVER FIGURE © Delphi and Bochum University
FIGURE ABOVE © Daimler

SUN FUEL

Dear Reader,

In just nine years' time, the catchphrase "Who invented it? The Swiss!" will be linked to something completely different from the cough drops that it advertises today. In 2020, the dream of producing a synthetic gas – and therefore fuel – from nothing more than water, CO_2 and sunlight will become a reality, or, in engineering terms, will be move into the phase of an industrial plant. On a laboratory scale, the process was already successfully performed recently. All three raw materials are sufficiently available in huge quantities on earth and are easily accessible. As a result, this is a step closer to mankind's dream of storing the sun's energy and converting it into a different form, thus closing the gap in the CO_2 cycle.

The basic idea proposed by the ETH Zürich and the Paul Scherrer Institute involves thermochemically splitting water (H_2O) and CO_2 using a two-step cyclic metal oxide redox process. In a first, energy-intensive step, the research team led by Professor Aldo Steinfeld reduce cerium oxide using concentrated sunlight at a temperature of 1500 °C. During reduction, the material releases oxygen atoms. In a second step, the reduced cerium oxide is made to react with water vapour and CO_2 at a temperature of around 900 °C. This results in the dissociation of the water and CO_2 molecules, and the oxygen atoms released are integrated into the material structure in such a way that cerium oxide is once again in its initial form and the cyclic process can begin anew. What remains is pure synthetic gas, or "syngas", a mixture of H_2 and CO. This is the precursor to petrol, kerosene and other liquid fuels.

These investigations, which are described in more detail in the magazine "Science", were made possible by a solar simulator that has been available at PSI since the year 2000. Experimentation was carried with a 2000 Watt solar reactor prototype subjected to solar concentration ratios exceeding 1500 suns. Unfortunately, the conversion efficiency of solar energy into solar fuel is only 0.8 percent. But this efficiency is about two orders of magnitude, in other words one hundred times, greater than the one observed with state-of-the-art photocatalytic approaches for CO_2 dissociation. Even today, calculated efficiencies of 19 percent seem attainable.

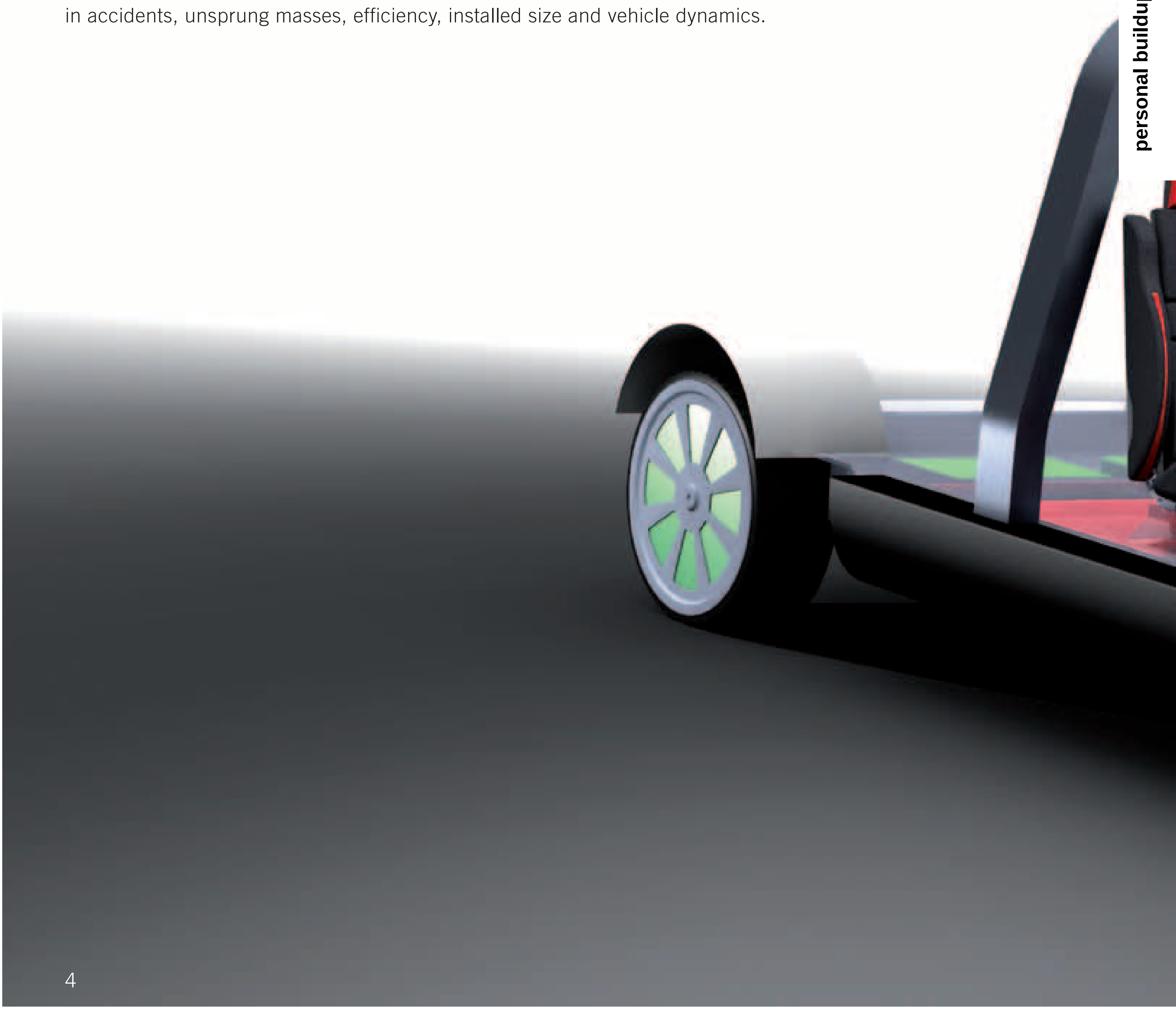
Incidentally, the news about the Zürich team's syngas experiments immediately became one of the top three clicked reports of the month at ATZonline.de. Obviously, the Swiss have much more to offer than herbal cough drops.

Michael Reichenbach

DIPL.-ING. MICHAEL REICHENBACH,
Vice Editor-in-Chief
Wiesbaden, 3 February 2011

DEDICATED DEVELOPMENT FOR A SMALL ELECTRICALLY DRIVEN VAN

For the BOmobil electric vehicle, Delphi and Bochum University use permanent magnet energized synchronous machines on all four wheels. This concept presents a whole series of challenges. These were resolved for technical safety, production costs, engine damage and occupant protection in accidents, unsprung masses, efficiency, installed size and vehicle dynamics.



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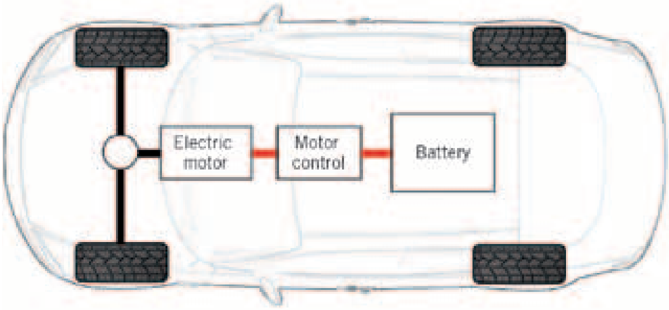


❶ Drive-train based on a central electric motor

❷ Skateboard with integrated electrical components

FUTURE DRIVING TECHNOLOGY

The decision on the types of drive to be used in future passenger cars will be reached by the customer of the future. At present, every year more than 20 million Chinese buy a Pedelec [2]. Electrically driven scooters are also very popular in China. Back in the sixties, our parents or grandparents bought an NSU Quickly (two-wheeled vehicle with IC engine) and then changed to an automobile with IC engine and not to a horse and carriage. In the same way, customers who have got used to electrical mobility will not change back to IC-engine technology. Tomorrow's drive technology will be determined by the mass markets of the future, and these are not in Europe. If we are lucky, we will produce merely the high-value products, but will have no say in the drive technologies applied.

CONVERTED IC-ENGINE VEHICLES

The electric-vehicle concepts to date have for the most part been based on converted IC-engine vehicles. Instead of constructing the vehicle around the components, we take the often conservative and complicated route and attempt to integrate new components into already existing vehicle platforms. No advantage is taken of the degrees of freedom and the advantages inherent in an electric vehicle. Here, the vehicle body as a whole together with the installation point for the components is no different to that of a conventional IC-engine vehicle. Often, the vehicle also features a propshaft tunnel. Almost without exception, when this method is used, central drive concepts are applied with two-wheel drive, but the left and right drive wheel are not controlled separately, necessitating complicated mechatronical solutions for the integration of driver-assistance systems as ABS, ESC and TCS.

Decentralized drive concepts, on the other hand, would feature considerable advantages with regard to weight distribution and the installation of such driver-assistance systems.

Additionally, when a four-wheel drive comes to use, the drive and brake torques at the front and rear axles can be individually controlled via the electric motors and a maximum of the braking energy can be recovered, ❶.

CONCEPT AND DESIGN OF ELECTRIC VEHICLES

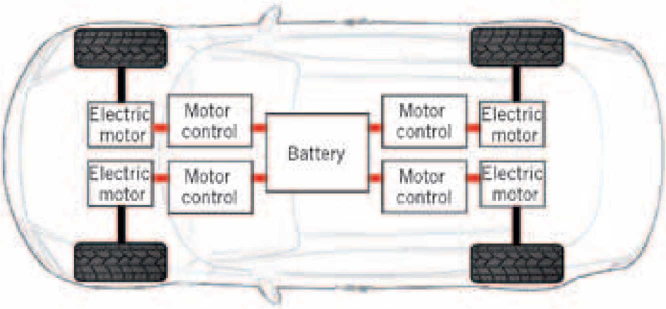
Electric vehicles can be, and must be, basically different in their styling and design. Compared to vehicles with IC engines, due to the lower levels of stored energy and heat loss, different criteria come to the forefront. Weight and thermal insulation play a far more important role and lead to other constructional features.

SKATEBOARD DESIGN

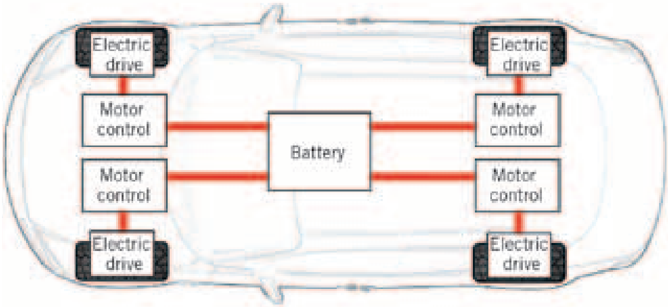
If one were to build a vehicle around the electrical drivetrain components as suggested in [1], it would be possible to achieve almost arbitrary weight distribution and a low center of gravity. It is practically inevitable that this method leads to a skateboard design in which all the components are integrated in the skateboard, ❷. This presents new possibilities for vehicle design and for a new platform strategy. Here, the most varied body shapes could be implemented on one and the same platform, and furthermore, the platform itself could be of modular construction.

Initially, the BOmobil, ❸, will be used solely as a small van during the research

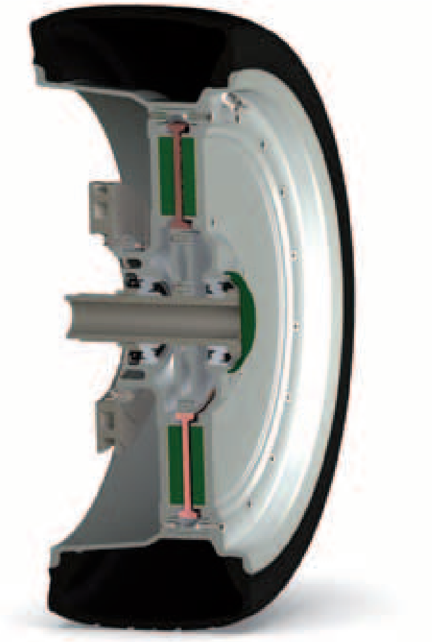
❸ Van concept BOmobil



❹ Drive-train based on four decentralized electric motors



❻ Drive-train based on four wheel-hub motors



❺ Wheel-hub motor

project's running time. On the other hand, other design studies are planned with other body shapes on the same platform.

DECENTRALIZED DRIVE

Decentralized drive concepts, ❹, provide considerable advantages with respect to weight distribution and the implementation of driver-assistance systems. Here, either the front wheels or the rear wheels, or all four wheels are driven independently of each other by means of electric motors. With two-wheel drive it is impossible to recover all the braking energy. With two-wheel drive concepts, in order to recover as much energy as possible the best solution is to drive the front wheels.

In the long term, four-wheel drive will gain acceptance for higher-class vehicles. This is because not only is energy recovery possible on all four wheels, but it is also possible to implement driver-assistance systems without any trouble. Here, the wheels can not only be braked independently from each other but also accelerated independently.

Wheel-hub drives can be used when the wheels are driven independently through a decentralized system, ❺. Since the driveshafts can be omitted, design freedom is improved. Novel solutions become possible for locating the major assemblies and the vehicle occupants, as well as for the weight distribution, ❻.

Permanent-field synchronous machines were developed for the BOmobil and used on all four wheels. This concept features a number of major challenges. These include: Technical safety; production costs; motor damage and occupant protection in case of accident; unsprung masses; efficiency; equipment volume; and the dynamics of vehicle operation. These questions were dealt with within the framework of the research project. The advantages and disadvantages of wheel-hub drives were discussed in detail in [2].

THERMAL MANAGEMENT

Almost three quarters of the energy required in conventional vehicles is converted to waste heat. This is why thermal insulation and heat exchange between incoming air and outgoing air only play a minor role in vehicles up to the present. This changes radically on electric vehicles where the high efficiencies of the electrical components only lead to relatively low levels of waste heat. The "expensive" energy stored in the battery is to be applied for moving the vehicle and not for heating and cooling it. This is why all heat sources and heat sinks have been integrated in the thermal-management system. All in all, the preheating/cooling of the vehicle during battery charging, and the storage of thermal energy in a heat accumulator, lead to a better energy balance.

THE ELECTRICAL SYSTEM

With respect to the conception and the development of the electrical system, it is first of all important to comprehend what changed basic conditions must be taken into account, and also to realise which familiar demands are no longer applicable at all in a purely electrically driven vehicle. These facts, together with the high level of voltage which is in any case available for the drive in electric vehicles, mean that new degrees of freedom become available. This goes specifically for the high-voltage-range, which takes over the tasks of the hitherto mechanical drive train. Instead of drive shafts, gears, clutch, electric generator and starter, now electrical high-voltage systems, contacts, wire with large cross sections, charging devices and electronic power transformers need to be placed and sized.

Special attention is put on the topics of safety and EMC. Here, new requirements hitherto not needed have to be defined. Contact protection is needed for voltages up to 750 V. The electrical insulation must be constructed in a way that no perturbing or dangerous electromagnetic emissions can influence or harm other technical components or the passengers. Other important aspects in system design are cost, weight, consumption of resources, producability and recyclability which create more possibilities to reduce the envi-

TECHNICAL DATA	
Range	> 150 km
Drive concept	4 wheel-hub motors
Front axle	McPherson spring strut axle
Rear axle	Twist beam
Tires	225/40 R19
Number of doors	4
Number of seats (van)	2
c_w value (target)	0.3
Turning circle (curb to curb)	10.5 m
DIMENSIONS AND WEIGHTS	
Length	3800 mm
Width	1800 mm
Height	1600 mm
Track (front)	1488 mm
Track (rear)	1510 mm
Wheelbase	2600 mm
Empty weight	1000 kg
Payload	500 kg
PERFORMANCE	
Maximum speed	130 km/h
Acceleration (1100 kg)	0 – 50 km/h < 6 s; 0 – 80 km/h < 11 s; 0 – 100 km/h < 18 s
Continuous hill-climbing capacity	7 % at 80 km/h
BATTERY	
Capacity	27 kWh
Number of cells	140
Weight, including battery container	< 300 kg
MOTORS	
Type	External rotor, permanent-field synchronous machines
Maximum power output	10 kW
Maximum speed	1000/min
Maximum torque	300 Nm

❼ Technical data

ronmental impact. An important task, too, is the production of the electrical, mechanical and cooling connection of the wheel-hub motors, which is going to be a very stressed connection in terms of flexibility and environmental effects. Available electrical energy equals cruising range, and thus, passenger comfort.

In order to minimise the vehicle's overall power loss, the most energy-efficient technologies are applied for BOmobil's electrical consumers. Furthermore, the electronics control unit (ECU) concept must be optimized with regard to terminal control, wake-up behaviour, reduction of operating and quiescent currents, and load management. Here, the central electronics also assumes the additional responsibility of monitoring the various current flows inside the vehicle, and controlling them as a function of the varying charge state, driving operations, and energy demands.

A further sphere of responsibility for the comfort and control electronics which is being evaluated within this project's framework, is the control of the loading processes in the private sector and the public sector. This includes vehicle/customer identification as well as the monitoring and invoicing of battery charging. Here, it would be possible to extend the immobilizer's range of functions to prevent unintentional or unauthorized movement of the vehicle.

BOMOBIL CONSORTIUM

The know-how required to develop and manufacture electric vehicles is available in Nordrhein-Westfalen (North Rhine Westphalia). Here, this know-how is also available for maintaining the lead in knowledge and capability which is needed to generate jobs for qualified engineers and skilled workers. This is to be underlined by the development of the electrically driven van BOmobil up to the stage at which it is suitable for volume-production, ❼.

The consortium comprises the following partners:

: Institute for Electric Mobility, Bochum: Head of consortium, overall system integration for electrical and mechanical systems, skateboard design, thermal management, design of vehicle body, and support in the layout and construction of the wheel-hub drive
: Delphi Deutschland GmbH, Wuppertal: High-voltage distribution system, body computer, low-voltage distribution system
: Neuhäuser Windtec GmbH, Lünen: Layout and design of the wheel-hub drive and conception of a production process which is suitable for volume production of the wheel-hub drive
: Scienlab electronic systems GmbH, Bochum: Development of the traction inverter
: CI Composite Impulse GmbH & Co., Gevelsberg: Development and design of a lightweight battery container, and support in the development of the lightweight body
: TÜV Nord Mobilität GmbH & Co. KG, Hannover: Specialist support in the development of the vehicle with respect to its suitability for volume production and homologation
: Hoppecke Batterien GmbH & Co. KG, Brilon: Development of the battery and the battery-management system
: Adam Opel GmbH, Rüsselsheim: Provision of the infrastructure and standard components.

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MERCEDES-BENZ VITO E-CELL FIRST VAN WITH ELECTRICAL POWER EX WORKS

With the Vito E-Cell, Mercedes-Benz is the first automotive manufacturer to produce an electrically powered van ex works. The van boasts lithium-ion batteries with prismatic cells at rated voltage of 360 V, weight around 500 kg and energy capacity of 36 kWh. Delivery of a follow-up series of 2000 vehicles started in the end of 2010.

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DAY-TO-DAY USE

The all-electric Mercedes-Benz Vito E-Cell, ❶, is not an experimental vehicle or a prototype, but a fully fledged series production model. The Vito E-Cell is the first electrically powered van in the world to be produced by an automotive manufacturer. Similarly, it handles just like a normal van in day-to-day use. It is operated in the same way and performs the same tasks as every van in its class. At the same time, it produces zero local emissions. There is just one difference: instead of the drive to the filling station, the Vito E-Cell is fueled from the mains supply.

Normality of the Vito E-Cell in terms of appearance and handling was one of the key aims of the Development department within the Mercedes-Benz Vans business unit. In everyday commercial vehicle fleet operations, the Vito E-Cell is intended for use just like any other van as far as fleet management, order scheduling and drivers are concerned. This is an essential condition for deployment of the first small series in 2010 of 100 vehicles in around 20 very different fleets in Stuttgart and Berlin as well as the subsequent series of 2000 units which delivery began at the end of 2010. The deliberately wide range of applications of the small series covers courier, express and parcel companies, service providers, trades people's businesses, airports, authorities, energy suppliers and individual customers. All 100 vehicles have now been delivered.

❶ All-electric Mercedes-Benz Vito E-Cell with unchanged load compartment

❷ Power output display instead of the rpm counter

❸ Lithium-ion batteries with an energy capacity of 36 kWh

COMPARISON TO THE BASIC VEHICLE WITH COMBUSTION ENGINE

The Vito E-Cell is based on a Mercedes-Benz Vito panel van with a long wheelbase and a standard roof. It was chosen because of the large amount of free space below the floor to house the traction batteries. On the outside, all that distinguishes the electric vehicle from a Vito with a combustion engine is its decor and the rear model badge. The bodywork has remained untouched. The charging socket is housed behind the unchanged fuel filler cap on the driver's side in the lower area of the B-pillar – the power is therefore supplied in the usual place.

The cockpit has also remained unchanged apart from a few details in the instrumentation. The speedometer is limited to a maximum of 120 km/h. There is a power output display instead of the rpm counter, ❷. A needle shows whether the vehicle is recovering energy through recuperation or consuming it in the respective driving conditions. In the Vito E-Cell, the needle of the usual fuel level indicator provides information on the state of charge of the batteries. In the display between the round dials, the driver can also check the state of charge via a display as bar chart or in the form of percentage values. The driver is likewise informed of the operating hours and, during charging via the mains supply, of the current state of charge and the likely end of battery charging.

