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INDUCTIVE Energy Transfer for Electric Vehicles

THE NEW VW Golf Convertible

COOPERATIVE Trajectory Planning Based on Car-to-X Communication

INNOVATIVE MATERIAL CONCEPTS FOR TOMORROW'S AUTOMOBILE

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COVER STORY

INNOVATIVE MATERIAL CONCEPTS FOR TOMORROW'S AUTOMOBILE

4, 10 I Hopes are resting on new material concepts to reduce the weight of vehicles. The ika of RWTH Aachen University designs with lightweight CFRP and GFRP a body floor structure such that the weight of the parts is reduced by 22 %. But it does not always have to be lightweight materials; new constructions also reach the goal. The Fraunhofer IWU reduces with shape memory alloys the weight of a petrol cap actuator by two thirds.

COVER FIGURE © BMW
FIGURE ABOVE © Volkswagen

END OF THE HYPE

Dear Reader,

A perfectly normal motor show, the first for years. At the Geneva Motor Show there was only one dominant trend: a car is more than just a low-CO_2 form of mobility. And there are other developments that are equally crucial to the future of the car.

Connectivity, for example: cars have to be regarded as part of an intelligent traffic system whose information and communication capabilities are on a par with those of the iPhone and iPad. And which is just as chic. BMW is proving that this can be accomplished with its "ConnectedDrive" concept. If BMW is quick off the mark in bringing the functions it has been exhibiting into series production, ranging from an emergency call system to remote control via apps, then the Bavarians have the opportunity of becoming the Apple of the automotive industry.

Future topic lightweight design: with its 4C design study, Alfa is exhibiting a beautiful sports car which owes its performance first and foremost to its extremely low weight of 850 kilograms. In series production from as early as 2012, in small production runs, the 4C will make extensive use of carbon fiber, at least according to the press release. In face-to-face conversation, the Alfa people are rather more nuanced: other lightweight materials such as GRP might also be used.

And the joy of driving a car – and owning it – also depends of course on its design. Among the myriad design studies, there is one in particular that stands out in my opinion: the A3 Concept with which Audi is previewing a new design era. Recently criticized for excessively uniform styling, this is proof that the Ingolstadt designers haven't lost their design prowess.

The Mercedes SLK in particular stands out amongst the production vehicles making their first appearance in Geneva. Or rather one particular detail, namely the "magic" glass roof that can be darkened at the touch of a button. In the SLK, whose roof can be completely opened in any case, this polar crystal-based technology may just seem to be a gimmick. But customers of vans with glass roofs or long wheelbase sedans will definitely want this equipment feature one day.

How wonderful it is that automobiles are still so vibrant after 125 years!

JOHANNES WINTERHAGEN, Editor-in-Chief
Geneva, 2 March, 2011

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CURRENT SITUATION

The significance of lightweight design has grown continuously over the past years and reached a new dimension due to the efforts of sustainably enhancing the efficiency of future vehicles. It will be necessary to think of advanced materials and new ways for the structural layout to significantly reduce the weight of vehicles. Lightweight materials on the basis of fibre reinforced plastics offer a large potential to improve resource and energy efficiency. Lower density and improved specific mechanical properties in comparison to metals are the advantages to reduce structural weight, besides this FRP also offer a huge flexibility in manufacturing and part design.

Currently economical and technological boundary conditions often do not allow the use of FRP in vehicle structures. The material class of fibre reinforced plastics has not yet reached the technology level of metals regarding the requirements of the automotive industry. For the use of FRP in a high volume production improvements have to be achieved in the field of materials, simulation and construction methods as well as production technology.

A possible way for gaining lightweight potentials with the use of FRP is the com-

LIGHTWEIGHT FLOOR STRUCTURE WITH REINFORCEMENTS OF CFRP AND GFRP

The discussion is more and more focussing on the use of fibre reinforced plastics (FRP), although challenges for the substitution of metal by these plastics in vehicle structures are well known. Therefore the Institut für Kraftfahrzeuge (ika) of RWTH Aachen University has investigated the use of FRP in order to reinforce locally metal vehicle structures with CFRP and GFRP. This lead to a lightweight floor structure, where through the efficient use of FRP (CFRP and GFRP) the weight of the parts could be reduced by 22 %. The project was funded by the Forschungsvereinigung Automobiltechnik e. V. (FAT).

bination with metal materials by means of local reinforcements. In a research project funded by the Forschungsvereinigung Automobiltechnik e. V. (FAT) the ika has investigated a new lightweight approach where continuously fibre reinforced plastics can be implemented efficiently and reasonably in high-production volume vehicle structures.