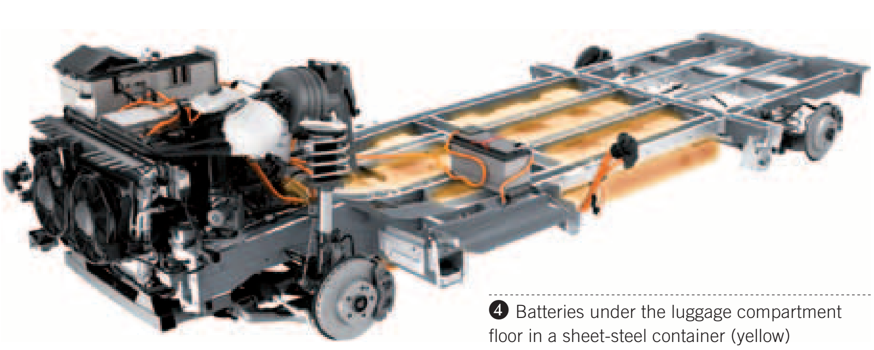
Instead of a gearshift lever, the driver has a selector lever as in an automatic transmission vehicle. In contrast to a vehicle with a combustion engine, the Vito E-Cell does not tend to creep forwards and backwards in gears "D" and "R" respectively. In selector lever position "N", power output of the electric motor is suppressed. As the drive components give off just a little heat due to their high level of efficiency, an electric heater booster heats the cab. It is switched on with a button. The temperature is controlled in the usual way with a rotary switch. All drivers are informed about the special features of the Vito E-Cell in the context of a briefing. In addition, each vehicle has specially prepared operating instructions.

Despite the battery-powered drive, the load compartment of the Vito E-Cell has remained unchanged: an important point as far as fleets are concerned. The payload of around 900 kg is the normal level for this vehicle class. Mercedes-Benz offers the Vito E-Cell with a permissible gross vehicle weight of 3.05 t as standard. Some fleets choose a 2.8-t version, which therefore has a lower payload of 650 kg. The permissible axle loads, the ground clearance and the angle of slope are equivalent to those of a conventionally powered Vito. Therefore, customers can integrate the Vito E-Cell into their processes without compromising on load carrying capacity or operation – a key factor in the acceptance of electrically powered vehicles.

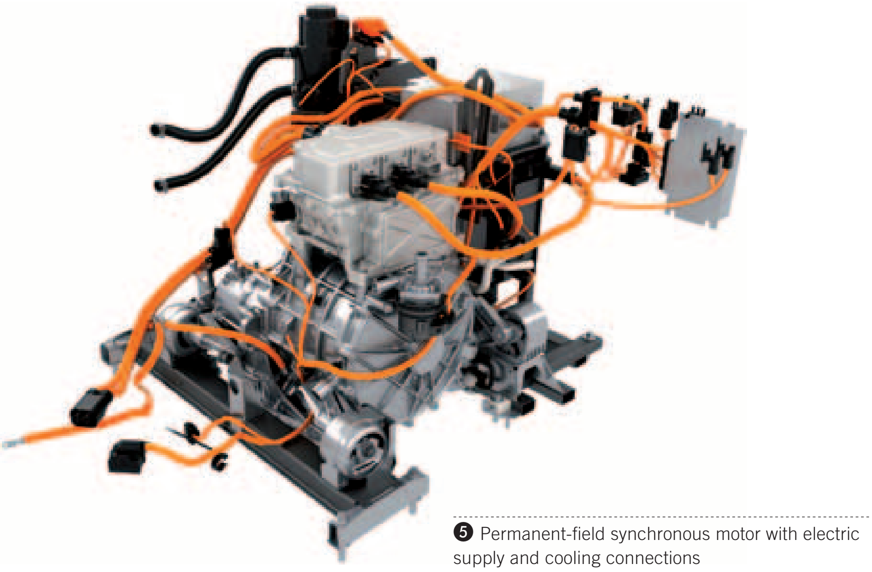
ELECTRIC DRIVE

The Vito E-Cell is equipped with lithium-ion batteries, ❸. A variant with prismatic cells has been chosen, partly because of the package. The battery consists of 192 cells, which are divided into 16 modules. The rated voltage is 360 V, the weight around 500 kg and the energy capacity 36 kWh. 32 kWh of this is usable, a relatively high figure. The internal development goal for the service life was ten years, thus clearly exceeding the four years that the 100 vehicles of the first small series will spend with their owners.

The batteries are located under the luggage compartment floor in a closed sheet-steel container with a glas-fibre reinforced polymer (GFRP) cover, ❹. The battery holder is inserted between the longitudinal members. Stress calculations, rough-road tests and crash tests have proved the stability of the suspension. In addition to the high-voltage network, the vehicle has



❹ Batteries under the luggage compartment floor in a sheet-steel container (yellow)



❺ Permanent-field synchronous motor with electric supply and cooling connections

given to using the floor assembly of the all-wheel-drive Vito 4 × 4 with more installation space between the axles as well as its front-wheel-drive modules, only parts of the front axle are now used in the Vito E-Cell. For instance, the axle subframe is a new development.

Whilst in motion, the Vito E-Cell obtains electricity to power the electric motor by means of recuperation during braking and in deceleration mode. In these cases, the electric motor works as a generator and supplies the traction batteries. From around 12 % brake pedal pressure, the hydraulic brakes are also engaged – unnoticed by the driver.

CHARGING PROCESS

For operation of the 100 Vito E-Cell vehicles in the first small series, energy suppliers Vattenfall (Berlin) and EnBW (Stuttgart) are providing the operators with charging stations at the respective depots, ❻. Charging is carried out here during break times, that means preferably overnight, with 380/400 V. Together, the two installed chargers of the Vito E-Cell have an output of 6.6 kW; meaning that it takes around six hours to charge a fully discharged battery. The vehicle and the charging station are connected by a multipole charging cable. The plug-in system, ❼, complies

a 12-V on-board power supply that is fed from the high-voltage traction battery. The corresponding storage battery is housed in the seat base underneath the driver, as in the Vito with a combustion engine. It supplies the usual 12-V consumers such as the lights and control units.

The motor, ❺, of the Vito E-Cell is a permanent-field synchronous motor (PSM). This design is ideal because of its high output density with a correspondingly compact design, its high level of efficiency of around 95 % and the fact that it requires no maintenance. The continuous output of the motor is 60 kW, and the peak output is 70 kW. The torque of 28 Nm is intrinsically available from the start and ensures outstanding acceleration. For instance, the Vito E-Cell goes from 0 to 60 km/h in just 6.5 s. Force is transmitted to the front axle by means of a single-speed transmission system with a fixed gear ratio.

The power electronics convert the DC voltage of the batteries into the necessary AC voltage for the PSM. They are installed just beside the motor. IGBT (insulated gate bipolar transistor) shifting elements are used as inverters because of their robustness. An intermediate circuit with capacitors ensures uniform energy flow with no ripple.

Three closed liquid cooling circuits ensure optimum temperature control of all components. The cooling circuit for the motor, inverter and DC/DC converter is filled with 5 l of coolant and limits the temperature of the components to a maximum of 60 °C. The interior heater together with a pump forms the second system. The third circuit with 15 l of coolant keeps the temperature of the batteries and the charger at around 30 °C.

During development, Mercedes-Benz used proven components wherever possible that were adapted to use in the Vito E-Cell. For instance, the DC/DC converter can also be found in the Mercedes-Benz M-Class with hybrid drive. In the same way, the electric motor and the control system have already proved themselves in other vehicles. Whilst consideration was initially

❻ Charging station for 380/400 V

❼ Plug-in system, complies with the rule IEC 62196 Type 2 with the rule IEC 62196 Type 2, on which the European automotive manufacturers have agreed. It is currently in the standardization process. On the charging socket of the vehicle, the status of the charging process is displayed by means of a colored signal: if there is a yellow light, the charging system has recognized the vehicle, but is not yet charging. A pulsating green signal indicates that the charging process is ongoing. Solid green means that charging is complete. A flashing yellow light indicates an error.

The special features of the Vito E-Cell include the Smart Charge Communication Unit (SCCU) in the vehicle. It was developed in the central research department of Daimler AG and ensures communication between the power supply, the operator and the vehicle. First of all, the vehicle is automatically identified after insertion of the charging cable, which is important in order to establish the individual consumption for billing. Individual charging strategies can also be specified. For instance, charging can be carried out in accordance with the electricity tariff, in line with feed-in times using "green" electricity from regenerative sources, or in line with the necessary charging capacity and the planned time for the next start-up of the vehicle. The corresponding parameters can be preselected by the distribution manager via computer or by the driver via the buttons on the steering wheel. This ensures that each individual Vito E-Cell is charged in a battery-preserving manner, started up with optimum conditioning and runs in the most cost-effective and environmentally friendly way with optimum availability. If a fleet charges several Vito E-Cell vehicles at the same time, the charging strategies smoothens peak loads so that the local mains supply is not overloaded.

The performance of the SCCU is ideal for commercial use. Operators can put the emphasis on cost, availability or rigorously environmentally sound energy supply. If the focus is on the use of "green" electricity, with an overall "Well to wheel" energy approach, the Vito E-Cell produces no CO_2 emissions at all, local or otherwise.

If required, the Vito E-Cell can also be charged from the 230-V mains supply with the usual grounding-contact type plug via an additional charging cable. However, charging then takes twice as long.

❽ Vito E-Cell complies with electricity test standard ECE-R 100 for the approval of battery-powered road vehicles

RANGE AND OPERATING COSTS

Customer surveys in various industries have shown that many vans cover between 50 and 80 km a day in short-distance transport. The Vito E-Cell is more than capable of meeting this requirement: according to the New European Driving Cycle (NEDC), the range of the Vito E-Cell is 130 km. The restriction of the maximum speed to the 80 km/h that is typical of commercial vehicles and the use of highly efficient components, intelligent charging strategies and low rolling-resistance tires constantly ensure optimum range. This also includes an automatic reduction in power output when the battery capacity falls below 7 %, with corresponding notification of the driver. Omission of some special equipment, for instance the air-conditioning system, maximizes the range of the Vito E-Cell.

The operating costs of the Vito E-Cell amount to just a fraction of the costs for a van with a combustion engine. This is partly because of the much-reduced maintenance scope. For instance, a visual inspection is only required once a year or every 20,000 km, and there is no need for oil changes.

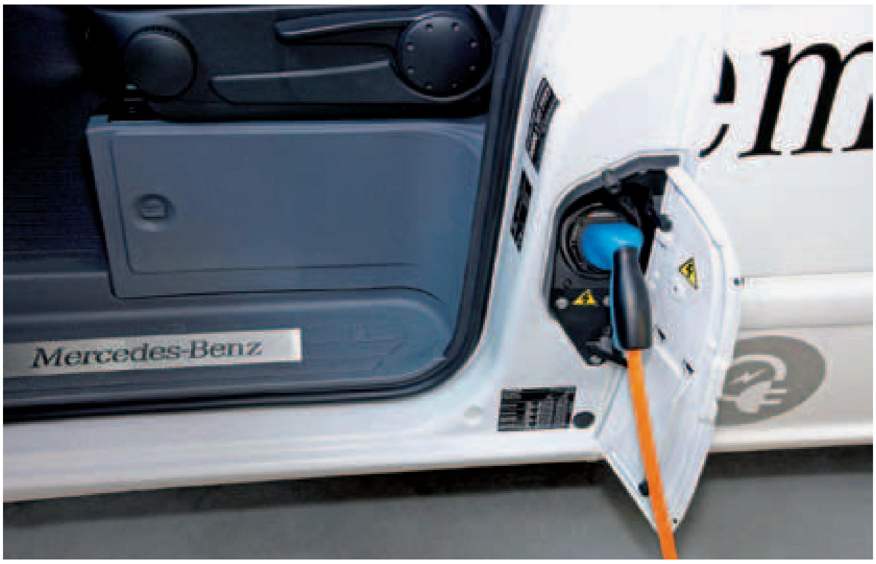
The Vito E-Cell undergoes familiar processes in production at the Vitoria plant in Spain. It is regarded as an additional model variant in production. The bodywork is unchanged: only the propshaft and rear differential have been omitted, and special cable harnesses are used. The new front-wheel-drive module is mounted at the same time as everything else is put together. The van is only transferred out for a short time for assembly of the battery package. Before production started, the employees were trained in handling the high-voltage system components. They also now regard the Vito E-Cell as a normal model.

SAFETY AND RELIABILITY

Mercedes-Benz tested and demonstrated the functional reliability of the Vito E-Cell in extensive driving tests with more than a dozen vehicles. This included tests in extremely cold winter conditions as well as rough-road tests and endurance tests. Due to the restricted range and the charging cycles, an electric vehicle is subjected to endurance tests at a different pace to vehicles with a combustion engine; the numerous times the battery is charged are part of this testing.

With an electric drive, testing of the electromagnetic compatibility (EMC) is particularly important. The Vito E-Cell benefits from the compact design of the drive here: with the exception of the battery, all components of the electric drive are combined under the engine cover and directly connected to each other.

The high-voltage systems of electrically powered vehicles present an opportunity to discuss safety when first dealing with the topic. The Vito E-Cell complies with



❾ An immobilizer prevents the driver from setting the Vito E-Cell in motion during charging

test standard ECE-R 100 for the approval of battery-powered road vehicles, ❽. In particular, this sets out regulations that prevent direct contact with current-carrying parts and corresponding test procedures. This ensures the operational reliability of the Vito E-Cell. In accordance with ECE-R 100, all high-voltage components have shock protection and carry warning stickers. Cables for supplying the high-voltage components are identified by their orange-colored sheathing. An immobilizer prevents the driver from setting the Vito E-Cell in motion during charging, ❾. All requirements of the set of standards developed by German automotive manufacturers are thus fulfilled.

The outstanding safety features of the Vito E-Cell include a new electronic stability program (ESP). The background to this is the change from rear- to front-wheel-drive with a correspondingly modified chassis, the different weight distribution and the different braking torque due to recuperation during deceleration. The ESP contains all the usual functions, such as the anti-lock brake system, traction control system, brake assist, hill hold control, electronic brake distribution and load detection.

Extensive crash tests in a specially developed simulation program and in reality prove the equally high level of passive safety of the Vito E-Cell. For instance, in real conditions, the Vito E-Cell had to undergo a frontal crash with 100 and 40 % overlap, side impact with a stake and a rollover test. As there is no longer a combustion engine as a protective element, the Vito E-Cell has a special crash element. In the event of a frontal collision, this frame holds the motor and pushes it downwards to protect the passenger compartment.

Due to the changed mass distribution, a changed airbag system with different trigger thresholds has been applied. If an airbag is triggered, and in the event of a side impact and a rollover, the high-voltage batteries are deactivated via a pyrotechnic fuse. After this, the vehicle can no longer be started up under any circumstances. The reason for this is possible sparking. It could prove fatal in a collision with a vehicle if fuel escapes from the other car.

In addition, in line with standards, the intermediate circuit capacitors are actively discharged to a level of less than 60 V within five seconds in the event of an accident. In the event of a short circuit, the high-voltage systems are switched off automatically in order to prevent cable overload. This is one of the reasons why the Vito E-Cell is part of the guidelines for rescue services for Mercedes-Benz vans.

PROJECT MANAGEMENT

The tight schedule was one of the challenges when developing the Vito E-Cell: the battery-powered van was developed in just over a year. Expertise in battery propulsion of vans within the company, gathered over several decades, proved to be a big advantage here. Vans of all generations have been electrified, starting in 1972 with the Mercedes-Benz LE 306 at the Olympic Games in Munich. The expertise covers the high-voltage architecture as well as the knowledge of specialist suppliers and development partners. The internal development of numerous components took place within series production development. The Vito E-Cell project benefited from various state incentive measures. The German Federal Ministry for the Environment and Nature Conservation supports development and industrialization, whilst the German Federal Ministry of Transport, Building and Urban Development supports customer use and the Basque government in Spain supports the construction of special production facilities.

Development of the Mercedes-Benz Vito E-Cell is going further: the first small series of 100 vehicles is to be followed by a series of 2000 Vito E-Cell vans, starting at the end of 2010. Enhancements of the battery technology towards lighter and more compact batteries with further increases in output density are already foreseeable. An enhancement of the battery cooling system aimed at reducing the weight is also under development. In addition, the next-generation Vito E-Cell could feature preheating in order to optimize the range even more. More specifically, enhancements include integrating the SCCU into the charger: so far, they are separate components.

OUTLOOK

As part of a forthcoming series production with an expansion to several export markets, Mercedes-Benz will add a right-hand-drive version to the range of the electric van Vito E-Cell. On production start-up, all registration-related issues will also be resolved.

Whereas the first 100 vehicles were registered to Daimler AG in the context of individual approvals, the current series of the Vito E-Cell has been homologated throughout Europe and therefore can also be registered throughout Europe with no additional special approvals. Another step towards the targeted normality of the Mercedes-Benz Vito E-Cell in customer application.

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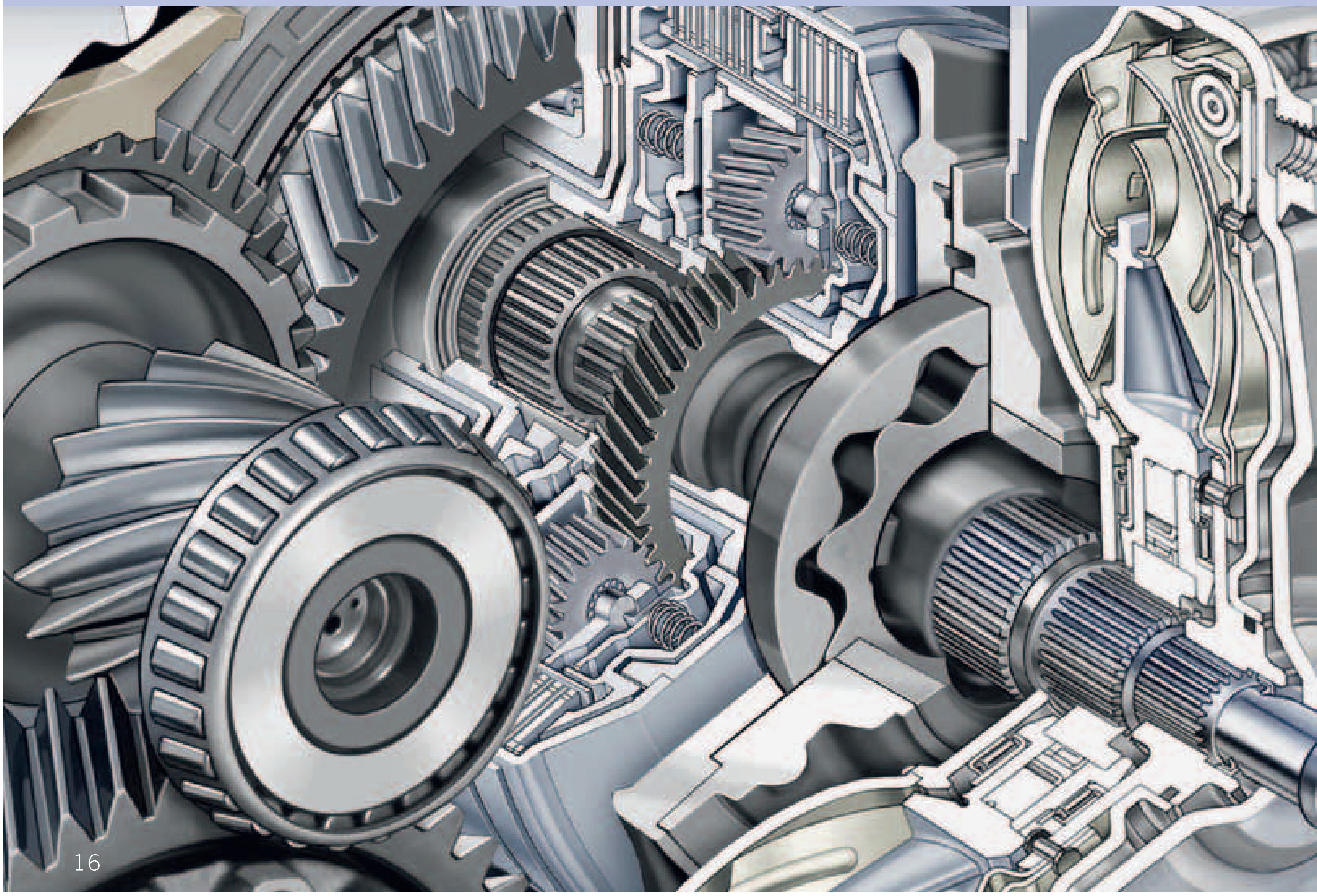
SECOND GENERATION SIX-SPEED AUTOMATIC TRANSMISSION FOR THE OPEL INSIGNIA

General Motors developed a second generation of their six-speed automatic transmission AF40 covering a torque range of up to 450 Nm. The main feature of this development, coded AF40 Gen II, is an additional reduction of CO_2 emissions. By comparison to the first generation from 2003, the new transmission improves not just the fuel economy of 2.9 % in NEDC, also drivability, shift times, weight and NVH were enhanced.



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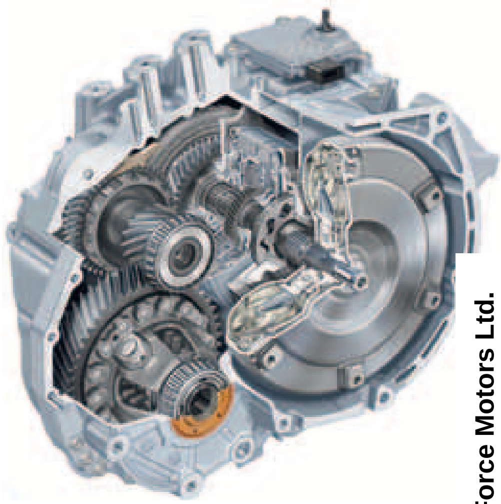
HOW TO OPTIMIZE THE "CAR OF THE YEAR"

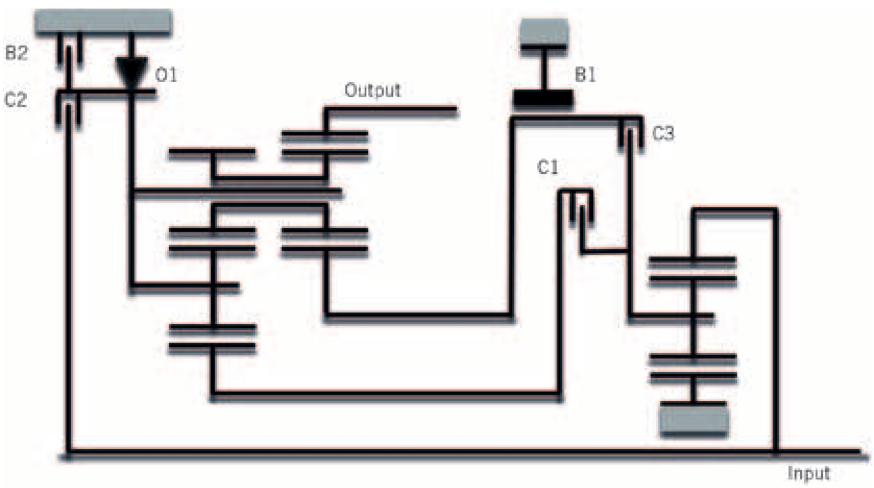
For midsize vehicles with front and all-wheel drive General Motors has developed a second generation of their six-speed automatic transmission AF40 covering a torque range of up to 450 Nm. This new transmission, ❶, was first introduced in the Opel Insignia in the summer of 2010. It fits to a broad variety of gasoline and diesel engines offering a wide displacement range with power ranging from 96 to 240 kW. The recent generation of the Opel Insignia offers a significant reduction of CO_2 emissions, thus responding to the increasing importance of fuel economy within customer requirements. Among other things, automatic transmissions contribute substantially to an increased performance efficiency by six gears and a wide ratio spread.

As a result of the permanent efforts at improvements, the second generation of the AF40 (the so-called AF40 Gen II) has been designed for the Opel Insignia and other GM midsize vehicles; the AF40 Gen II debuted in the Opel/Vauxhall Insignia in the summer of 2010.

The well-known AF40 transmission is a compact, lightweight, and electronically controlled six-speed automatic transmission with differential gear for front wheel drive and all-wheel drive applications. It can handle engine torques of over 400 Nm for gasoline engines and 450 Nm for diesel engines. The AF40 features a centre distance of 197 mm and its overall transmission length is 357 mm. One reverse and six forward gears are achieved by a Lepelletier gear set, together with three rotating clutches, one stationary clutch, one brake band, and a one-way clutch. The power flow is illustrated in ❷.



❶ Section through the new six-speed automatic transmission AF40 Gen II for 450 Nm torque



❷ Power flow of the transmission with two brakes (B) and three clutches (C) as well as one one-way clutch (O)

The overall ratio spread of the AF40 is 6.05. Depending on the type of engine and on vehicle application, the transmission offers a variety of final drives in the range of 2.7 to 3.75. The transmission control module is placed in a separate case and mounted on top of the transmission housing.

The AF40 is equipped with a hyper elliptic torque converter with lockup clutch. The transmission is filled for life with low friction oil, so no change interval is scheduled for the vehicle lifetime even under severe usage conditions. While maintaining the original concept of the AF40, the aforementioned targets were achieved by changing the transmission hardware in several areas and by modifying the controls strategy.

MODIFICATIONS FOR THE SECOND GENERATION

While the six-speed AF40, first introduced in 2003, had been an excellent product representing "state of the art" technology, the development team was seeking to further improve the design. The project of upgrading has been driven by increasing customer demands concerning the vehicle itself, the powertrain, and the automatic transmission. General customer expectations in the vehicle segments into which this transmission is integrated have been rising further, particularly regarding CO_2 emissions and fuel economy, shift comfort and noise (NVH).

Not only is the efficiency of the transmission a direct contribution to fuel efficiency and CO_2 emissions, also component weight and controls strategy (shift patterns and lock-up points) have an impact on the vehicle's CO_2 emissions and fuel consumption. Shift comfort is gaining more and more importance in midsize vehicles; so shift times and shift response are subjects of substantial efforts in the transmission industry.

New vehicle generations and model-years have improved significantly with regard to noise and vibrations behavior, and powertrain and especially transmission design needs to follow this trend. At the same time, modern downsized combustion engines with improved fuel efficiency and reduced emission levels create, as an additional challenge, more torsional irregularities the transmission will have to absorb. Generally speaking the requirements on transmissions generated by NVH are increasing continually.

Facing the areas in which enhancement should be gained with the AF40 Gen II, the necessary changes and adaptations were derived from these rather abstract challenges. There are three general areas for technological upgrading, ❸:

: starting device
: gear train
: controls.

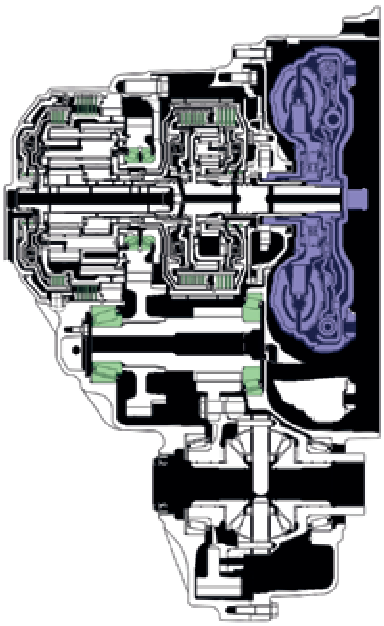
Modifications of the starting device (torque converter) concern the extension of the damper spring travel in conjunction with a closed converter clutch featuring softer spring characteristics as well as a smaller torque converter with lower inertia. The long travel damper enables wider lockup areas for the converter clutch featuring changes in the calibration towards a more efficient engine load point.

Friction reduction in the drive train is addressed by new technology for clutch plates and roller bearings as well as bearing optimization on the output shaft and the differential. In addition, newly developed seal rings reduce rotational friction. Changes in the hydraulic and electric transmission controls consist of an advanced quick shift control logic in the software (S/W) as well as hardware (H/W) improvements on the solenoid valves.

EFFICIENCY

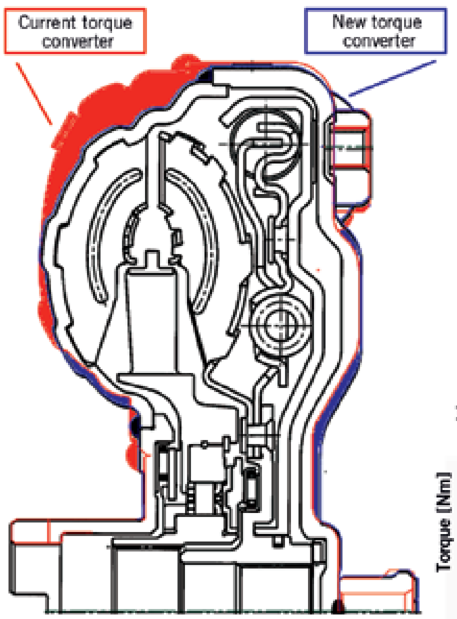
Transmission efficiency by reducing the internal friction without changing the powerflow is gained mainly in the torque converter and the gear train. A new damping solution in the torque converter enables different controls strategies closing the converter clutch in large operation areas, ❹. In return, this reduces the losses caused by an open converter and thus contributes to higher efficiency.

The second area of improvement, when it comes to friction reduction, is the gear train. Optimization of the gear train is applied to three groups of components, that means the friction plates, the bearings, and the seal rings. New technology friction plates for all stationary and rotating clutches reduce drag in clutches not actuated. Different dimensions of the oil grooves and enhanced design of the friction segments lead to improving the drag torque of the plates when not actuated. This improvement is achieved neither by changing the

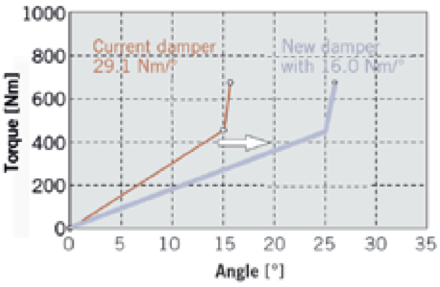


Improvements to the predecessor			Fuel economy	Quick shift	Comfort/NVH	Safety/Packaging	Lightweight
Starting device		Long travel damper for wider lockup area	●		●		
		Smaller size and lower inertia for lower torque engine		●			●
Gear train		Lower drag torque : friction plates : tapered roller bearings : seal rings	●				
Controls	S/W	Advanced quick shift control logic		●			
	H/W	Direct-controlled linear solenoids		●		●	●

❸ Improvements of the AF40 Gen II transmission versus the predecessor AF40 – association of modification to the three general areas



	Current design	New design
Torque converter		
Mass	14.8 kg (wet)	14.1 kg (wet)
Inertia	0.147 kgm²	0.141 kgm²
T/C characteristics	204 K	207 K
Spring stiffness	29.1 Nm/°	16.0 Nm/°



❹ New torque converter with longer travel damper compared to the current design

friction material nor the lift-off of the friction plates from both transmission generations. Keeping the lift-off at its original level leads to the same axial compactness of the clutches as already seen in the Gen I transmission.

Several bearings in the transmission are realized as tapered roller bearings. For the second generation, they are optimized concerning friction and fuel efficiency. The improvement is achieved by reducing the contact area between rollers and bearing face while, at the same time, reducing the rotational speed of the rollers in rotating condition. This, in turn, is achieved by reducing the length and the number of rollers. The roller diameter is increased in order to compensate for the load and, at the same time, the speed of the rollers is reduced.

In order to minimize the friction of the seal rings used in the new transmission, a new trapezoid profile of the seal rings is used. This change reduces the axial forces as well as the size of the friction surface acting on the ring, and it reduces the friction of the seal rings as well as new material used without compromising seal efficiency.

SHIFT COMFORT, SHIFT TIMES, AND SHIFT RESPONSE

Improvements in both shift times and shift response as well as shift comfort are achieved by optimizing controls hardware and modified software. Hardware modification consists of a new integrated type of solenoid, the Direct Control Linear Solenoid. It allows a linear adjustment of pressure in order to ease actuation of the clutches. Besides, a simplified oil flow results in improved response characteristics of the system shortening shift delay time by 100 ms.

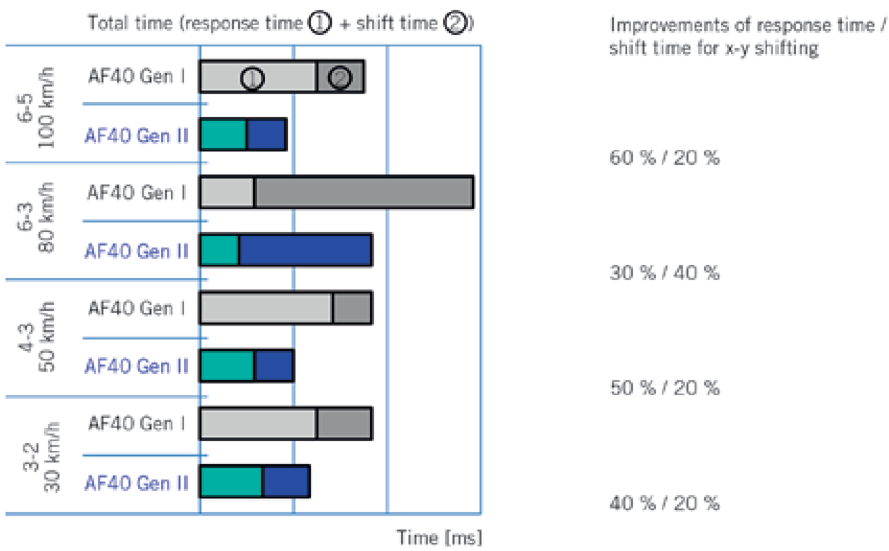
In addition, the new software support could reduce shift times. The gain in shift and response time depending on several parameters such as shift type (up/down), gears involved, engine rpm etc. can be read in ❺. What is particularly remarkable is the reduction of response time for the 6-5 down shift representing an improvement of 60 %, and of shift time of the 6-3 down shift with a likewise significant improvement of about 40 %.

Shift quality could be optimized, too, via the mentioned measurements. Shift feeling for skipped downshifts is improved by eliminating the two-step response behavior, ❻.

NOISE AND VIBRATIONS

Improvements of the noise and vibrations behavior (NVH) are mainly achieved by an optimized damping inside the torque converter. In line with a hyper elliptic torque converter with an electronically controlled lockup clutch there is a damping element consisting of a coil spring acting in direction of the rotation. In the AF40 Gen II the travel of the damper spring is made longer, from 15.7° to 26.4°, together with a reduction of spring stiffness from 29.1 Nm/° to 16 Nm/°.

This new configuration can absorb a considerably higher level of vibrations than the current spring. This enables calibration to be adapted in order to reflect the better damping behavior of the long travel damper. Calibration changes comprise wide areas of driving conditions with closed clutch and the operation in controlled slip condition.



❺ Response time and shift time comparison for the current and the new transmission for four x-y down shiftings

PACKAGE AND WEIGHT REDUCTION

While optimizing several functions, significant weight reduction and a beneficial package situation were achieved. The changes in hardware contributing to these fields were the modifications of the solenoids in the valve body and an optimized torque converter.

The new solenoid not only improves shift behavior, it also packages significantly more compactly in the valve body housing allowing a changed outer contour. This change shortens the transmission by 30 mm in vehicle longitudinal direction.

The new torque converter has a smaller outer diameter resulting in lower inertia as well as in reduced weight. The elongated travel of the damper springs plus the softer spring stiffness packages in the given space without any enlargement of the outer contour of the converter housing. The overall weight reduction of both the changes in the valve body and in the torque converter adds up a 1.2 kg total although weight is added by introducing the long travel damper.

FUEL ECONOMY

The contributors to fuel economy improvements in the package of modifications are not just those concerning the gear train where they have a direct effect on fuel economy by way of reducing internal friction; control strategies enabled by the NVH package applied to the starting device have significant impacts, too.

Of course the controls strategies described are subject to variations depending on the application at hand. Not only the engine but the vehicle, too, into which the AF40 Gen II transmission is installed does influence the controls approach. Fuel economy improvements for a 2-l gasoline engine in an Opel midsize vehicle add up to 2.9 % in the NEDC, resulting from internal friction reduction and controls strategy.

SUMMARY

A new generation of the six-speed automatic transmission for GM midsize vehicles with front and all-wheel drive has been developed. The new AF40 Gen II transmission is based on the predecessor (Gen I) from 2003 and debuted in the summer of 2010 in the Opel Insignia. It covers up to 450 Nm of torque and will be applied to a broad variety of gasoline and diesel engines in a wide displacement range with power outputs ranging from 96 to 240 kW.

Most notably the development of the second generation features improved fuel efficiency of 2.9 % in NEDC and enhanced drivability. The transmission is 1.2 kg lighter.

In the process of development the original concepts of the first generation were maintained. But optimization was reached in several areas of the transmission hardware and controls software. Focus of the changes in hardware was on reducing the internal friction via friction plates, tapered roller bearings and better seal rings. The damping capabilities of the transmission were enhanced aiming to absorb more engine irregularities and to improve the vehicle's overall NVH behavior.

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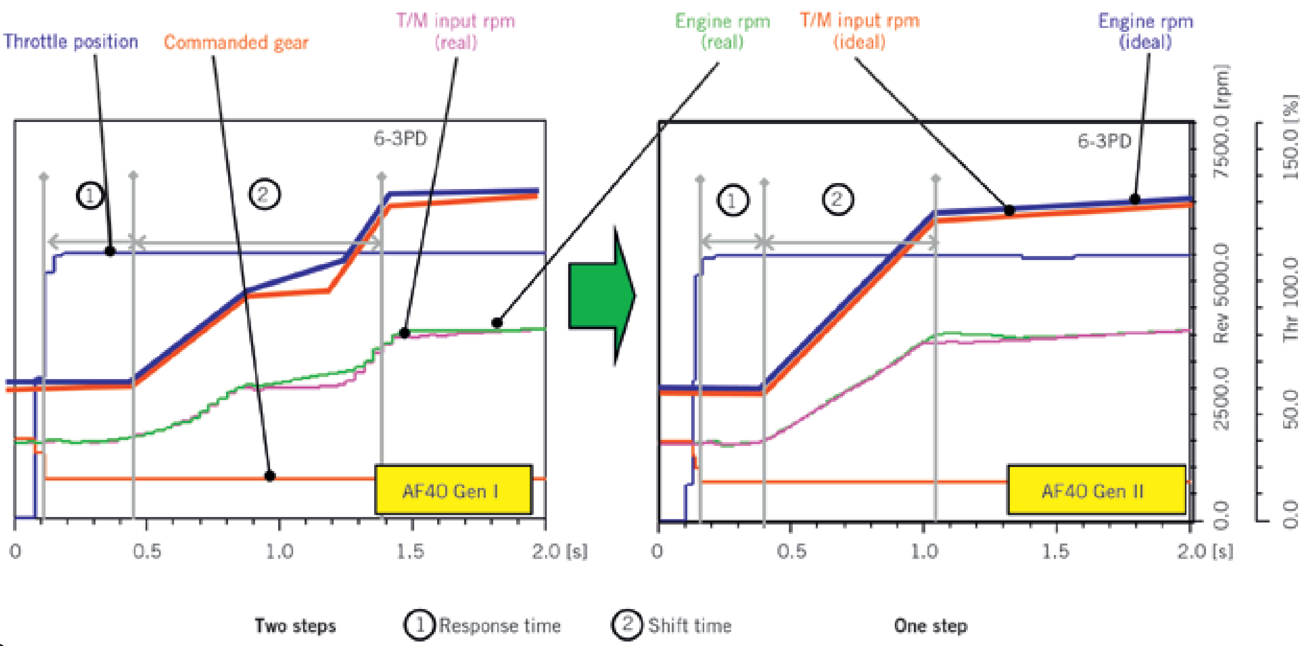

❻ Time diagram for shift comfort improvement by eliminating the two-step response behavior with the new transmission

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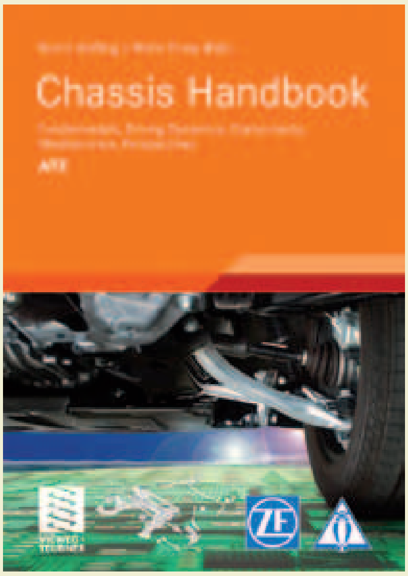

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Chassis Handbook

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ADVANTAGES OF THE FORGING PROCESS

Gears are frequently used geometrical elements in cars. They find application primarily in the transmission (gearwheels and planet gears) and in the powertrain (torque transmission shaft/hub, multi-disk clutches). Due to their complex geometry, production of these elements requires high levels of production engineering efforts and is thus costly.

The high cost-efficiency of forging processes renders the manufacture of ready-for-assembly gears less expensive. Even the production of gears with near-net-shape geometry using forging operations holds the potential of decreasing the overall production costs.

In this article, Hirschvogel outlines the possibilities of manufacturing gears through forging production processes [1] using various examples from series production as well as from development. Besides cost savings, these cases also reveal additional technical advantages, such as a reduction in the assembly length (geometrical restrictions of cutting tools do not apply), monoblock designs and manufacture of geometries that cannot be produced by machining (accessibility, gears in blind holes). From the entire spectrum of forging (hot, warm and cold forging) and of machining, these examples reveal how various types of cost-saving potential may be tapped and technical advantages exploited.

One principal task of gears lies in transferring speed and torque in the form of gearwheels from one shaft to the other and transforming them at the same time. Another important area of application for gears lies in the group of splines. In most transmissions, splines are more frequently used than gearwheels. The task of this machine element is to transfer torque on the same shaft. The fixed gearwheels of a transmission, for example, are connected to the shaft via splines. A further area of application for splines is the powertrain, for example the shaft ends of constant velocity joints, wheel hubs of driven wheels, connection elements of the drive shaft, etc. Producing these gears by means of forging represents a particularly cost-efficient process with technical advantages that will be outlined below.

FORGING FUNDAMENTALS

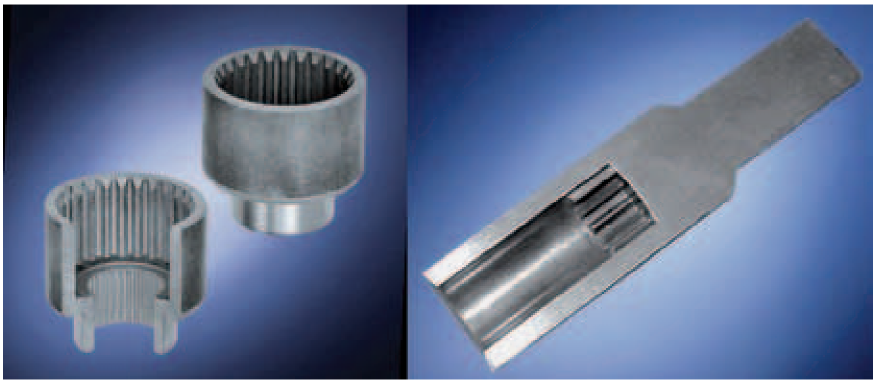
Forging is an extremely economical process for producing complex components in large volumes at minimum cycle times. Furthermore, forging processes are characterized by high material utilization as well as favorable mechanical material properties in the manufactured parts, particularly when these are subjected to dynamic load.