LIGHTWEIGHT APPROACH

Idea of the lightweight approach is the reduction of the sheet thickness of metal parts and compensating the weakening of the structure by local reinforcements made from FRP. The use of FRP in this hybrid structure offers numerous advantages in comparison to a substitution of the complete part. The efficient and local use of FRP can prevent the large increase of material costs.

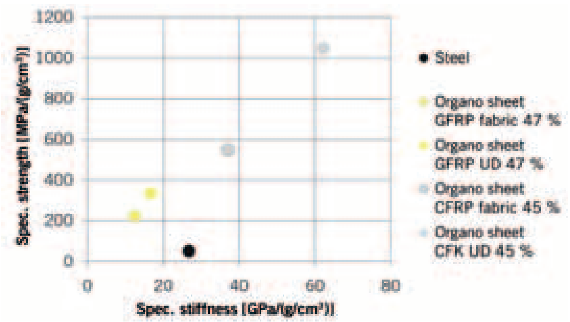
Besides this the basic structural layout as well as the integration into the infrastructure of the production can be maintained by keeping the geometry of the metal parts unchanged. The development of this technology includes the structural adaption by numerical simulations, the layout of a large scale production technology as well as the economical assessment. ❶ shows the overview of the two FRP materials glass fibre reinforced plastics (GFRP) and carbon fibre reinforced plastics (CFRP) used in the project.

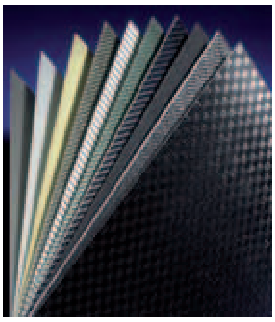
TECHNOLOGY DEMONSTRATOR

The detailed structural layout was carried out for the floor structure of a representative middle class vehicle structure. For this purpose the simulation model of the reference body structure of the collaborative research project SuperLightCar (SLC) [1] was available. The floor structure is an appropriate demonstrator. As a central element of the passenger cell the floor structure offers large scale effects besides the relevant lightweight potentials due to the common segment and brand crossing use of the same structure for different vehicle types and derivates. In the project the structural parts of the central floor structure were regarded. Relevant parts are the rear tunnel bridge, the seat cross members, the front and rear tunnel supports as well as the floor long members, ❷.

The structural layout of the reinforcing elements requires a detailed analysis of the structure. Representative stiffness and crash load cases were regarded in the layout phase. The assessment of the stiffness covered the global bending and torsion stiffness load cases. The crash worthiness is assessed for the frontal impact, the side impact, the pole impact following the Euro NCAP rating and the rear crash in the FMVSS 301 configuration. The intrusions of the passenger compartment are compared to the reference.

The outer shape of the reinforcing FRP elements follows to the geometry of the sheet metal structure, to prevent a modification of the body-in-white (BIW) or to make them as low as possible. Length,





FEATURE	CFRP	GFRP
Matrix	PA 6.6	PA 6
Fibre volume content	45 %	47 %
Density	1.47 g/cm³	1.80 g/cm³
Tensile modulus	53 GPa	22 GPa
Tensile strength	785 MPa	404 MPa
Breaking strain	2.1 %	2.2 %
Melting point	260 °C	210 °C

❶ Classification (diagram) and characteristic values (table) of the two implemented FRP materials CFRP and GFRP (UD = uni-directional)

laminate thickness, number and position of these elements are varied. In the assessment of possible solutions, aspects concerning production technology are already taken into consideration, including tooling costs, cycle times and assumed scrap rate.