A significant differentiating factor between the various forging processes is the temperature of the billets at the start of the process. When hot forging steel, the metal is heated to temperatures of over 1200 °C. This decreases the force required and increases deformability. During cold forging, the billet has room temperature at the start of forging. As no shrinkage or scale formation occurs, cold forged parts demonstrate greater geometrical and dimensional accuracy than comparable hot forged parts. However, compared to hot forging, the deformability of cold forged parts is limited. When warm forging steel, temperatures between 600 to around 900 °C are required. The goal of warm forging is to combine the benefits of cold and hot forging.

METAL-FORMING PROCESS OF GEARS

The current precision requirements demanded of splines lie in the quality range of between 8 and 9 (according to DIN 5480). This can be achieved using state-of-the-art forging. In order to further increase accuracy when forging gears, optimum conditions must prevail prior to the forging process. This may be achieved by intermediate machining, for example. This eliminates any volume fluctuations caused by upstream processes that may otherwise have a negative impact on the quality of the gears.

Taking the overall quality of the gears into account, quality 7 (according to DIN 5480) currently represents the best that may be achieved reliably on an industrial scale. The precision of the tools needed is two or three quality classes better than the gears of the finished part. Some individual characteristics of the gears, for example the pitch, are transferred by the tools to the workpiece almost identically during the forging process, enabling indi-



❶ Output flange and sliding shaft

❷ Disk carrier

vidual deviations in the range of quality 5 to be achieved. It is highly important, therefore, to adapt the gear quality to the component function. In some cases, it is advisable to deviate somewhat from the rigid standard and to consciously shift from considerations of individual tolerances towards functional relevance in order to generate optimum components with respect to task fulfillment and costs.

Which type of forging is used for producing gears depends greatly on the part itself. By combining hot and cold forging processes, both complex geometries as well as the required accuracy may be achieved, for example through downstream cold forging of the gears. Savings potential arises if investments in costly gear milling machines are dispensed with, or if producing the gears by means of cutting processes involves disproportionate amounts of effort or requires special processes. Geometrically favorable designs that may be generated by means of forging can also bring about cost savings through the production of smaller parts.

PRACTICAL EXAMPLE 1 – SPLINES

While shafts are usually provided with external teeth on the shaft end, hubs normally have internal teeth introduced during a broaching process. The teeth must have good accessibility from both sides. If splines need to be produced in blind holes, a costly slotting process is often unavoidable, as broaching is not an option due to lack of accessibility. Here, forging can offer an alternative that is advantageous from both a quality and a cost perspective as the following examples show.

The output flange, ❶, has splines which extend to the base plane of the component without a transitional geometry. Such a design is not economically feasible using cutting processes. The sliding shaft with internal teeth on the cup floor is produced in a three-stage cold forging process. As the nature of this production method results in practically no inlet and outlet geometries, the total height of the splines can be used. Both the splines and the adjoining cup are produced entirely by means of forging, leading to a very high level of material utilization. This represents an additional benefit in the face of an ever scarcer supply of resources.

The absolute size of forged splines has no effect on the production speed, ❷. Both the large internal as well as the small external splines were produced by means of forging. A combination of warm and cold forging plus machining allows the ready-for-assembly manufacture of this part. Whereas the smaller shaft splines need to be induction hardened due to the small diameter, this process step may be omitted for the larger splines in the cup. In spite of high local compressive loads due to the thin clutch disks, the strain hardening from the forging process is sufficient. The disk carrier is assembled as a central component in a transfer clutch, which is responsible for the torque balance between the front and rear axle.

The production of splines by means of forging means that inlet and outlet zones are eliminated, leading to a significant shortening of the part. The example link shaft in ❸ shows a connecting part that was shortened in length by approximately 25 % by switching from milling to forging. The use of a forging process even allowed the possible load to be increased. The preform of this part is generated in a multiple stage warm forging process followed by the production of the ready-for-assembly splines using cold forging.

❸ Link shaft

❹ Parts with face gears (Hirth joint)

	REDUCTION OF WEIGHT RAW/FINISHED	SAVING OF SPACE/ LENGTH
OUTPUT FLANGE	≈ 20 % / –	≈ 11 %
SLIDING SHAFT	≈ 15 % / –	–
LINK SHAFT	≈ 20 % / ≈ 14 %	≈ 25 %
FACE GEARS	≈ 10 – 20 % / ≈ 15 %	≈ 10 – 20 %
NEAR NET SHAPED GEARS	≈ 8,5 % / –	–

❺ Percentage savings for running gears as well as the other gear types

PRACTICAL EXAMPLE 2 – HIRTH JOINT

Face gears allow maximum torques to be transmitted across a minimum amount of space. Radial connection of the teeth, ❹ Centre, even increases this potential further. This is also known as a Hirth joint and has been recognized for a long time. One reason that has so far prevented wider use of this geometrical element lies in the production costs. Producing the Hirth joint in sufficient volumes by means of forging now opens up the possibility of large-scale industrial application.

With Hirth joints produced by machining, the teeth always need to protrude above the neighboring geometries. When forging these joints, the teeth may be located almost anywhere. The teeth of a part that tends to be weaker may be designed in a more stable way through radial connection of the teeth, for example. Even the forming of the tooth flank angle which, up to now, usually amounted to 60°, is barely subject to limitation. Crowning in both an axial as well as a radial direction is also possible if required.

PRACTICAL EXAMPLE 3 – RUNNING GEARS

Pre-forged running gears with complex geometry also hold cost-savings potential with respect to material and thus resources. ❺ shows the percentage savings for running gears as well as the other gear types. Due to using less material, the essential cutting volume is reduced. This has a positive effect on working time and tooling waste. Pre-forged gears have a little bit higher cost but can be integrated in the raw part.

Differential bevel gears that rotate slowly can be produced with ready-for-assembly forged running teeth today, as noise problems here are almost non-existent. Due to their high rotational speed, normal running gears have quality requirements that may usually only be met by means of grinding, honing or lapping.

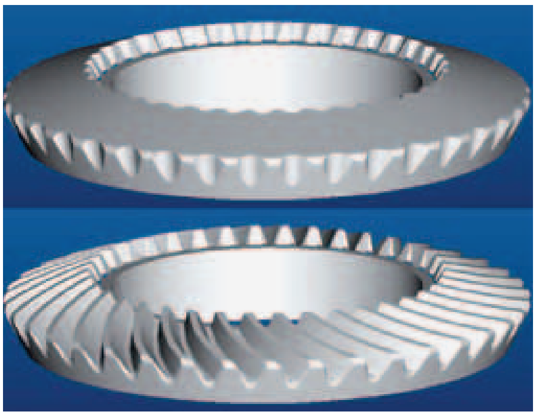
PRACTICAL EXAMPLE 4 – NO BURRS

However, producing running gears by means of machining is problematic due to the generation of burr or sharp edges. For this reason, usually great efforts are made in an additional operation to chamfer the edges generated during machining. Using a new concept for producing chamfers at crown gears, ❻, this costly process step may be omitted. As the chamfers need to fulfill considerably fewer requirements than the tooth flanks, these may be produced by means of forging. The machine tool then no longer exits in the original end faces of the tooth gaps, but rather in the preforged chamfers.

This minimizes or even prevents burr formation. Introducing the chamfers by means of forging is much more cost-efficient than a subsequent mechanical removal process. Apart from the initial alignment of the rotational position during soft machining, the existing production concept does not need to undergo any changes.

CONCLUSION

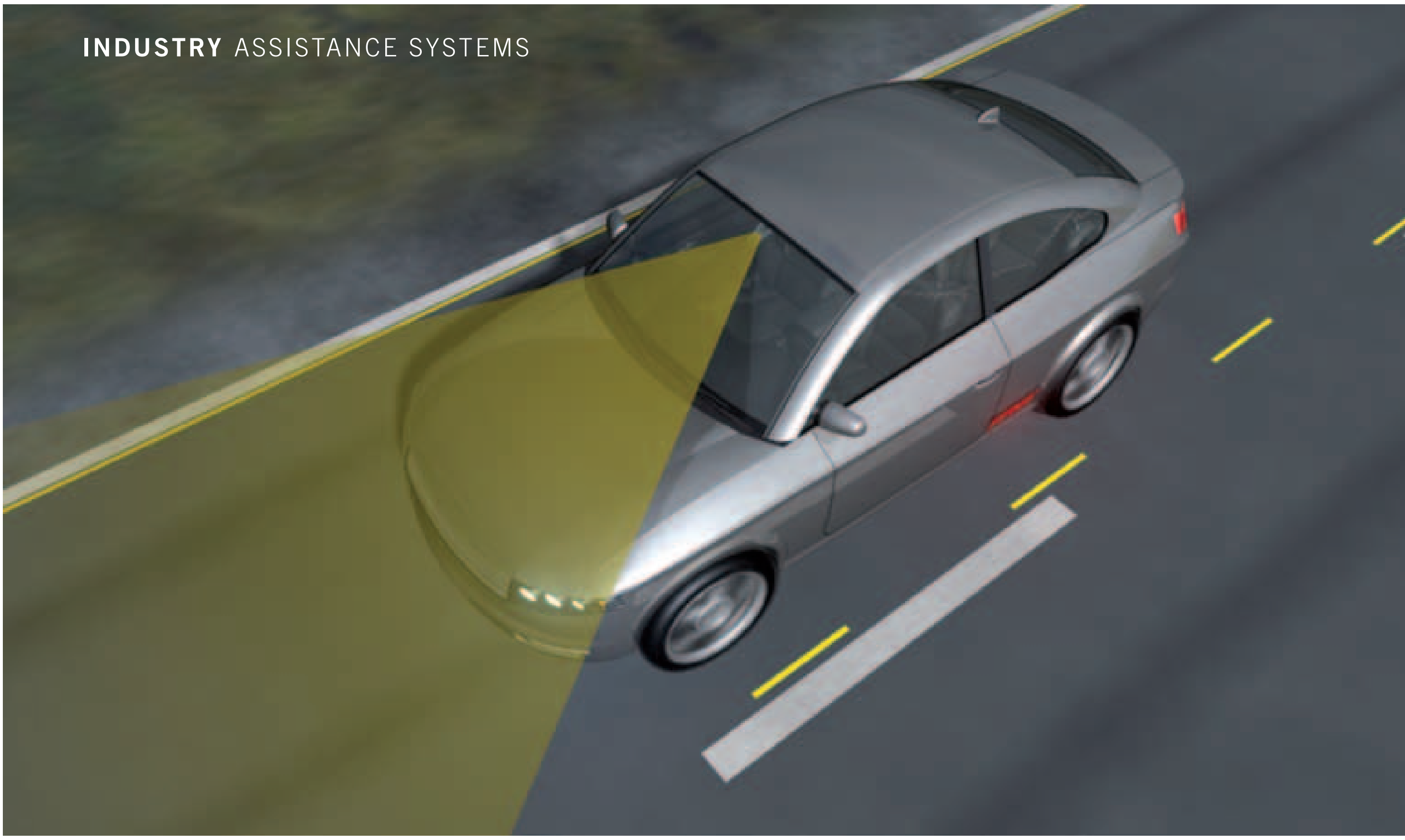
Forged splines and gears offer a lot of opportunities. It is possible to produce parts more economically, with optimised design or with higher fatigue life. For this customer and forging manufacturer need to cooperate closely. An early interaction in the product development process is beneficial for both sides.



❻ Crown gear with pressed chamfers

REFERENCE

[1] Raedt, H.-W.: Hochleistungsbauteile aus massivumgeformten Werkstoffen. In: ATZ 108 (2006), Nr. 9, S. 732 – 737



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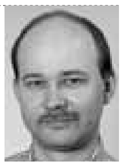

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INTRODUCTION

Automotive manufacturers are increasingly focusing on equipping vehicles with new and more sophisticated driver assist systems – supported by a raft of technologies based on proximity sensors, radar, laser-based lidar and the CMOS (Complementary Metal Oxide Semiconductor) camera. Of all these sensors, the camera is perhaps the most versatile because unlike to radar it can detect and classify a wide range of relevant "objects". Because of its multi-tasking capability, the CMOS video camera is of particular interest for vehicle manufacturers.

TRW's earlier T-CAM – which is currently in production on the Lancia Delta – is already established in the areas of lane keeping. It activates audible or visual warnings to prevent inadvertent lane changes or departures, and when integrated with electric power steering (EPS), can provide discreet inputs (torque overlay) via the steering wheel to guide the vehicle back towards the center of the lane. These functions are being continually improved. In the case of lane departure warning, a lane keeping function has evolved, while the high/low beam assistant is developing from one that simply switched the headlights between main beam and dipped, to one that offers a "staged" control. Vehicle manufacturers also use a forward-looking camera to support radar-based functions such as adaptive cruise control (ACC); city driving ACC Stop-and-Go systems; collision warning; and collision mitigation. Traffic sign recognition as well as video-based pedestrian safety functions that work in conjunction with radar sensors are also fast-expanding areas of development. These trends are gaining momentum due to their recognition by important vehicle test organizations such as Euro NCAP, which has launched awards to recognize the performance of active safety systems. Legislation is having an influence on the continuous development of driver assist systems, too. To fulfill current and future requirements for advanced video sensing, the engineers of "Driver Assist Systems" and "Integrated Active & Passive Safety Technologies" at TRW have developed a scalable camera with improved performance, the so called S-Cam. The highly integrated and compact sensor, ❶, is able to detect vehicles (by day and night), lanes, traffic signs, and pedestrians – enabling the vehicle manufacturers to offer features such as collision warning, lane departure warning, lane keeping, traffic sign indication, high/low beam, gliding light assistance and pedestrian safety function with one single unit.

"ALL-IN-ONE" – VIDEO-BASED DRIVER ASSISTANCE SYSTEMS

TRW has developed a new scalable and compact camera. The so called S-Cam is able to see and interpret what is happening on the road ahead of a vehicle more effectively than preceding systems. As a single component, it supports OEMs with an array of safety and driver assist functions, for example collision and lane departure warning, lane keeping, traffic sign indication, high/low beam, gliding light assistance as well as pedestrian safety functions.

DESIGN REQUIREMENTS

In order to deliver a wide range of customer functions, the new video camera sensor had to be capable of detecting, classifying and localizing objects to a high degree of accuracy and reliability. These include: lanes, light-emitting objects such as tail lights and headlights, road signs, vehicles and pedestrians (stationary or moving). Additionally the sensor needed to be as compact as possible to accommodate its ideal forward-looking mounting position – behind the windscreen near the rear-view mirror. The camera also had to deliver its many functions as cost-effectively as possible. In addition to all detection functions, all customer functions had to be integrated into a single module – in other words, a one-box solution. Another requirement was the easy mounting and dismounting during car manufacture, servicing or windscreen replacement. This impacts on the mechanical connection requirements and also means that camera calibration procedure must be exact, fast and as straightforward as possible.

SCALABLE S-CAM SOLUTION

With the newly developed scalable camera, TRW has developed a sensor meeting the most common requirements of vehicle manufacturers, ❷. At the heart of the system are the EyeQ2 chip with algorithms from the company Mobileye, and a customer-specific microprocessor. A magnesium housing provides both structural integrity and a sufficient heat sink to dissipate waste heat produced by the microprocessors and sunlight loading. The camera itself is a wide VGA (752 x 480 pixel) CMOS imager. Three out of four pixels are "clear", measuring pure light intensity independent of color while the fourth "red" pixel measures only the red component of the incident light. This so-called RCCC imager combines the advantages of a pure black-and white-imager – higher resolution and higher sensitivity – with the benefit of being able to distinguish the red channel. This helps to differentiate tail lights from white reflectors and it enables the camera to distinguish between, for example, the "speed limit 80" and the "highway exit number 80". Combined anti-reflective coatings minimize the effect of stray lights.

Two CAN controllers can be installed. Typically one is connected to the vehicle CAN to obtain specific information like host vehicle speed, yaw rate and the state of indicators, brakes, wipers, headlights and so on while also communicating with the vehicle's human machine interface

❶ TRW S-Cam: multifunctional sensor supporting an array of driver assistance and safety functions in a single unit

PARAMETER	VALUE
FIELD OF VIEW (DETECTION AREA)	42 ° horizontal, 27 ° vertical
IMAGER SIZE	752 x 480 pixel
VELOCITY RANGE	Up to 250 kph
UPDATE RATE	13,8 Hz (with 4 exposures)
POWER CONSUMPTION	3.50 W
MODULE WEIGHT	74 g
PACKAGING SPACE REQUIRED (CAMERA + BRACKET)	X – (fore/aft) 110 mm Y – (cross car) 60 mm Z – (up/down) 36 mm
OPERATING TEMPERATURE	-40 to +85 °C (+105 °C for CAN communication only)

❷ Key features of S-Cam

❸ PCB of S-Cam

(HMI). The second CAN interfaces exclusively with the radar sensor, if fitted, for high order data fusion in the radar.

The S-Cam is totally scalable with respect to the software modules which are executed on the EyeQ2 chip. At the moment the scalability of the hardware is restricted to the RAM and ROM modules used on the printed circuit board (PCB). The full software bundle requires the PCB, ❸ and ❹, to be equipped with 128 MB of SDRAM (Synchronous Dynamic Random Access Memory) and either 8 or 16 MB of flash memory. The second microprocessor is Autosar compliant and dedicated to the basic software modules like CAN communication and diagnosis as well as customer specific functions and HMI modules. Besides customer specific functions such as lane keeping control, pedestrian detection, and collision warning, it offers OEMs the opportunity to integrate their own application code so that their interfaces have a unique look and feel.

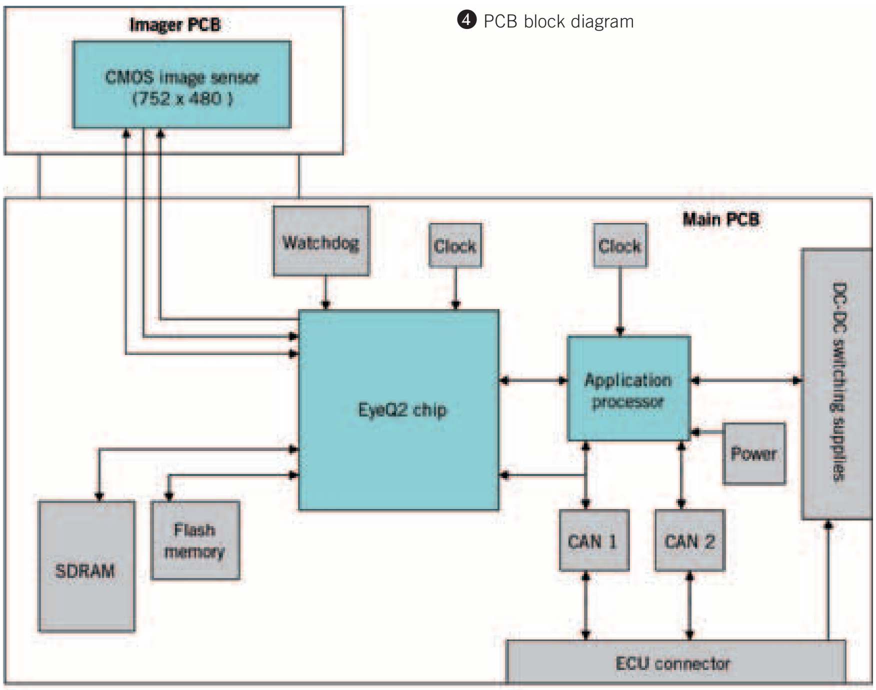
The EyeQ2 architecture consists of two floating point and hyper-thread 32 bit RISC CPUs (Central Processing Units). Based on its architecture the camera is able to perform intensive vision computations needed for functions and applications.

The assembly process of the S-Cam is easy and robust, ❺. The assembly is attached to the windscreen by a plastic bracket which is pre-bonded to the glass, using polyurethane (PU) adhesives. The camera module is snapped into this bracket, ❻, leaving a small but important gap between it and the glass. This ensures that there is some air flow in the area, ❼, so that any moisture that could affect the functionality of the camera is quickly removed by the heating and ventilating system. TRW carried out extensive airflow simulations to optimize the air flow.

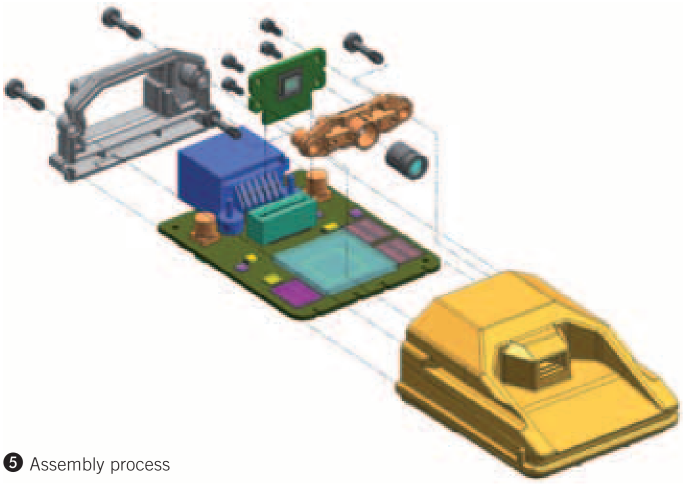
APPLICATION POTENTIAL

S-Cam builds on the capabilities of its predecessor. The lane-keeping algorithm is able to detect every kind of lane markings used whether they are solid, single, double or triple; or colored white, yellow or blue. Even dots and road edges, including grass verges, can be detected. This capability massively enhances the camera's capability in the application of lane departure warning systems, lane keeping and guidance systems. At night, the new camera is able to detect and classify objects from an analysis of their lights. It differentiates oncoming vehicles; transport traveling in the same direction; reflectors located around the road; and can tell whether the vehicle is in an urban area by detecting street lamps and other types of ambient light. S-Cam also keeps pace with advanced headlamp design, supporting actuation of complex beam patterns and graduated high-low beam control.

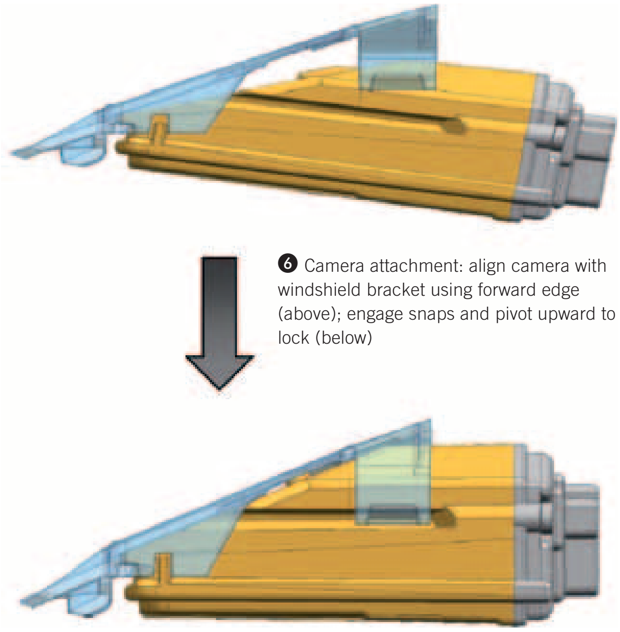
All motorized vehicles can be detected together with accompanying data – distance; lateral offset; position in angle; vehicle width; speed; acceleration; class



❹ PCB block diagram



❺ Assembly process

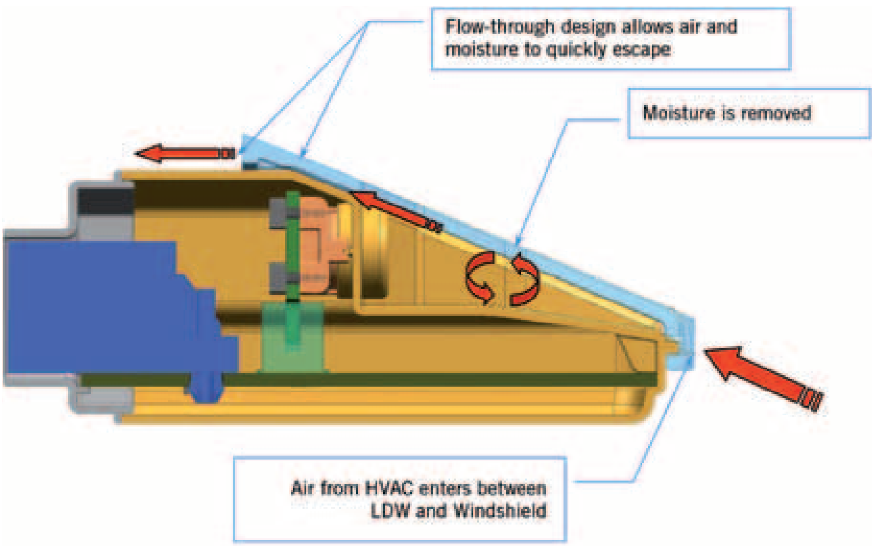


❻ Camera attachment: align camera with windshield bracket using forward edge (above); engage snaps and pivot upward to lock (below)

(car, motorcycle, truck); time-to-collision (TTC); and status of brake, indicator and hazard lights. The guaranteed detection range for cars is 90 m but, in reality, is 130 to 150 m. Due to their narrower width the detection range for motorcycles is 40 to 60 m. By combining the advantages of a video based sensor with the performance of a radar sensor through data fusion, vehicle manufactures are able to provide forward collision warning, collision mitigation braking and full emergency braking systems to further improve vehicle safety. While radar is precise in its measurement of distances and relatives speeds, the video camera is precise in determining an object's lateral position. Together these sensors are able to deliver the required precision for an automatic emergency braking although the camera is able to estimate the distance to the vehicle ahead. This is why the S-Cam is able to provide the less critical functionality of forward collision warning together with a distance warning.

Detection and recognition of traffic signs is mainly based on those specified by the Vienna Convention [1], but US and Arabic speed signs are also integrated into the system. Greater robustness in poor weather conditions, difficult light levels and world wide local differences in signage has been integrated. Ongoing development will lead to recognition of additional signs including: stop, no passing, city entrance, freeway entrance and end of freeway. Higher resolution images will also allow sub texts to be read – for example, the times when a speed limit is in operation.

Children and adults, both walking and standing, can also be detected. S-Cam's designers have put a lot of effort into this area and the capability now includes bicycles crossing the vehicle's path as an additional class of "pedestrian". Optical flow calculations are currently in development at TRW which – basically – allow the system to recognize whether any kind of object has entered a specific area in front of the vehicle.



❼ Air flow concept in order to remove possible moisture in front of the camera

SUMMARY

With its new camera, TRW has developed a high performance sensor that is the smallest and most compact unit on the market. Its ability to detect and classify a very wide range of objects – and the subsequent broad customer functions that this allows – should satisfy the requirements of vehicle manufacturers. As a single component, it supports an array of functions which – in the near future – will be delivering higher levels of comfort and safety to a growing number of vehicle platforms.

REFERENCE

[1] Economic Commission for Europe: Convention on Road Signs and Signals. Vienna, 1968

GEAR SHIFTS AS SITUATION ADAPTED PRE-WARNING OF THE DRIVER

In a research project, BMW Group Research and Technology, Universität Duisburg-Essen and Technische Universität München try out a novel pre-warning concept for emergency braking systems. A downshift is initiated in the automatic transmission as soon as the warning time is reached. The resulting jerk attracts the attention of distracted drivers without irritating overtaking drivers that are aware of the situation. Additionally, the overtaking driver takes advantage of the higher engine torque within the lower gear.

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EMERGENCY BRAKING SYSTEMS – CHALLENGE AND STATE OF THE ART

Present-day driver assistance systems are able to avoid an imminent collision by actively triggering the brakes. The required distance for this braking maneuver increases as a quadratic function of the relative speed between the ego vehicle and the potential collision object. Compared to this braking distance, there is only a linear relation between relative speed and the required distance for a close overtaking maneuver. This means that going beyond a relative speed of around 40 km/h, overtaking is still possible after having passed the last moment for a collision-avoiding braking maneuver [1].

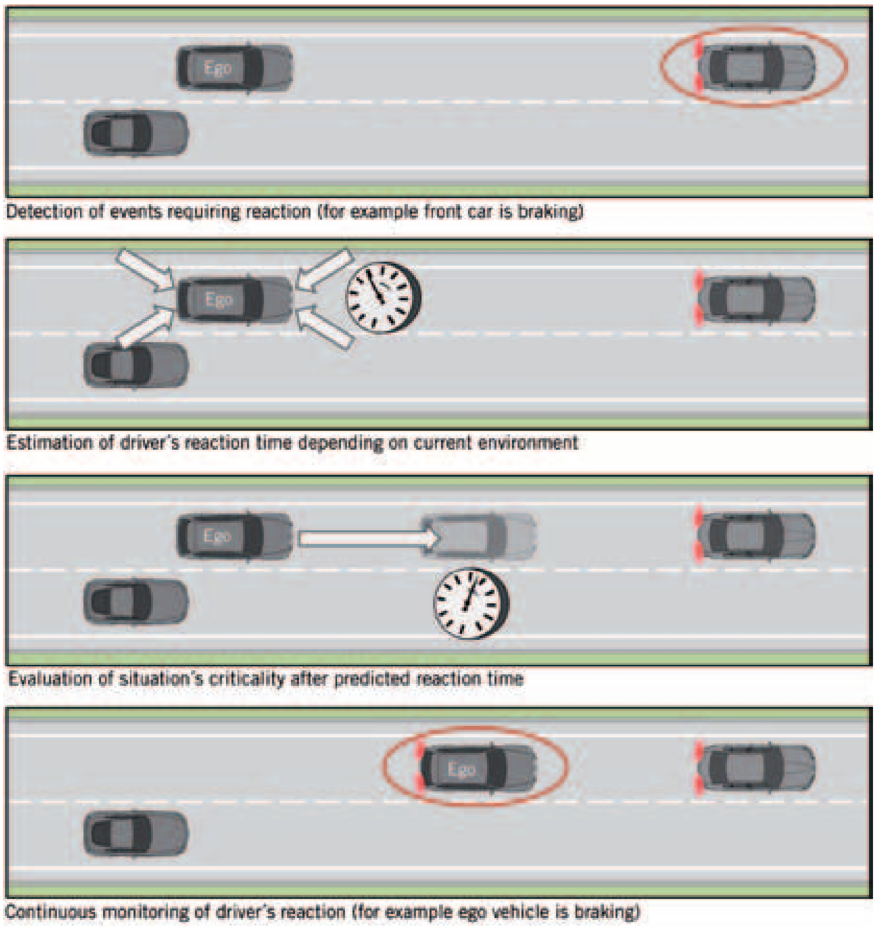
This so-called dilemma of intervention causes a trade-off between collision avoidance and collision mitigation when specifying the system's parameters. Though the collision is avoided if the system initiates full braking at reaching the required braking distance, a driver who has planned a close overtaking maneuver will be surprised by the intervention. For safety reasons, current serial systems are therefore typically specified to only initiate braking when reaching a time range where the driver cannot resolve the situation by braking or overtaking on his own ("point of no return"). That means that at higher relative speeds a collision's effects can only be mitigated – the collision itself however cannot be avoided.

At BMW Group Research and Technology, an emergency braking system has been developed in a project that integrates a driver model into the system algorithm. In certain situations, this allows an earlier conclusion about the driver's state of attentiveness, see four phases in ❶. For this purpose, the driving situation is analyzed at an early stage in terms of possible events that require a driver's reaction – for example a cut-in vehicle or a sudden braking maneuver of the preceding vehicle. The autonomous braking is neglected in case the driver reacts within his statistically maximum reaction boundaries. If an adequate amount of time has elapsed and still no driver reaction is visible or alternatively if there is not enough time for an appropriate reaction, the autonomous braking maneuver can be activated [2].

NEED FOR A SITUATION ADAPTED DRIVER WARNING

By shifting the brake timing to an earlier point of time with the objective to achieve collision avoidance also at higher relative speeds, as exemplified, also an earlier timing for a driver warning that has to be triggered some time before the automatic braking results. At this point, information about the driver's intention and attentiveness gets even vaguer. The respective warning dilemma states that a driver warning is more effective the earlier it occurs, but at the same time the rate of false alarms will increase.

Driver warnings already in series production (optical/acoustical warning, haptical brake jerk or light braking) are mainly designed to support distracted drivers that are not (yet) aware of the dangerous situation. Due to the braking at higher relative speeds for collision avoidance and the attending earlier warning, drivers that merely plan to overtake have to be taken more into account. For those drivers, however, the existing warning methods mentioned above appear to be rather irritating or even endangering. In any case, they offer a minor pardonableness in case of a false activa-



❶ Mode of operation of the emergency braking system in four phases

tion. Therefore, the goal of a novel driver warning is to warn distracted drivers without irritating overtaking drivers.

GEARSHIFT JERK AS DRIVER WARNING

The driver pre-warning presented here uses the resulting jerk from downshifting as haptical feedback to the driver, see also [3]. Thus, the attention of the distracted driver while approaching a possible collision object is attracted and he is therefore warned, while at the same time the overtaking driver derives advantage from the downshift. Higher engine torques within the lower gear facilitate the required acceleration for an overtaking maneuver. The subjective faulty activation is therefore transformed into an assistance action.

Additionally, a series of other advantages accrues: The jerk from downshifting activates the kinesthetic-vestibular sensory channel that addresses the equilibrium sense and the kinesthesia. This channel shows the lowest perception delays which results in a shorter reaction time compared to an optical or acoustical warning [4]. With an increasing engine speed within the lower gear and a therefore increasing sound level in the vehicle interior, also the acoustical sensory channel is activated without using audio warnings.

Also a driver assistance system's requirement to not compromise the driver [4] in front of his passengers is fulfilled by the downshift. An obvious driver warning could be interpreted as imminent danger that jeopardizes the passengers' safety and should be avoided. In comparison to an audio warning or a hard brake jerk, the shift jerk remains rather imperceptible for the passengers.

TECHNICAL REALIZATION

Goal of the technical realization is the generation of a reproducible and parameterizable jerk from downshifting. As the resulting jerk depends on the initial gear and the engine speed when shifting, its amplitude differs. For that reason, the jerk is amplified by a supplemental synchronal application of the vehicle's brakes.

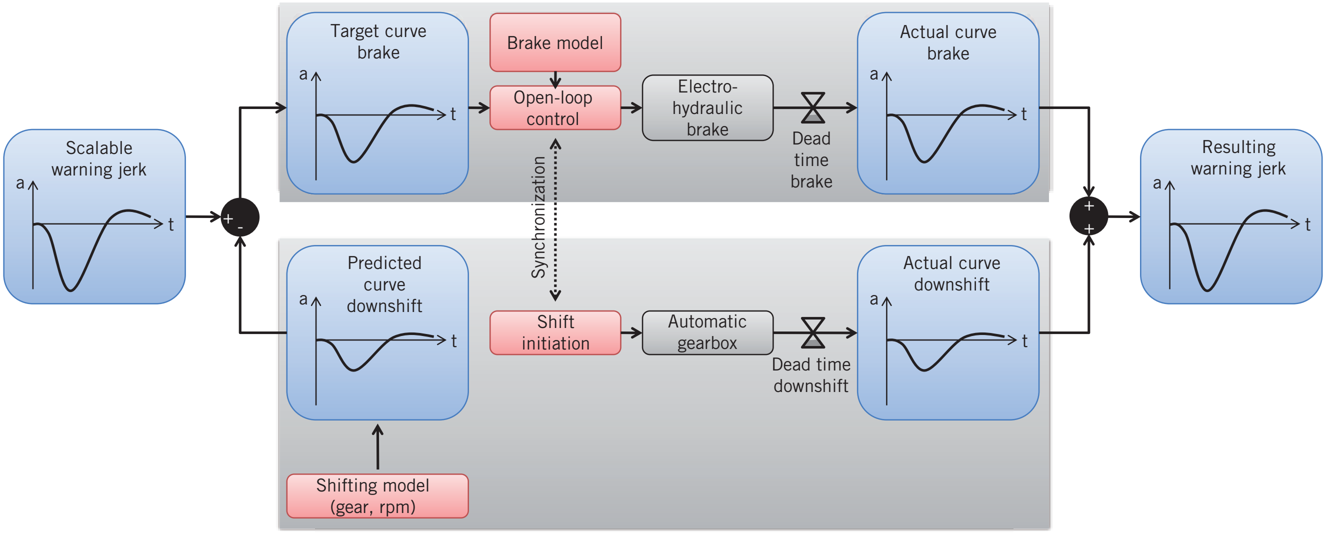
The complete system is therefore composed of a brake-side and a transmission-side component. To determine the target curve for the electro-hydraulic brake, it is necessary to predict the longitudinal acceleration resulting from a downshift during constant movement that depends on the initial gear and the initial engine speed. The predicted jerk is then subtracted from the desired scalable jerk and the brake target curve results. As the two components have different dead times, a synchronization of the brake and the shift initiation makes sure that the overlay of the actual curves results in the desired jerk. The complete warning system is shown in ❷.

SHIFTING MODEL FOR DECELERATION PREDICTION

❸ shows the characteristic curve of the longitudinal acceleration during a downshift. For eliminating high-frequency stimuli from the road surface, the curve is low-pass filtered. The two slopes – first plunging down and quickly switching over to ascending, even above the zero level – are typical. Finally, the acceleration returns slowly to its point of origin.

The step response of a mass-spring-damper system (MSD system) is used as substituted mechanical system for modeling the given curve. The MSD system is uniquely defined by the three coefficients mass m, spring constant c and damping coefficient d. From these values the system's oscillation period T, as well as the damping ratio δ, can be calculated.

The step response essentially depends on the damping ratio δ. If it remains below one, overshoots appear; with values greater than one the system does not reach its final position. For $\delta = 1$ however (aperiodic borderline case), the curve approaches asymptotically the final value and has no harmonic content. Due to these transparent characteristics, the aperiodic borderline case is used for modeling the downshift curve. The equation for the step response thus only depends on the two parameters oscillation period T and excitation amplitude K as well as on the time t:



❷ Scheme of technical realization of the warning system

EQ. 1

$$g_{step}(t) = K \cdot \left(1 - e^{-\frac{t}{T}} \cdot \left(1 + \frac{t}{T}\right)\right)$$

As a single step response can only describe the first part of the deceleration down to the minimum, the substituted mechanical system is induced by a set of three different and time-shifted steps for reproducing the entire curve shape. The first and the third step are oriented in negative direction in order to map the two falling slopes. To achieve the regression to the zero level, the three excitation amplitudes' sum needs to be zero:

EQ. 2

$$\Sigma_{i=1}^{3} K_i = 0$$

To describe the temporal offset of the subfunctions and thus the dead time $t_{T,i}$ until their "activation" mathematically, the Heaviside function $\theta(x)$ is used. In summary, by using the functional equation of a MSD system activated by three time-shifted steps, the following equation for the car's deceleration during a downshift results:

EQ. 3

$$a_{downshift}(t) = \Sigma_{i=1}^{3} -K_i \cdot \theta\,(t - t_{T,i}) \cdot \left(1 - e^{-\frac{t-t_{T,i}}{T}} \cdot \left(1 + \frac{t-t_{T,i}}{T}\right)\right)$$

As the established equation should describe the course of any possible deceleration curve from downshifting, the free parameters K_1, K_2, $t_{T,1}$, $t_{T,2}$, $t_{T,3}$ and T need to be a function of the engine speed n. A linear variation leads to the following system of equations:

EQ. 4

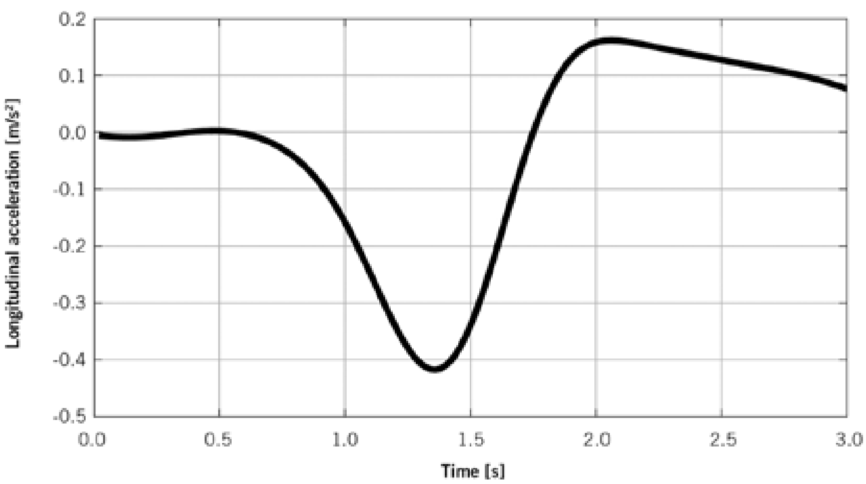
$$\begin{pmatrix} t_{T,1} \\ t_{T,2} \\ t_{T,3} \\ T \\ K_1 \\ K_2 \end{pmatrix} = \begin{pmatrix} p_1 \\ p_2 \\ p_2 \\ p_3 \\ p_4 \\ p_5 \end{pmatrix} \cdot n + \begin{pmatrix} p_6 \\ p_7 \\ p_8 \\ p_9 \\ p_{10} \\ p_{11} \end{pmatrix}$$

After fitting the resulting eleven parameters p_i to the original deceleration curves by a least-square optimization, a continuous description of the downshifts within one gear is possible. In a six-speed automatic transmission with five possible downshifts, 55 parameters describe the complete mathematical model of all single downshifts of the transmission.

CONCLUSION

The development of driver warnings for emergency braking systems is challenging due to the fact that by shifting the warning timing to an earlier stage their efficiency increases while at the same time the rate of false alarms grows larger – especially for drivers that merely plan to overtake and close in on the preceding vehicle.

For resolving this dilemma, this project at BMW Group Research and Technology presented a new approach that warns the distracted driver as well as supports the



❸ Characteristic curve of longitudinal acceleration during a transmission downshift overtaking driver without knowing the explicit driver intention. For that purpose, a downshift is triggered within the automatic transmission and the resulting jerk is used as haptical warning. At the same time, the overtaking driver takes advantage of higher engine torques provided within the lower gear.

Further empirical research studies will show the concept's acceptance in real traffic. Also the optimal jerk's "hardness" as well as the best activation timing depending on the current driving situation and environment will have to be determined.

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SEALING OF TRANSMISSION PISTONS WITH PTFE FOR INCREASED GEAR SHIFT COMFORT

Gear shift comfort is, next to a higher degree of efficiency, one of the main goals in the development of modern automatic and double clutch transmissions. Until now, the crux of the matter had always been the sealing application for the transmission piston. Freudenberg has now successfully developed a way to enhance a transmission piston seal through the integration of a PTFE layer. Using this new sealing, called Torque Control Seal (TCS), can significantly reduce all previous disadvantages caused by friction such as break-away force, non-linear behaviour or hysteresis.