SIMULATION OF LIGHTWEIGHT STRUCTURES

The solvers Optistruct (stiffness simulation) and LS-Dyna (crash simulation) that are used for the assessment of the structural performance offer material models for FRP. For the relevant loading condition and fibre architecture, the material model MAT_058 is used for the crash simulation. A specified material card for the regarded material was not available therefore a material card was calibrated using material and component tests.

RESULTS OF THE TECHNOLOGY DEMONSTRATOR

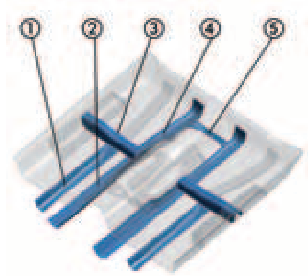
High mechanical stresses are found in the long member structures in the front crash configuration and the seat cross member during the pole impact, if the sheet thickness is reduced without a compensation through reinforcements. Variations of the sheet thickness as well as the shape and thickness of the reinforcing element have a strong influence on the structural behaviour. Especially local thickness gaps can lead to a disadvantageous buckling behaviour of parts and in some cases can lead to high intrusions into the passenger cell.

Nevertheless the reference behaviour can be achieved by an adequate adjustment of the sheet thickness in combination with reinforcing elements of GFRP. To maintain the global stiffness requirements, the additional use of CFRP is necessary. Rear tunnel supports and the rear tunnel bridge are identified as most relevant components and therefore reinforced with CFRP inlays.

The analysis of 120 variations with adaption and optimisation of the parameters sheet thickness, laminate thickness of the FRP elements as well as number, position and length of the reinforcing elements, lead to a lightweight floor structure, where through the use of 1 kg fibre reinforced plastics (GFRP and CFRP) a total weight reduction of 2 kg was achieved. This corresponds to a weight reduction of 22 %. The lightweight structure meets all requirements in terms of assessed crash and stiffness requirements, ❸.

The results of the numerical simulation were verified in BIW real tests on the basis of a VW Golf VI. Three BIW were prepared for this purpose. The structural

#	RELEVANT PARTS	MATERIAL	SHEET THICKNESS	WEIGHT
①	Lower long member (r/l)	ZStE 260	1.35 mm	2.24 kg
②	Front tunnel support (r/l)	ZStE 300	1.75 mm	2.75 kg
③	Seat cross member (r/l)	ZStE 340	1.30 mm	1.93 kg
④	Rear tunnel support (r/l)	ZStE 300	1.20 mm	1.57 kg
⑤	Rear tunnel bridge	ZStE 260	1.75 mm	0.83 kg



❷ Five relevant parts of the floor structure behaviour was compared to the reference behaviour in a modified crash configuration of the pole impact test (vehicle overall mass 1304 kg, crash speed 7.8 m/s). Results of the numerical simulation were confirmed in these real tests, ❹.

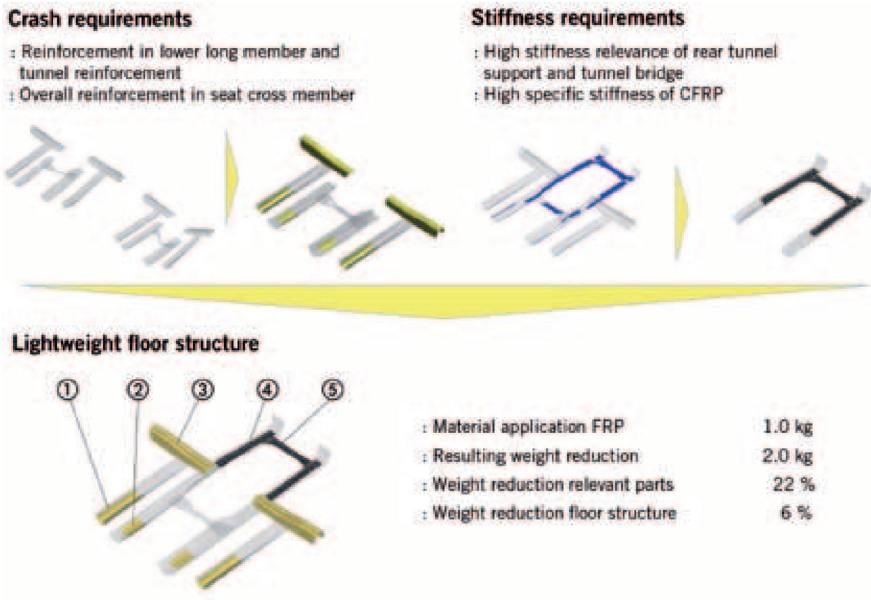
PRODUCTION TECHNOLOGY AND ECONOMICAL ASSESSMENT

Central requirement for the selection of the production technology is to make a short cycle time for a high volume production possible. Target scenario where an annual number of 100,000 vehicles. The resulting cycle time of approximately 3 min did not allow the use of the common RTM (resin transfer moulding) process. Geometrical boundaries on the other hand did not allow the layout for continuous production technologies such as filament winding, tape laying or pultrusion processes.

But the thermoforming process with thermoplastic FRP (organo sheets) fulfils the requirements and combines the advantages of short cycle times with a shape giving process similar to common press processes. The process chain, ❺, includes the supply of organo sheets as pre-consolidated material, the heating via infrared beamer, the pressing by thermoforming with a heated metal stamp and final trimming via laser or abrasive water jet cutting. Joining with the metal part is carried out in a separate adhesive bonding process. ⑤ shows also the cost breakdown.

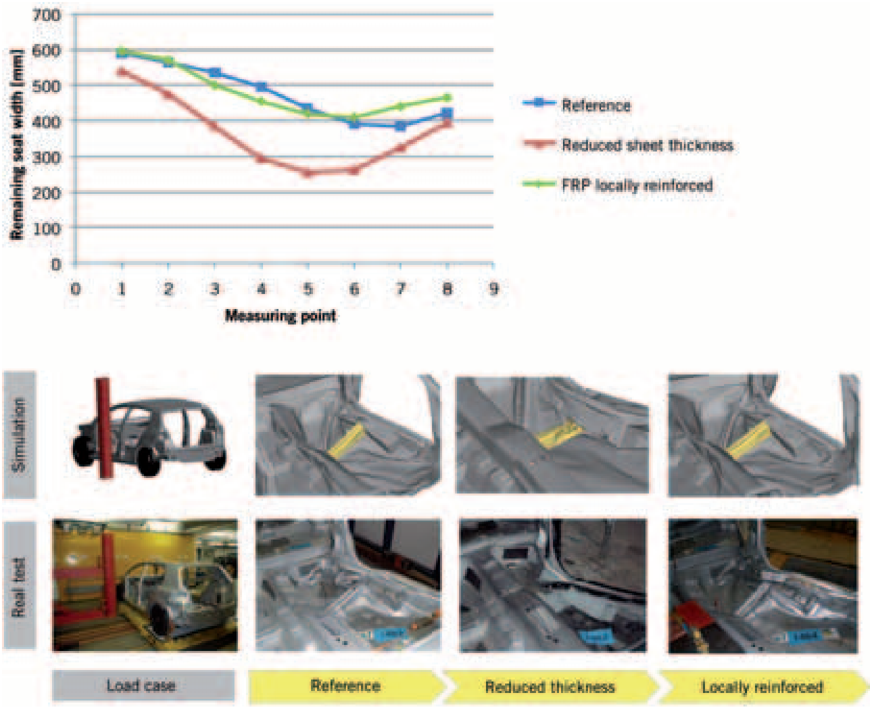
CFRP and GFRP with a fibre volume content of approximately 50 % are used as materials for the reinforcing elements. The implementation of FRP into the vehicle body structure demands a high temperature stability of the thermoplastic matrix. For this project, temperature requirements of constantly –40 up to +80 °C as well as a short term stability of 200 °C were considered, because the reinforcing elements would have to withstand the cathodic dip coating process and temperatures in the baking oven. Polyamide 6.6 (PA 6.6) covers these requirements.