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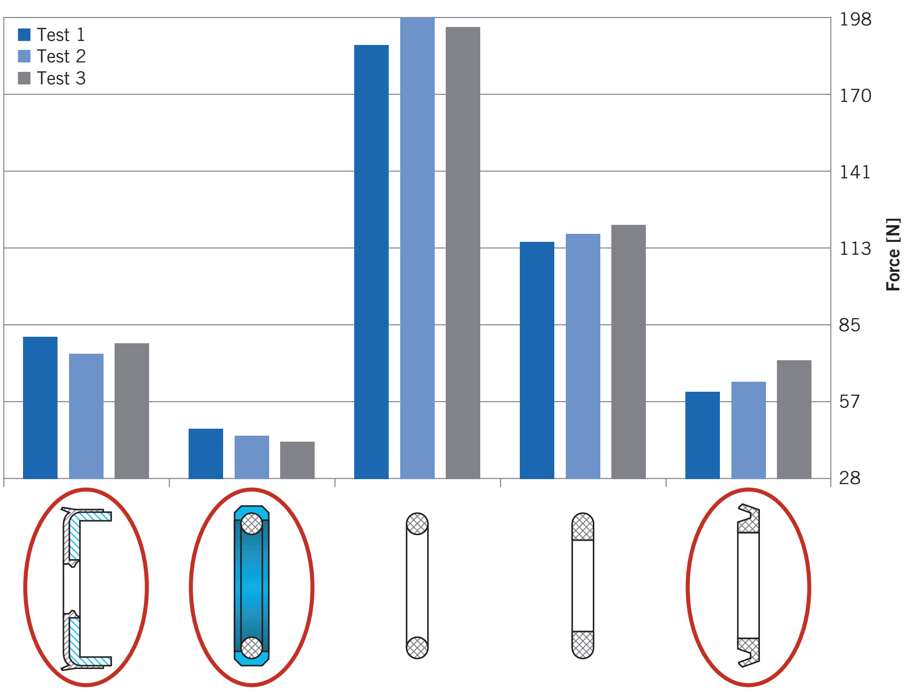
FRICTION BEHAVIOUR PREVENTED PRODUCT IMPROVEMENTS

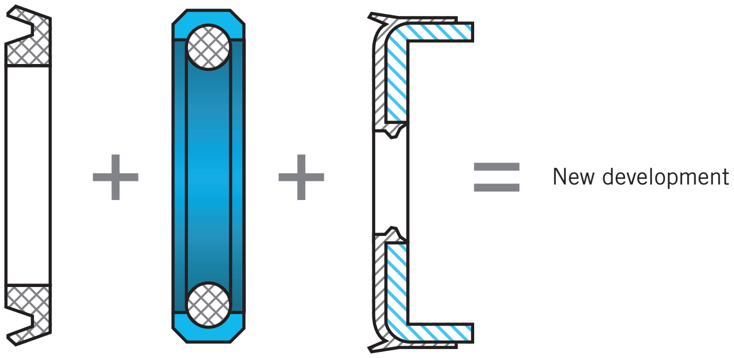
Hydraulic transmission pistons have been part of transmission technology for decades. Efforts to achieve higher gear shift comfort and optimal performance have usually been hampered by the complex friction behaviour of transmission piston seals. This friction behaviour is influenced by many parameters due to the fact that the performance of rubber as a sealing material varies with temperature and with different lubricants and stroke forces, resulting in non-linear friction values of the transmission piston. There are also other factors, such as break-away force, stick-slip effects and hysteresis between operating and return stroke of the piston, which have so far prevented a precise shifting of gears which can be repeated over millions of shift cycles. These complex friction characteristics make is necessary to find compromises for the application and for the design of the shift strategy and have therefore presented serious additional obstacles for improvements in comfort and performance.

This is why Freudenberg has carried out a benchmark study in which it analysed different criteria such as friction behaviour, installation, packaging and cost of different transmission piston seals in detail. The examined parts were composite transmission piston seals, a combination of O-ring with PTFE slip ring, O-rings, D-rings, as well as U-packings. A comparison of friction forces is presented in ❶ for all five seal types. The combination of O-ring with PTFE slip ring showed the lowest friction values. However, its difficult assembly and unfavourable installation space requirements are both reasons why this sealing solution has not been able to compete with the composite transmission piston seal (with vulcanised sealing lip).

The basic idea behind the development of a next-generation transmission piston seal is to join the best characteristics of both current solutions in one new seal, ❷. The aim was therefore to combine the excellent friction characteristics of PTFE with the rigidity, the centring characteristics and the lip geometry, which is similar to that of a U-packing, as they are present in the current composite transmission piston



❶ Basic tests with different transmission piston seals reveal big differences in their friction behavior – the solutions, which have so far delivered the best results, are marked in red (from left to right: composite transmission piston seal, a combination of O-ring with PTFE slip ring, O-ring, D-ring, as well as a U-packing; measurements of maximum friction at 500 mm/min, 5 bar sealing pressure and 23 °C)



❷ New development: the idea behind the transmission piston seals TCS is to combine the most favourable characteristics of each of the three individual seals in a single one

seal with metal base element. The result is the new Torque Control Seal (TCS) from Freudenberg, ❸. Friction studies with sample parts of a particular type of elastomeric-metal composite with PTFE layer have shown significant improvements of sealing-related criteria such as gear shift comfort, gear shift timing, efficiency and service life.

NEW TRANSMISSION PISTON SEAL UNDER TESTING

In order to evaluate the improvement of friction reduction achieved by the new TCS seal, Freudenberg initially produced two different samples. One sample was equipped with a normal rubber seal lip, to act as a reference part for the other sample, which is geometrically identical and whose seal lip had been enhanced with a PTFE layer.

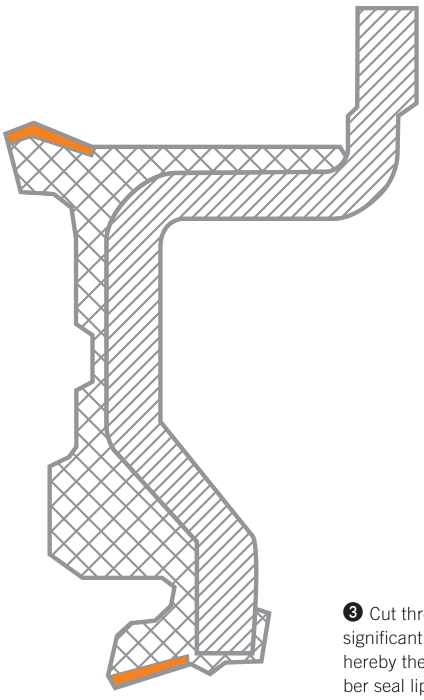
Extensive friction tests with these two samples revealed that the friction values of the TCS seal were only a fraction of those of a standard seal. A subsequent optimisation of the seal lip geometry resulted in a further reduction of friction values. The improved sample also showed only insignificant differences in breakaway force and dynamic friction. This means that it is possible to achieve a very linear dynamic behaviour.

The next step for Freudenberg was to adapt this technology to suit a real transmission piston seal and to carry out first tests with sample transmissions in cooperation with automotive and transmission manufacturers. Also in these development projects with real transmissions the first TCS samples showed excellent friction characteristics. The fact that the PTFE layer of the samples in the second test stage was merely applied onto existing transmission piston seals explains the deviations in the results between the original samples and the TCS samples. This is mainly due to the fact that the present seal lip geometry is not yet designed for the extremely short shift times it is exposed to in a real transmission. The design is currently being adapted to suit the application in order to be able to carry out further tests with real transmissions.

APPLICATION OF A PTFE LAYER ALSO FOR OTHER SEALING SOLUTIONS

The application of a PTFE layer onto an elastomeric-metal composite part is a complex process which Freudenberg has perfected over the last 15 years on a number of different sealing solutions for machine constructions. The TCS seal for transmission pistons is the first automotive application for which this method is being used in a stable manufacturing process.

The outstanding advantages of this manufacturing process make it possible to significantly reduce friction values and they also open up completely new development approaches for other transmission sealing solutions. This technology is therefore currently being transferred onto other seal designs so that friction surfaces of, for example O-rings or D-rings, can soon be enhanced by a PTFE layer. Freudenberg is thereby paving the way for seal ring other solutions in automotive industry with minimised friction to higher comfort and less fuel consumption.



❸ Cut through seal: the transmission piston seal TCS achieves significantly improved gear shift performance; key technology is hereby the combination of the PTFE layer (orange) with the rubber seal lip (checked) and the metal base element (hatched)

INTEGRATED CONCEPT FOR MANEUVER-BASED DRIVER ASSISTANCE

Can a vehicle in normal day-to-day traffic situations be conducted without continuous stabilization inputs but almost exclusively by maneuver commands? The Institute of Automotive Engineering (FZD) and the Institute of Ergonomics (IAD) of Technische Universität Darmstadt are exploring this question. To answer it, a simulation in IPG CarMaker and Matlab/Simulink is used during the DFG funded Conduct-by-Wire research project.

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CONTINUOUS AND EVENT-DISCRETE VEHICLE GUIDANCE

The conventional vehicle guidance task can be described in the form of three cascading control loops [1]: The navigation task encompasses route planning and possibly required modifications. The trajectory guidance task as a subordinate control loop includes the situation-dependent configuration of the route through the selection of suitable driving maneuvers and associated trajectories. They provide the command variables for the stabilization task that means the minimization of the difference of actual and required trajectories. It accounts for the major portion of the driver-vehicle interaction in conventional vehicle guidance and consists of continuous stabilizing inputs by means of the steering wheel and the pedals.

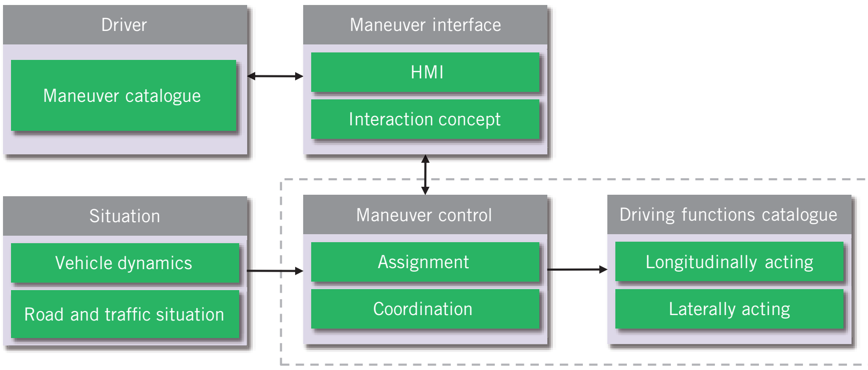
The Conduct-by-Wire approach of TU Darmstadt consists of elevating the conventional driver-vehicle interaction from the stabilization level to the guidance level. The continuous stabilization action for manual implementation of maneuvers and trajectories planned at the guidance level is replaced by event-discrete communication via a novel type of maneuver interface. By means of maneuver inputs the driver delegates the task of configuring and stabilizing the trajectories to the vehicle, influences the execution of maneuvers by parameterizations as appropriate and, if necessary, can still make stabilizing interventions.

The term maneuver interface stands for both the design of the human-machine interface and the associated interaction concept. This cooperative approach [2] relieves the driver of the stabilization task, integrates the driver, in addition to the automatic environment interpretation, as a decision-maker, continues – unlike autonomous vehicle guidance concepts – to require maneuver and route decisions and thus continues to hold the driver directly responsible in conformance to the 1968 Vienna Convention on Road Traffic.

MANEUVER COMMANDS AND EXECUTING FUNCTIONS

The maneuver commands [3] communicated by means of the maneuver interface are interpreted on the part of the vehicle by a maneuver control unit designed as a state machine and allocated to so-called driving functions for execution, ❶. The catalogue of driving functions consists of elementary, interlinkable and either longitudinally or laterally acting functions such as velocity control, preparing for reach into gap, target braking, obstacle avoidance inside lane markers, lane changes, turning and much more. At any given time exactly one pair of a longitudinally and a laterally acting driving function is active. The superordinate maneuver control unit is responsible for their selection, activation, deactivation and parameterization.

The modular structure of the functions catalogue accounts for the fact that the same maneuver command requires different executing functions, depending on the situation. A lane change, for example, may be ordered from congested into free-flowing traffic, from free-flowing traffic into a follow-on situation or into a situation in which no suitable target gap is available yet. While the driver would order the consistently identical “lane change” maneuver in this case, various functions, which



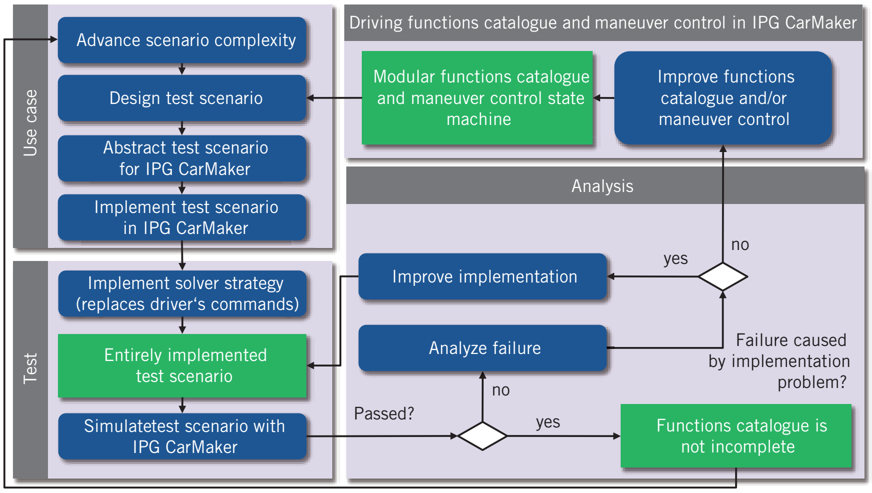
❶ Architecture overview with maneuver control and catalogue of driving functions may even change within one maneuver, in the longitudinal and the lateral dimensions are involved. Due to the dimensional separation and elementary interlinkability of its components the functions catalogue is also capable of handling complex traffic scenarios on the one hand, on the other hand it remains compact and flexible with respect to extensions and adaptations.

FUNCTIONS DEVELOPMENT FOR CONDUCT-BY-WIRE

One of the major demands made on the functions catalogue and transition controlling set of rules is completeness that means the suitability for use in any type of traffic situation. Since it is from a logical perspective not permissible to draw the conclusion of suitability in any type of scenario from a successfully completed series of traffic scenarios, the functions development process follows a falsification approach: In keeping with good scientific practice the task is to disprove the universal hypothesis of a completeness of the existing functions catalogue and the associated set of rules. Or to put it in other words: the aim is to search for a traffic situation which cannot be handled with the scope of available functions.

The functions are developed using IPG CarMaker and Matlab/Simulink from MathWorks. In addition to a parameter-based multi-body vehicle model, a sophisticated driver model plus a road model that is extended in the project, CarMaker offers the possibility to integrate Simulink-based controllers and to let the simulated vehicle model interact with static and dynamic environmental objects in so-called TestRuns. From the project perspective, CarMaker represents the ideal environment for automated testing of the driving functions that have been developed plus their associated function transitions.

❷ shows the associated iterative development process. Starting at the top right-hand side, the respective current development state of the functions catalogue and the maneuver control are tested in relevant test scenarios, which for the simulation are reduced to the required details and then implemented as a simulation case. Each test case has a solution strategy in the form of simulated event- or route-dependent driver inputs.



❷ Iterative development process with simulation aid

The combination of the test case and solution strategy results in a test course that can be simulated and that is either passed or failed. A successful completion does not allow the conclusion to be drawn that the functions catalogue and set of rules are complete. It merely does not prove that they are incomplete and results in increasing the complexity of the scenarios or the selection of a new scenario for the next test. In the event of a failed test scenario a check is required to determine whether the failure was caused by an insufficiently implemented function or by the lack of a driving function or a function transition.

POSITIVE RESULTS

An initial functions catalogue presented in [4] has already proven its viability in simulation in relevant extra-urban traffic scenarios. Show stopper scenarios for maneuver-based driving could not be identified in this regard to date and the positive results of initial acceptance investigations [5] encourage the pursuit of further detailing of this concept.

In work that is currently underway the functions catalogue and the implementation of the functions using the methodology described are systematically being tested and extended in application cases of increasing complexity and, following a design example [6], a human-machine interface is being developed which meets the demands of maneuver-based vehicle guidance.

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PEER REVIEW ATZ | MTZ

PEER REVIEW PROCESS FOR RESEARCH ARTICLES IN ATZ AND MTZ

Scientific articles of universities in ATZ Automobiltechnische Zeitschrift and MTZ Motortechnische Zeitschrift are subject to a proofing method, the so-called peer review process. Articles accepted by the editors are reviewed by experts from research and industry before publication. For the reader, the peer review process further enhances the quality of the magazines‘ content on a national and international level. For authors in the institutes, it provides a scientifically recognised publication platform.

In the ATZ | MTZ Peer Review Process, once the editors has received an article, it is reviewed by two experts from the Advisory Board. If these experts do not reach a unanimous agreement, a member of the Steering Committee acts as an arbitrator. Following the experts' recommended corrections and subsequent editing by the author, the article is accepted.

In 2008, the peer review process utilized by ATZ and MTZ was presented by the WKM (Wissenschaftliche Gesellschaft für Kraftfahrzeug- und Motorentechnik e. V./German Professional Association for Automotive and Motor Engineering) to the DFG (Deutsche Forschungsgemeinschaft/German Research Foundation) for official recognition.

FINGERPRINT OF THE DRIVER FOR THE ADAPTATION OF ADVANCED DRIVER ASSISTANCE SYSTEMS

Reliable knowledge about specific characteristics of the driver, such as driving style, feedforward and feedback control behaviour, or current performance level, contains large potential for the adaptation of advanced driver assistance systems and the optimization of customer benefit (increase in safety and comfort) as well as customer acceptance. At the Institute of Automotive Engineering (IAE), TU Braunschweig, a method was developed which allows the identification of the drivers' characteristics by using a personal "fingerprint".

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REVIEWED BY EXPERTS FROM RESEARCH AND INDUSTRY.

	TEST SERIES			
	1	2	3	4
TOTAL KILOMETERS [TKM]	28.0	7.4	18.9	18.0
TRACK DISTANCE [KM]	560	367.5	575	600
NUMBER OF TEST PERSONS	18	9	33	10/20
AGE OF TEST PERSONS	29-59 Ø36.1	26-63 Ø32.4	24-41 Ø30.1	23-25/63-81 Ø24.2/Ø68.1

❶ Basic data of test series 1 to 4

1 MOTIVATION AND OBJECTIVES

The fingerprint is based on an analysis of the individual characteristics of the driver, which is obtained by determining defined parameters of longitudinal and lateral dynamics, steering and tracking behaviour, and the use of active assistance systems by the driver. If these parameters are known, the identified values and the temporal changes of the parameters enable conclusions to be drawn with regard to

: driving style
: driving strategy (age/experience)
: driver performance level.

The individual fingerprint and the time-variant characteristics of the driver form the basis for the design of adaptive assistance systems. The first two categories (driving style and driving strategy) are used primarily for the adaptation of the basic characteristics. The continuous observation of the driver´s performance level over the driving time allows adapting thresholds of interference for the transition from warning to intervening assistance functions.

2 DATABASE

A distinction is made between the test series which model real customer behaviour according to the 3D method and the test series for data acquisition for the identification of the drivers' condition.

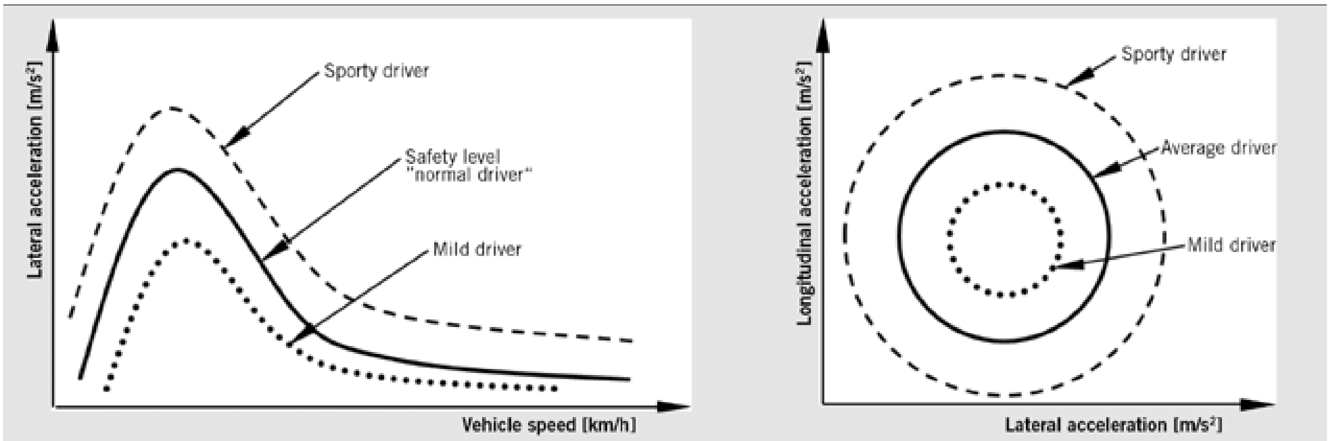
The 3D method is based on the systematic collection of customer operation data under all relevant operational conditions. This method consistently considers the driver as well as the driven vehicle and the driving environment (3D) as interacting modules [4]. In comprehensive studies (> 1.5 million measuring kilometers), the drivers' actions as well as driving environment parameters were measured with diverse vehicles in real road traffic and integrated into a database.