A production cell for the manufacturing of the FRP and the integration into the metal parts structures was lay out for the economical assessment. It was found that by processing of thermoplastic FRP with

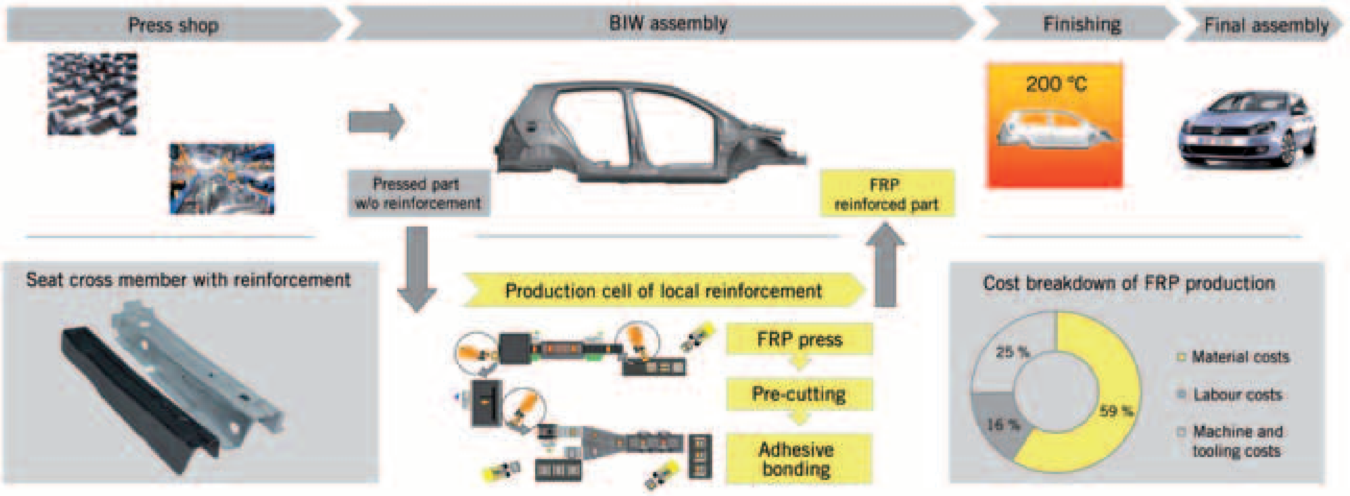


#	REINFORCEMENT	SHEET THICKNESS	FRP THICKNESS	WEIGHT REDUCTION	
①	Lower long member (r/l)	– 33 %	1.5 mm (GFRP)	0.55 kg	24 %
②	Front tunnel support (r/l)	– 37 %	1.0 mm (GFRP)	0.96 kg	35 %
③	Seat cross member (r/l)	– 50 %	1.5 mm (GFRP)	0.45 kg	23 %
④	Rear tunnel support (r/l)	– 9 %	2.0 mm (CFRP)	0.00 kg	0 %
⑤	Rear tunnel bridge	– 25 %	2.5 mm (CFRP)	0.13 kg	16 %

❸ Crash and stiffness requirements as well as results for lightweight floor structure design



❹ Real test validation of the simulation results with the lateral pole impact



❺ Overview of the process chain and the cost breakdown

thermoforming and a high degree of automation allows cycle times of less than 1 min. Labour and machine use costs can therefore be reduced in comparison with RTM or autoclave processes. Calculated lightweight costs for the production scenario amount 20 Euro per saved kg. However these costs can be compensated in a high volume production by the material savings of lower stressed unreinforced structures, if this technology is used to compensate local loads of high performance derivate vehicles or electric cars.

SUMMARY AND OUTLOOK

In the FAT funded research project ika was able to demonstrate new lightweight potentials through the use of continuously fibre reinforced thermoplastic FRP structures in combination with conventional steel sheet structures. The identified results on the basis of the reference structure can be transferred to further areas of the vehicle. Possible components can be further long and cross member structures, roof frame, A-, B- or C-pillars or rocker panels, ❻. Besides that further potentials can be found in chassis and interior components.

Lightweight potentials beyond this can be achieved by a variation of the steel sheet materials. First calculations at ika are promising and give an outlook on possible potentials concerning a combination of advanced high strength steel or hot forming steel with FRP reinforcements. By integration of this technology into the early phase of the development process of new vehicle structures and an optimisation of the production technology it is possible to improve manufacturing costs. The technology of local FRP reinforcements could therefore lead a route for the material group of fibre reinforced plastics into high volume production of vehicles, in order to reach lightweight targets that cannot be achieved by singular sheet thickness reductions.

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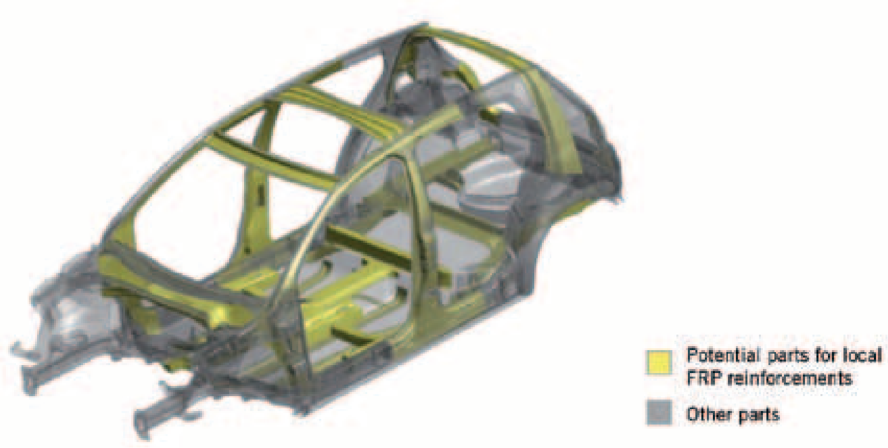

❻ Possible components with potential for the implementation of local FRP reinforcements: further long and cross member structures, roof frame, A-, B- or C-pillars or rocker panels

LIGHT SHAPE MEMORY ACTUATORS IN AUTOMOBILES

The major research objective of the Department of Adaptronics and Acoustics at the Fraunhofer Institute for Machine Tools and Forming Technology (IWU) is to investigate new application fields of active materials. This paper is primarily focused on thermal shape memory alloys (SMA). Using the example of "small servo drives" in cars the extraordinary potential of SMA based drives is compared to conventional solutions.

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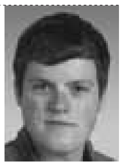

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MORE MECHATRONICS

In recent years cars evolved into increasingly complicated mechatronic systems with wide range of functions controlled by electronic devices. Beyond the main systems like engine management, braking system, or the chassis there are numerous small servo drives which are for example used to move mirrors, seats, electric windows, or petrol caps. Furthermore, there are hidden drives that the driver mostly does not notice such as air flaps in the air conditioning system, charge air flaps, or systems which control engine or gearbox temperature. These components are almost exclusively based on DC drives combined with gears.

Because of increasing demands regarding weight, cross section, and costs this trend will certainly sooner or later reach its limits. Therefore, future research and development has to focus on new technologies like microelectronics and smart materials [3].

The Department of Adaptronics and Acoustics at Fraunhofer IWU has been investigating the potential capabilities of smart materials such as magnetic and thermal shape memory alloys (SMA) for years. Using this background Fraunhofer IWU was able to transfer this technology to applications in automotive and mechanical engineering. Due to the intensive developments regarding materials, electronics, and control the substitution of the addressed small DC drives by practicable SMA actuators became possible.

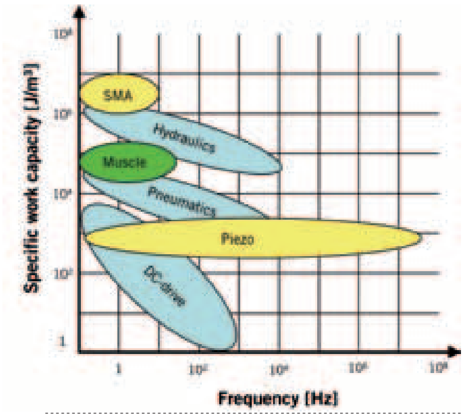
SHAPE MEMORY ALLOYS

Certain metallic alloys, several plastics, fibre composites, and few chemical substances are able to remember a defined shape if an indicating physical value is applied to them. This occurrence is designated as shape memory effect. It requires a special material conditioning that is essential for remembering the shape. Depending on the physical value the materials are distinguished by thermal, magnetic, and optic SMAs [1].