Several successive measuring campaigns, ❶, were carried out using a special experimental vehicle in order to identify the driver performance level (DPL). Thanks to integrated camera and environmental sensors, this test car enables the longitudinal and lateral control behaviour of the driver as well as the ambient conditions to be determined, ❷. In addition to the control inputs set by the driver (steering wheel angle and pedal position) and the typical vehicle motion variables (lateral acceleration, yaw rate), driving environment data such as lane offset, yaw angle error, and relative distances/speeds were taken into consideration. Additionally, the drivers evaluate their subjective performance level in uniform time intervals.

3 FINGERPRINT GENERATION

As defined at the beginning, fingerprint generation is divided into the identification of the driving style, the driving strategy, and the driver performance level.

❷ Experimental vehicle TEASY (Testing & Engineering of Automotive Systems)



❸ Reference samples regarding the correlation of vehicle speed and lateral acceleration and usage of Kamm's circle

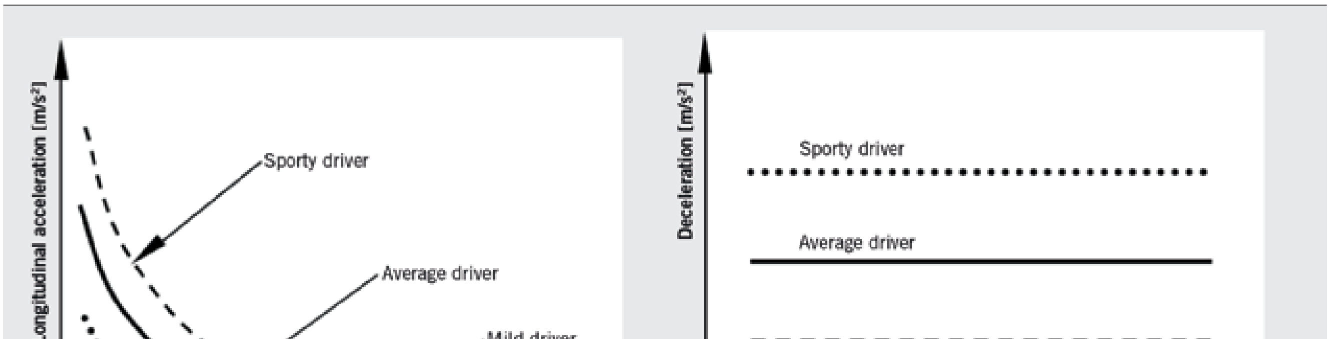
3.1 DRIVING STYLE

The driving style must in principle be interpreted as a natural characteristic of the driver. However, the natural driving style can change for short periods of time during short or situation-dependent driving maneuvers, such as overtaking. This requires statistical long-term observation of the driving style, which can detect and, if necessary, suppress short-term effects.

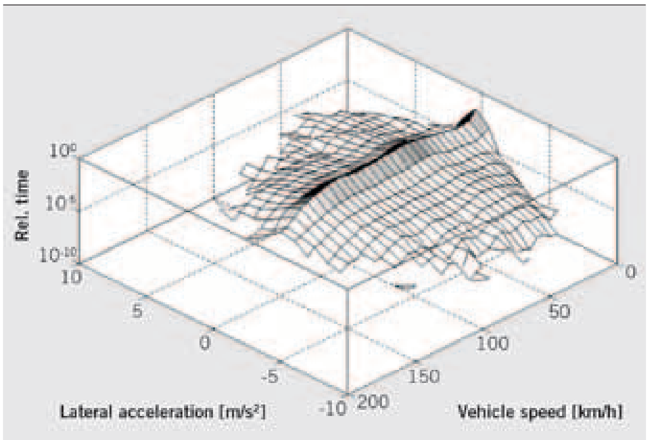
Three vehicle-independent connections which allow objective conclusions to be drawn are employed in order to identify the driving style: the "safety limit of the normal driver", the use of Kamm's friction circle, and the exploitation of the acceleration and deceleration potential. The safety limit of the normal driver, ❸ left, was originally introduced in traffic accident reconstruction in order to assess the driving conditions [6].

This approach shows significant differences between different drivers which clearly correlate with the driving style. The core observation is that the normal driver considers transverse accelerations of more than 4 m/s² above a speed of about 50 km/h unpleasant and therefore avoids them. Since these limits are known in the literature only for the normal driver (average driving style) and up to speeds of 140 km/h, the above-mentioned 3D customer measurements were analyzed and reevaluated in order to determine the limits of mild and sporty drivers. The use of Kamm's friction circle, ③, right was employed as a second criterion. This is a speed-independent method for the determination of the driving style. Sporty drivers show a conspicuously great simultaneous exploitation of the longitudinal and lateral acceleration potential of the vehicle during braking and acceleration in bends, for example. Mild and average drivers, however, generally drive through bends without noticeable longitudinal acceleration. In addition to these two criteria based on lateral acceleration, the driving style is deduced from criteria based on longitudinal acceleration, which in principle distinguish between braking and acceleration behavior, ❹. While acceleration behaviour clearly depends on the power to weight ratio of the vehicle [4], braking behaviour remains virtually uninfluenced by this factor.

Depending on the driving style, the values approach the limit patterns shown in ③ and ④ at a certain percentage rate. For illustration, the correlated frequency of occurrence of lateral acceler-



❹ Reference samples regarding the correlation of longitudinal acceleration and deceleration to the vehicle speed



❺ Correlation of lateral acceleration and vehicle speed for sporty extra urban driver

ation and driving speed of a typical sporty highway driver is shown in ❺. The relative time shares of certain driving regimes contained in this model are used in order to identify the driving style of an unknown driver.

These methods are used to deduce two sets of driving style information for the individual driver, which result from long-term observation and the statistical analysis of the driver as well as the short-term observation of the current driving situation.

3.2 DRIVING STRATEGY

The driving strategy can be characterized by the control behaviour of the driver, which not only includes the driving style, but in particular also the factors based on the experience and the age of the drivers. Typical features in a comparison of younger and older drivers can be identified using lateral vehicle control, for example.

A driver model [2], divided into a level of information processing and a level of control-technical elements, serves as a basis. The control-theoretical model level is subdivided into a feedforward (anticipation) and feedback (compensation) component, ❻.

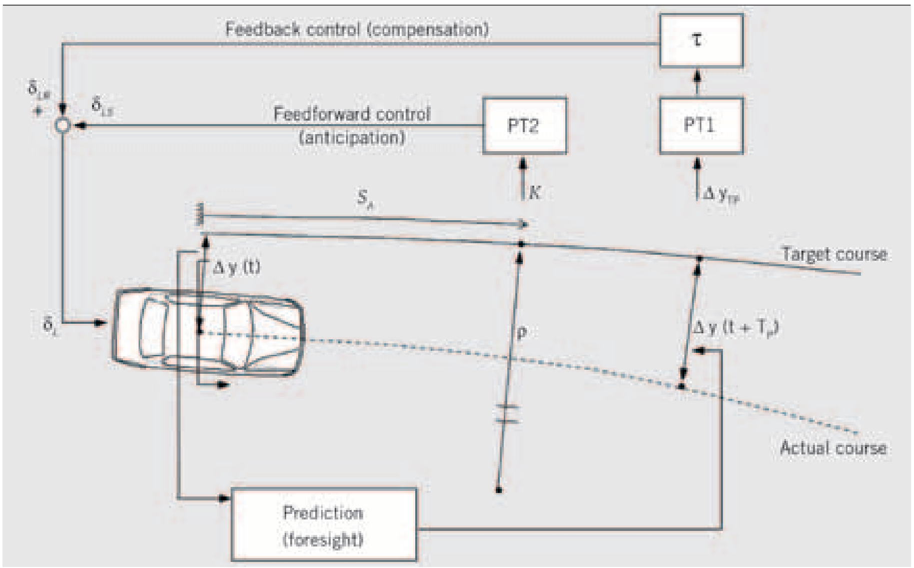
In the feedforward control mode (anticipation), the driver model sets a steering wheel angle based on the road curvature κ_S. In the feedback control mode (compensation), an additional steering angle due to the deviations Δy_{TP} of the actual course from the target course predicted at the prediction time T_p is considered. From the viewpoint of human control behaviour, the main driver parameters to be set are the gain factor V_{MR} (ratio of the steering angle and the deviation between the actual course and the target course) as well as the prediction time T_p.

❼ shows the identified parameters V_{MR} and T_p in a comparison of the two groups of test persons. The results show that older drivers control with greater gain factors V_{MR} and a slightly longer prediction time T_p. The shorter prediction time of the young drivers illustrates that they react with less anticipation to lateral deviations of the vehicle from the target course. At the same time, they compensate for smaller deviations with less gain due to smaller time delays within the information processing. ❽ shows these conditions by means of a coefficient diagram in which driver gain V_{MR} is plotted over the prediction time T_p. The diagram shows the isolines of identical phase margin which characterize the properties of the entire driver-vehicle control loop. The curve of the 0° phase margin characterizes the stability limit. Even though the younger and older drivers set their average control parameters in different value ranges, control remains stable with an identical phase margin. Thus, the control strategy of the driver is quantified as the second component of the fingerprint. The control parameters also enable indirect conclusions about the age of the driver to be identified.

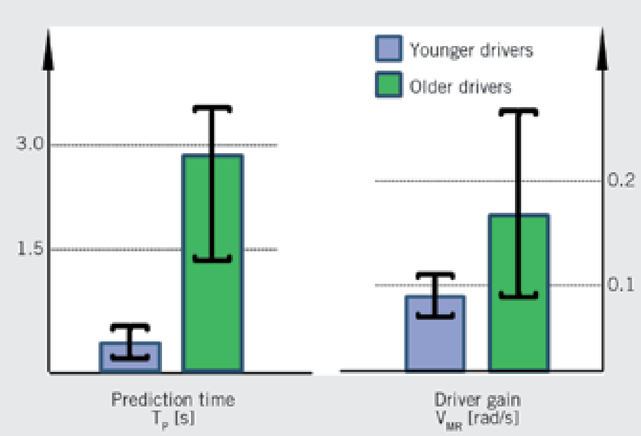
3.3 DRIVER PERFORMANCE LEVEL (DPL)

Despite the growing number of advanced driver assistance systems, the driver is still ultimately responsible for the vehicle and controls it. How well he completes this task depends on his performance level. In addition to the talent, the constitution, and the experience of a driver, fitness (fatigue) and attention influence his performance.

The approach pursued at the IAE focuses on the indirect measurement of the driver performance level (DPL). In contrast to



❻ Control-theoretical driver model for vehicle lateral control



❼ Identified parameters of compensation control mode

known systems [7, 8] the parameters are calculated by time and frequency-related analyses of vehicle track signals and the driver's transfer behaviour using the driver model shown in ⑤. Due to the use of camera-based track monitoring systems, all necessary information for the continuous on-line identification of driver behaviour, such as the control input parameters curvature, track deviation, and yaw angle error, is available. The other vehicle motion parameters are determined based on the CAN signals together with the steering angle as an output value. The steering and control parameters are identified using the driver model implemented on-line. In both cases, the results show that driver gain factors and time constants change with increasing driving time and diminishing performance level [1]. According to a rule which specifically applies to control, driver gain V_{MR} increases over the driving time while the prediction time T_P decreases. As the driving time increases, the drivers control more strongly and more closely to the stability limit of the control loop than at the beginning of the ride.

A comparison of the objective DPL parameters with the subjective estimation of the performance level illustrates the strong correlation between the driver performance level and the changes observed in control behaviour. If the performance-related dependence relations are known, the performance level of the driver can be objectified. ❾ shows exemplary results. The objective DPL index calculated based on the regression model is plotted over the subjective evaluation of the performance level. The parameters used are a combination of defined criteria from the analysis of tracking behaviour and the driver model. It must be emphasized that the integration of the driver model parameters improves the quality of DPL prognoses considerably. The objectivation result has a model quality of $r^{*2} = 0.91$, which provides significant potential for reliable adaptation in the transition from warning to adaptive, intervening assistance functions.

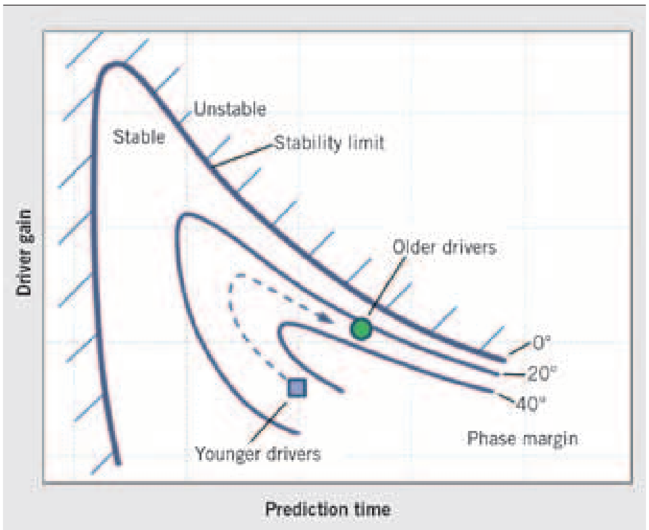
4 ADAPTATION OF ADVANCED DRIVER ASSISTANCE SYSTEMS

The approach of adaptive driver assistance systems is based on the fingerprint with the three identified characteristics driving style, driving strategy, and driver performance level. The objective of adaptation to the driving style is the minimization of false interference and false warnings due to a dynamic driving style. Adaptation to a performance level seems appropriate in order to disrupt the driving style of the awake, active driver as little as possible while supporting him when his performance level drops so that traffic safety is optimized. In addition to adaptation to a performance index, the consideration of differences in the control strategy caused by age or experience is also relevant.

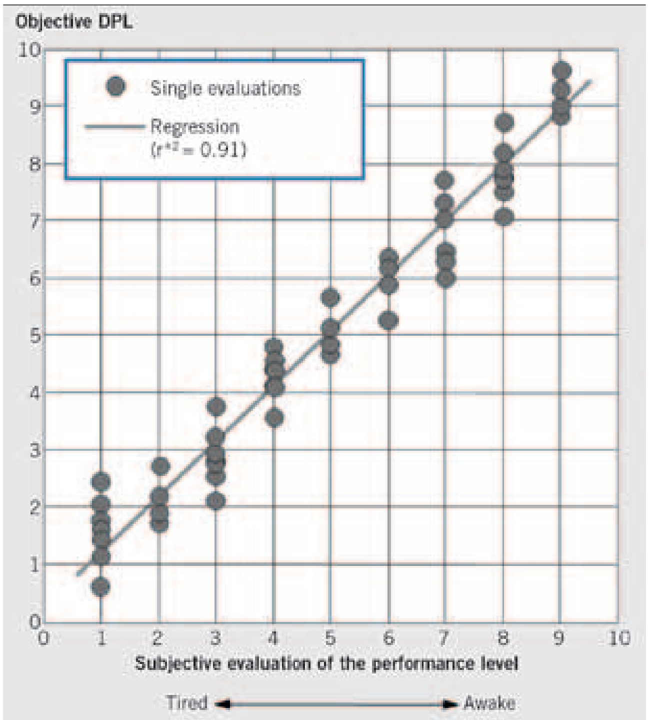
The result of the IAE development work is an adaptive tracking assistance algorithm, which is shown schematically in ❿. As an input, all relevant data is read in and the warning conditions and the necessity of a warning (core algorithm) are calculated. In the second area, the higher-ranking current driver adaptation index is considered in order to determine the kind and intensity of the warning (acoustic signal, steering wheel vibration, interference with steering). The support provided by the system is adapted depending on the adaptation index. Based on the mere track leaving warning (vibration), this allows lane keeping to be assisted by increasingly intervening steering wheel torques. Both the amount and the increasing gradient of the additional steering torque are influenced as significant adaptation parameters. In the core algorithm, the warning and interference limits are changed by adapting the time-to-line crossing (TLC).

For adaptation to the driving style, the warning and interference limits are shifted in the direction of a more dynamic driving style. Due to his dynamic driving style, the sporty driver is considerably more active as compared with the mild driver so that the warning suppression limits are set higher than for a mild driver. In addition, the driving corridor for tracking guidance is enlarged, which means that additional steering wheel torque set in at larger lateral track deviations, and torque-overlay in the edge areas is slightly increased.

Age-specific differences showed that older drivers tendentially applied a more anticipative driving strategy. Therefore, support is based on changed TLC values and harder centre-point control. Practical studies show that the objective tracking quality of the drivers improves.



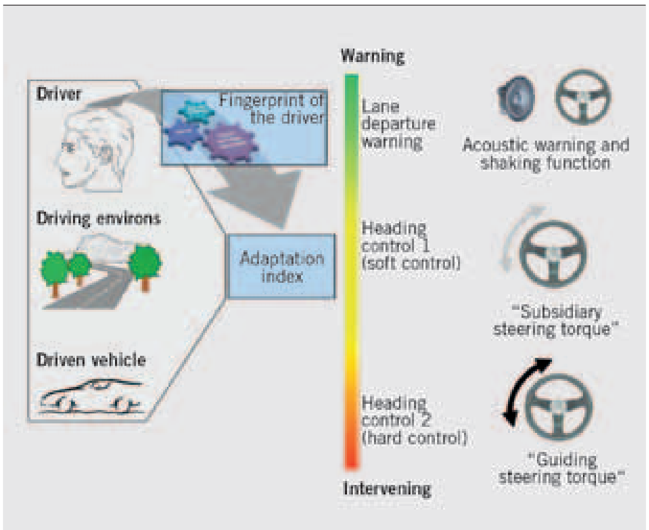
❽ Conditions for stability in the coefficient diagram



❾ Objective DPL versus subjective evaluation of the performance level

With regard to performance and in particular tiredness-adaptive assistance, the system must be adapted such that performance-related deficits are compensated so that accidents are avoided without animating a very weak driver to actively participate in road traffic considerably longer. Adaptation to the DPL index takes place stepwise beginning with the adaptation of the TLC-based warning thresholds. In a second step, the gradient of the additional torque is increased so that track centre control becomes stricter. This means that the subjective correction frequency experienced by the driver grows. As a result, he drives more closely to the track centre.

Current test series with test persons show that adapted lateral guidance provides greater acceptance and an average subjective safety gain by 1 grade point.



❿ Adaptive algorithm for lane keeping assistance

5 SUMMARY AND OUTLOOK

In the present contribution, the methods, database, and models for the generation of a driver-specific fingerprint were described. Differentiation includes the characteristics "driving style", "driving strategy" (age/experience), and "driver performance level". The reliable knowledge of objective classification characteristics and weighted parameters such as the driver performance index open up far-reaching potential for the design of adaptive driver assistance functions. The example of lane keeping assistance presents mechanisms for the adaptation of the additional steering wheel torque as well as warning and interference thresholds for transition to different intervention steps. Driver-specific acceptance and subjective safety gain can be increased significantly as compared with the reference system.

For additional tests of adaptive assistance functions and in order to ensure them for a wide range of customers, the next step includes comprehensive system studies. The relevant test series are being prepared. In addition, the potential application of these approaches to intervening systems for longitudinal control is being studied.

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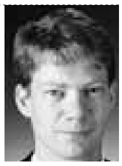

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CAPACITIVE ELECTROCARDIOGRAM MEASUREMENT SYSTEM IN THE DRIVER SEAT

In a cooperation project between the Philips chair of medical information technology at the RWTH Aachen and the Ford Research Center in Aachen a capacitive electrocardiogram measurement system, integrated into the driver seat, was developed and evaluated. This system allows monitoring of the heart activity of the driver.

THE SEAL OF APPROVAL FOR SCIENTIFIC ARTICLES IN ATZ.
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1 BIOMEDICAL ENGINEERING IN THE AUTOMOTIVE SETTING

Innovation in automotive technology not only emerges from within the community, but may also benefit from interaction with non-automotive branches of research. During the last decade, biomedical engineering industries in Germany have made important progress in research and industrial production which yield innovative ideas; the transfer of these ideas will have a positive effect on the automotive industry. In the field of home monitoring of the chronically sick, the transmission of biologic signals, such as the electrocardiogram (ECG), has already shown its potential. Currently, it is possible to monitor the health status of patients at risk in their own home. Such measurement systems are often linked to a telemetric data transmission device for clinical validation.

The monitoring of patients at risk outside the home environment is also being investigated [1, 2]. In particular, whilst driving a car any important change in the driver's health status or even more the state of mind is considered relevant because, in contrast to home monitoring, not only the monitored person but also third persons might be affected. Therefore, early detection of dangerous situations is important. Acute incidents, such as heart attack, often lead to total loss of control of the vehicle. In Germany alone, in 2009 there were over 4000 serious road accidents with 106 deaths attributed to a heart attack [3]. Also, less serious conditions, such as stress or dizziness, need to be taken into account as important factors in the development of errors/misjudgements, which (according to data from the Federal Bureau of Statistics) led to about 50 % of all road accidents in Germany in 2009.

Due to this relevance the research project 'SmartSenior' targets the development of an emergency stop assistance system [3, 4]. In addition, the 'Insitex' project aims at integration of sensors for biosignal measurements inside a car [5].