Thermal SMAs as thermo-mechanical energy converters have been in the focus of researcher for several years now. Compared to bimetals they produce their actuator capabilities within a rather small temperature range. The principle is based on a reversible micro structural transformation caused by the applied temperature. The effect is therefore mentioned as thermal shape memory effect (SME).

SMAs are currently available as semi finished goods in shape of wires, rods, tubes, plates, and sheets [10]. They are easy to integrate into mechanical structures and capable of handling high specific workloads. Therefore, SMAs possess an outstanding potential to serve as positioning devices in automotive applications. ❶ shows the correlation between frequency and specific work capacity of SMAs compared to conventional actuator principles.

It is obvious that they are rather not subjected to any scaling effects. The specific work capacity does not decrease with the dynamic behaviour.



❶ Comparison of actuator principles

The actuator concept of SMAs is based on two different application scenarios. On the one hand the actuator element can be activated by an external energy supply as for example by heating via direct application of an electrical current or by surrounding heating elements. On the other hand it is possible to use certain process heat to activate the effect. This possesses the possibility to integrate additional temperature controlled functions such as fail safe systems.

The design process of SMA actuators is as far as possible investigated. It is based on the fundamental demands of applied stroke and force [8, 9]. The maximum stroke is limited by the reversible strain of the wire that furthermore depends on the number of cycles. Under certain conditions more than 1 million cycles can be achieved [9]. To investigate these ageing characteristics of SMAs Fraunhofer IWU designed a test bench and set it to operation. Within current activities it is used for basic investigations of different actuators under different load conditions.

There are numerous established approaches to model SMAs that occasionally differ in their complexity. These range from microstructural approaches to describe the macroscopic behaviour of an actuator to phenomenological methods. Considering the technical relevance the approach described in [6] seems to be an appropriate basis because it constrains the mathematical approach to the inner behaviour of the material. This yields physically defined model parameters, which can be measured if they are not given in the material specifications. The basis of the so developed numerical model is the power balance of the activation behaviour of SMAs. This not only allows investigation of static mechanical values but also enables analysis of the thermal dynamic behaviour.

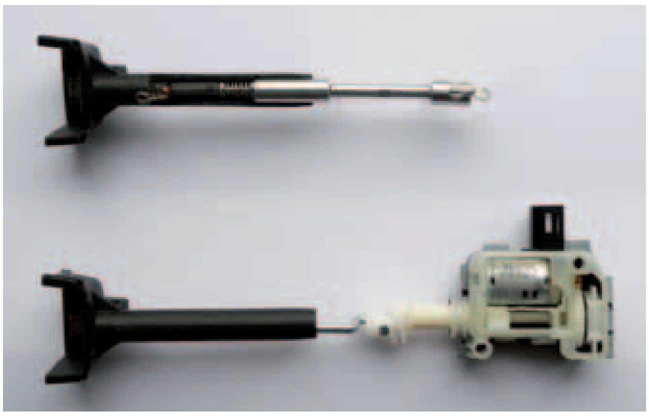
Due to the highly nonlinear, hysteretic correlation between applied heating energy and stroke, the control of SMA's without a closed loop is only suitable for switching devices. A closed loop control as described in [9, 8] is rather suitable to implement SMAs as position controlled actuators, even if there are strong external disturbances. Furthermore, SMAs have a distinctive correlation between stroke and electrical resistance. That effect enables control of the actuator's position without the need of external sensors, exclusively by measuring the resistance [8].

Since ten years ferromagnetic shape memory alloys (FSMA) represent a new field in material science. The worldwide activities are mainly focused on the development of monocrystalline NiMnGa FSMAs. Due to their movable lattice structure they are able to generate exceptionally high strains of up to 10 % [11]. The essential benefit of FSMAs is the combination of high strains (factor 100 compared to piezoceramics) coupled with high dynamics (factor 1000 compared to SMAs). To decrease the currently high production costs of FSMAs it is crucial that future developments in material science focus on much more cost effective polycrystalline alloys [4].