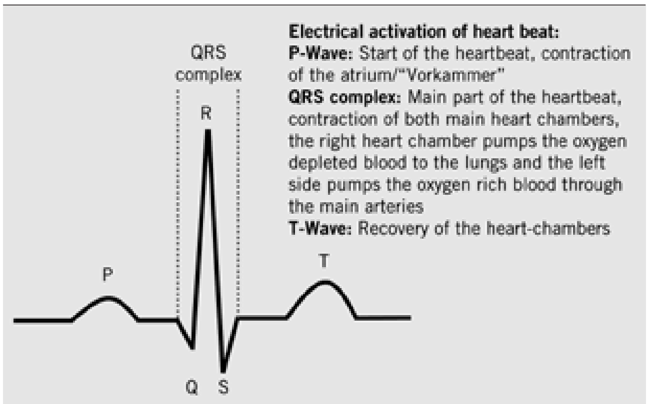
Monitoring of the driver shall allow for an early detection of a deteriorating health condition. Then appropriate actions to avoid dangerous traffic situations can be taken. During the last decades research projects showed the feasibility of monitoring a driver's performance with medical devices [6, 7]. Also, it is known that blood pressure levels change relative to the stress level of a patient; this has been measured by means of pulse transit time using an ECG and an oxygen saturation sensor [8]. However, whereas in some situations a combination of devices is necessary, for other applications a single-modality approach is often sufficient. For instance, heart rate rises under conditions of stress, which can be detected by an ECG.

The ECG is the captured sum of the electrical activity of all heart muscle cells. ❶ shows a typical ECG pattern. Characteristic sections are the P and T waves, as well as the significant QRS complex, which represent the excitation of the ventricular muscle and consequently the contraction of the heart. The heart is the central organ in the human circulatory system and its function gives important information about the patients' condition. Furthermore it is possible to draw a conclusion about physical and mental stress. Based on previous experience [9], a joint project between the Philips Chair of Medical Information Technology at RWTH Aachen University and the European Ford Research Center in Aachen was started to integrate a multichannel ECG system into a car seat. The aim is to enable a contactless and imperceptible measurement of heart activity during car driving.

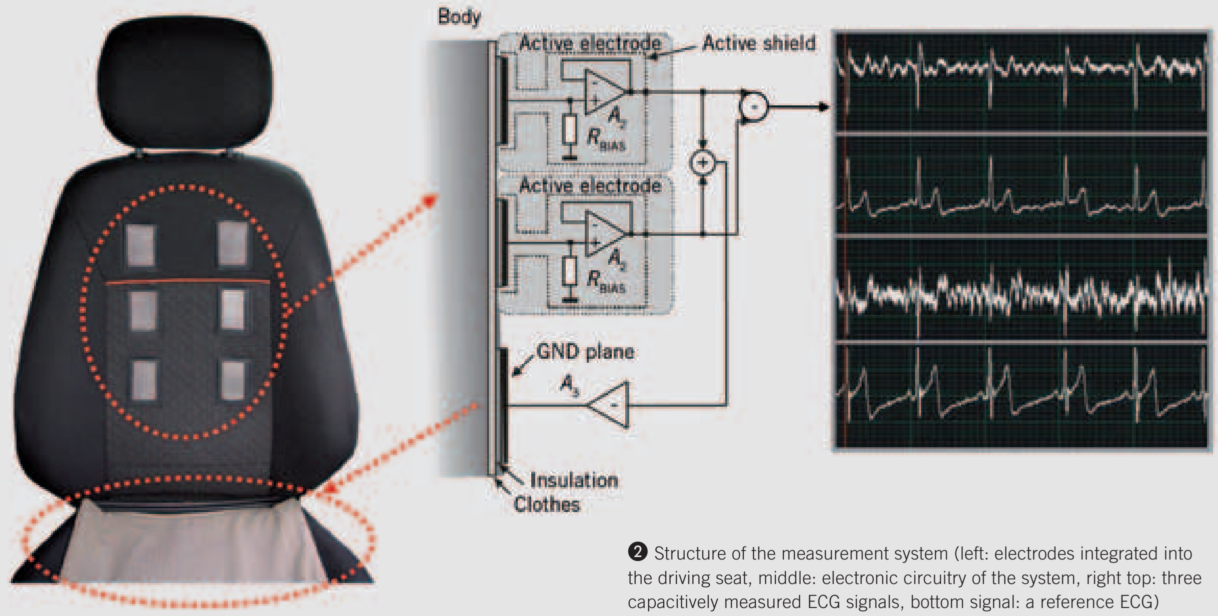
2 CAPACITIVE ECG MEASUREMENT TECHNIQUE

Central elements of the measurement system are the so-called capacitive electrodes which, in contrast to conventional adhesive electrodes, do not need direct conductive contact with the driver's skin. Instead, measurement of the potentials on the driver's body surface produced by the heart takes place through the driver's clothes. This allows integration of the electrode into the back of the driving seat. Although the principle of capacitive measurements was introduced in 1967 [10], progressive miniaturization of the electronic components now allows the entire electronic set-up to be placed on the back of the electrodes. The core element of the electrodes is an impedance converter, which decouples the measurement signal from the subsequent signal conditioning stages. For this purpose a voltage controlled amplifier with a high input impedance is used. Besides the electronics for the biosignal measurement, accelerometers are mounted on the back of the electrodes, by which the acceleration of the vehicle can record in all three directions in space, which could be used for a later signal processing. Subsequently, the signal processing electronics (consisting of power supply, instrumentational amplifiers, and filter and gain stages) are connected.

❷ shows the design of the measurement system. The left part shows the electrodes integrated into the driving seat. For enhancement of the common mode rejection, as the measure for the transmission of common signals at the electrodes to the output of the system, an additional electrode (made of conductive textile material) was manufactured, whose potential equals the inverted, amplified sum potential of the electrodes. In this way, common



❶ A typical electrocardiographic signal pattern



❷ Structure of the measurement system (left: electrodes integrated into the driving seat, middle: electronic circuitry of the system, right top: three capacitively measured ECG signals, bottom signal: a reference ECG)

mode voltages on the body surface are not transmitted to the output of the system.

The middle part of the figure shows the electronic components of the electrodes, including the bias resistors next to the signal input for leading off bias currents, as the continuously flowing operating current of the amplifier, and the impedance converter. Afterwards (right part of the figure), the ECG signals are generated by calculating the difference between the electrode output signals. Note that the system can also be integrated into series production vehicles at an acceptable expenditure.

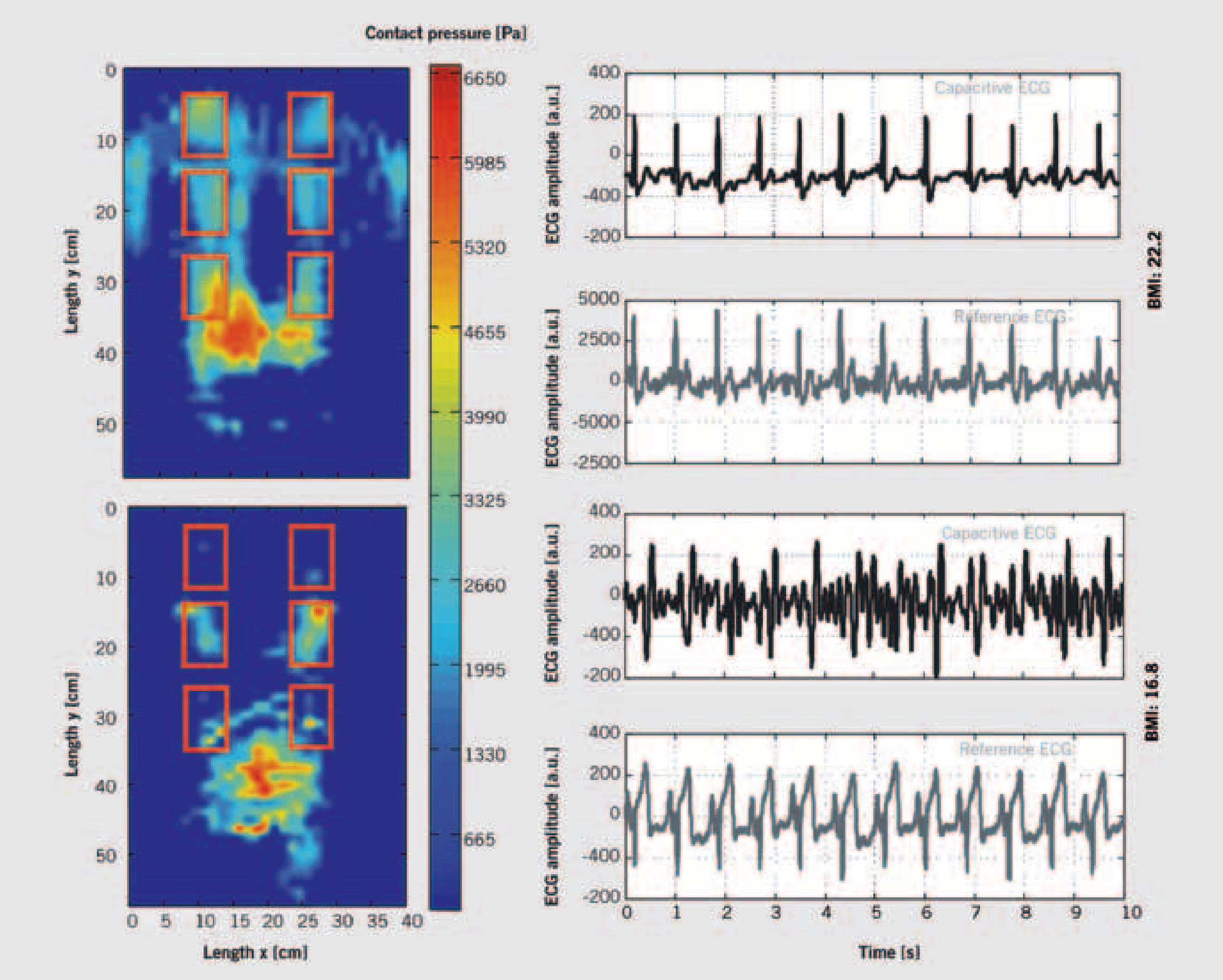
To take into account different body profiles during the test and validation phase, six active electrodes were integrated into a normal driving seat of a Ford S-Max in the form of a 2x3 matrix, ❸. Bearing in mind differing proportions of the human body, the positioning of the electrodes need to be chosen to allow sufficient contact with the electrodes. A tight mechanical fit of the electrodes is essential to guarantee high signal quality. To identify suitable positions for the electrodes, a pressure mat (XSensor X3 Medical Mattress System) was used to measure the contact pressure of ten different subjects with different gender and stature on the back of the driving seat. By means of averaging the pressures the optimal positions for the electrodes were identified and again verified with a few subjects with respect to the signal quality of the capacitive ECG. Parallel with these measurements, both the capacitive and a reference ECG were recorded.

As an example, ❹ presents both the contact pressure and the related ECG measurements from a test person with a normal BMI (22.2 kg/m²) (top), whose weight was in the 43 % percentile among all adults in Germany. The BMI is defined as the body weight in kg divided by the squared height in cm und thus is a measure for the assessment of the weight of man. In comparison a test person with a low BMI (16.8 kg/m²) (bottom), whose weight was in the percentile below 1 %, is presented. The signal quality of the capacitively recorded ECG decreases with reduced contact pressure with the driving seat. Thus the BMI is an indicator for an adequate mechanical electrode contact. The height and stature of the driver are additional factors for the electrode body contact. Furthermore, the construction of the system in the form of an electrode matrix showed that at least one electrode plane is suitable for about 90 % of all subjects; this means that, with the measurement of all channels, an ECG is available at least in one channel.

3 STATIC AND DYNAMIC TESTS

To validate the system and to test the general functionality of the system, tests with the engine turned off were performed with

❸ Capacitive electrodes integrated into the back of the driving seat, and a feedback electrode (driven ground) in the form of a seat cushion



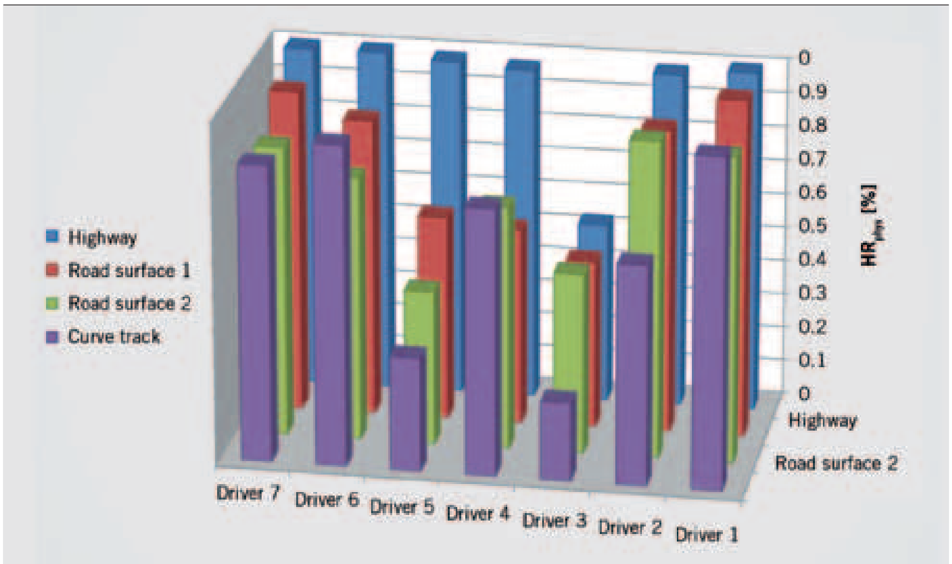
❹ Contact pressures and related ECG signals for different body mass indices in artificial units [a.u.] (top: BMI in normal range, bottom: BMI below the normal range)

59 test subjects without excluding any specific influencing factors (e.g. clothing or BMI).

Also dynamic test drives under controlled conditions were performed by test drivers on highway, country and urban roads of the Ford proving ground in Lommel (Belgium). The surface/texture of the highway test track of the proving ground (track b in ❺) has characteristics similar to that of a German highway ("Autobahn") [11]. The other two test tracks were characterized by a multitude of curves with plane asphalt (track a in ⑤) and straight track segments with various road surfaces (track c in ⑤). Therefore, the road surfaces differed in their unevenness in the form of small potholes closely following each other (road surface 1) and concrete panels with uneven transitions (road surface 2).

For analysis of the measurements during car driving, a QRS detection algorithm (validated by means of a database from MIT Massachusetts Institute of Technology) was used to determine the heart beat [12]. Depending on the driving situation, strong motion artifacts were occasionally even observed in the reference ECG, which did not allow direct comparison of the measurements. Because of this, the percentage of the heart beats in a physiological range, i.e. between 60 and 100 beats per minute, was used as the evaluation criterion for the performance of the system. Artifacts due to road enevenness, which were wrongly assigned to QRS-complexes, result in a heart rate beyond the physiological range and are added to non-analyzable ranges. This assumes that indeed no exact comparison with the reference ECG is possible. For long test drives, however, quantitative conclusions about the validity of the system can be drawn.

❺ Test tracks of the Ford proving ground in Lommel (Belgium)



❻ QRS detection rate in the physiological range for different drivers and different test tracks; extreme acceleration and curved way of driving for Driver 3

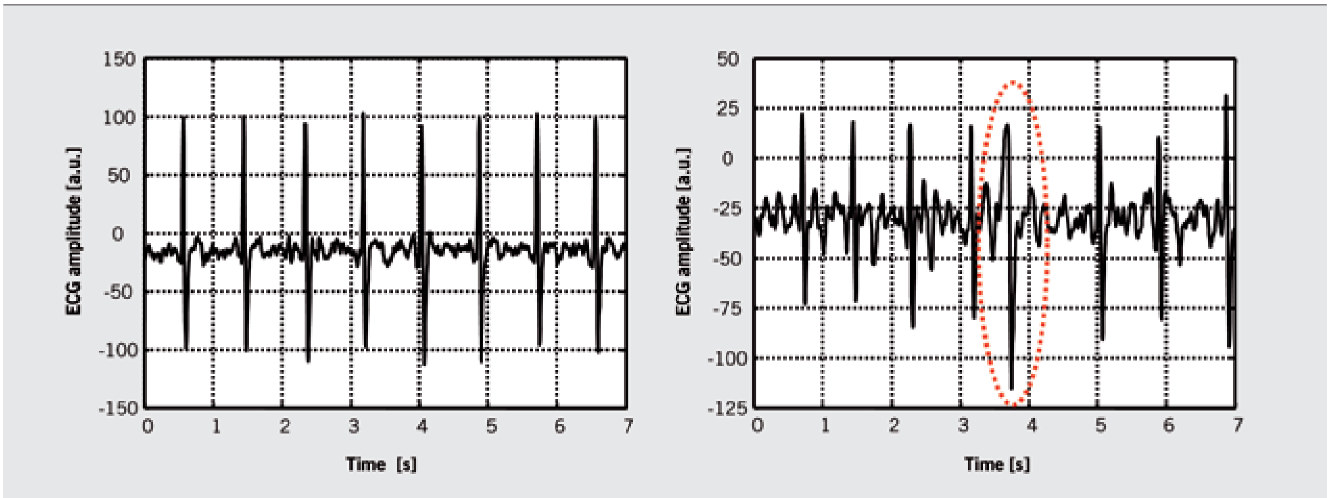
4 DISCUSSION OF MEASUREMENT RESULTS

During the static tests, an ECG could be measured in 85 % of all subjects. Of the remaining 15 %, in five persons the signal quality could be improved by removing the outermost layer of clothing, so that an ECG became measurable. Hence, in 93 % of all test subjects an ECG could be measured. Only in 7 % of all subjects no ECG measurement was possible. An analysis of the reasons is ongoing.

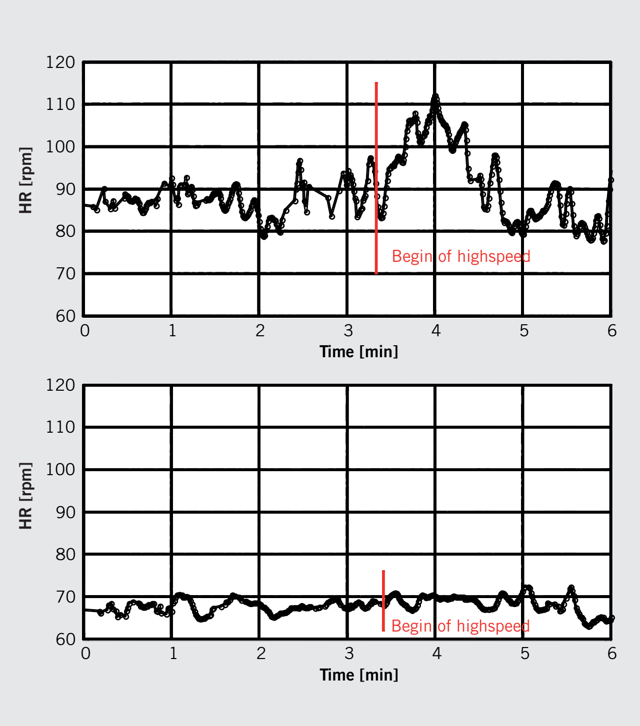
❻ gives an overview of the QRS detection rate in the physiological range on the three different test tracks of the proving ground for different drivers. It can be seen that the system shows the best signal quality on highway tracks. However, very dynamic driving (driver 3) hampered the signal accuracy and decreased the percentage of measurement coverage. It can be concluded that there are no significant quality change between the static measurements and the measurements made while driving on the highway. The system is highly valid during smooth highway drives with an ECG coverage rate of 92.4 %, but in urban traffic (where road damage and extensive steering movements occur) capacitive ECG monitoring may have a lower coverage rate. However, integrated acceleration sensors could be used for analysis of the driving situation and with the objective to identity and mask motion artifact-corrupted signals. In any case the signal quality appears to be sufficient for the detection of irregularities in the ECG.

With respect to the usability of the system with different clothing measurements with one or two layers of pure cotton were possible with most of the subjects. The applicability of other materials (polyester, silk, blended fabric, wool etc.) was limited and should be targeted by additional investigations.

During the static measurements, the system was also tested by volunteers with known pathological conditions. As an example, ❼ indicates that the detection of arrhythmias (such as extra systoles) is possible. Marked in red is a heart beat beyond the normal heart rhythm, a so called extrasystole.



❼ Extra systole (right) and sinus rhythm of a healthy driver (left) measured with capacitive electrodes



❽ Development of heart rate at the beginning of a high-speed track for a young driver (top) and an experienced driver (bottom)

Besides the heart rate, the heart rate variability (HRV) is an indicator of the ability of the heart to adapt to external influences. This parameter could be determined by means of the heart rate measured over a fixed time frame. It has been shown that the underlying activity of the autonomic nervous system is influenced by stress, which leads to a reduction of HRV in a stressful situation [13]. Therefore, after demonstrating the measurability of the heart rate in a car in this project, stress monitoring during car driving seems feasible.

Relating to this, first results were obtained on the high speed track of the Ford proving ground in Lommel. For example, ❽ compares the heart rate of a young driver (top) and an experienced driver (bottom) at the transition between the urban and the high-speed track. The felt "stress" of the young driver (upper chart) is demonstrated by the increase in heart rate.

5 OUTLOOK

With the results achieved in this joint project between the Philips Chair of Medical Information Technology at RWTH Aachen University and the European Ford Research Center, an important milestone in the field of vital monitoring during car driving has been reached. It is shown that a clinically usable ECG can be recorded in a contactless way, without any restriction of comfort. However, before actual production, further research is required. For example, textile integrated electrodes are necessary. The dependence of signal strength on the type of clothing of the driver, as well as the anatomic differences (e.g. the individual heart axis or body height) needs to be better understood. In the shorter term, implementation of a secure driver monitoring seems to be possible. With respect to demographic developments towards elderly drivers, this might be important. Those or vehicle drivers suffering from cardiovascular disease could be provided with additional security by means of an integrated system working in the background.

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