Another group of memory materials are optical shape memory alloys (OSMA). They are presently available as shape memory polymers. Like common SMAs OSMAs can change their amorphous state (flexible, elastic) to a crystalline (stiff) state [2]. The exposure to light affects the grade of cross linking in the material and therefore influences their elastic properties. As a result of the relatively low specific work capacity and the strong temperature dependence OSMAs are not applicable as actuator materials. Current applications are limited to fixed temperature intervals and are therefore constrained to medical and space devices.

APPLICATION POTENTIAL OF SHAPE MEMORY ALLOYS IN CARS

Considering the previously explained material properties of the different memory alloys particularly thermal SMAs seem to be made to be applied in cars. Potential applications are drive functions with moderate force and stroke demands. These functions are currently performed by con-



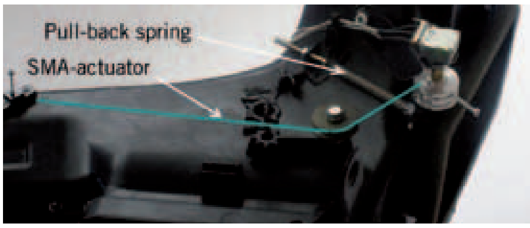
a) SMA – and conventional solution

ATTRIBUTE	DC DRIVE	SMA ACTUATOR
Cycle time	0.5 s	1 s
Power consumption	5 Ws	5 Ws
Cross section	Compact	Customizable
Acoustic emission	High	None
Complexity	High	Low
Weight	Approximately 104 g	Approximately 33 g
Number of components	10	3

b) Comparison of concepts

❷ Comparison of petrol cap locking devices

a) Current approach



b) SMA approach

ATTRIBUTE	DC DRIVE	SMA ACTUATOR
Cycle time	3 s	2 – 3 s
Price	Approximately 5.00 €**	Approximately 2.50 €**
Cross-section	Compact	Customizable
Acoustic emission	Low	None
Complexity	High	Low
Weight	Approximately 65 g	Approximately 20 g
Number of components	> 10	< 10
Positioning accuracy	±1,5°	±1,5°

* Price DC Drive: Specification supplier
** Price SMA Actuator: IWU purchase price of components, excluding development costs

c) Comparison of concepts

❸ Comparison of air-flap-adjustment solutions

ventional gear headed DC drives. Possible applications are thermal activated motion components for air condition flaps, ventilation systems, headlamp covers, and mirror or headlamp adjustments.

Compared to electromechanical DC drives the benefits of SMA solutions are obvious. They are lighter, need less cross section, the number of parts decreases, they are much more cost effective, and moreover operate silent. This makes SMAs especially suitable for applications in the interior and the major benefits will, based on two examples, be documented precisely below.

APPLICATION EXAMPLE: LOCKING DEVICE OF A PETROL CAP

❷ shows a conventional, electromechanical petrol cap locking device (down) compared to the developed SMA solution (top). The drive task was to perform a stroke of 5 mm with an applied force of 10 N. The movement occurred uncontrolled because the petro cap is constantly closed and the actuator only has to be activated if the driver requests to open it. The electromechanical component consists of a DC drive with an additional multistage gear. The novel solution does not require such complexity because the linear movement can simply be realized by an appropriate designed SMA wire with a pull back spring.

Thus, the weight of the component could be reduced from 104 to 33 g with the applicated SMA material occupying only 3 g of total mass. The number of parts could be decreased from ten in the electromechanical component to three in the SMA drive. Another advantage is the cross section. The new solution does not need any additional space for the actuator, which makes the entire assembly highly compact and therefore superior. Furthermore, the SMA drive is completely silent. The power consumption of the developed petrol cap is 5 W for 1 s so it needs exactly the same amount of energy as the conventional solution that uses 10 W for 0.5 s.

The durability of the wire for more than 10,000 cycles was experimentally verified. There was no measurable deterioration.

APPLICATION EXAMPLE: INTERIOR AIR FLAP

Besides uncontrolled applications of SMA actuators Fraunhofer IWU developed closed loop position controlled systems. ❸ shows an SMA based air flap adjustment for the car interior compared to the conventional solution with stepper motor and gear. The task was to adjust the flaps opening angle to control the flow of the air conditioning system.

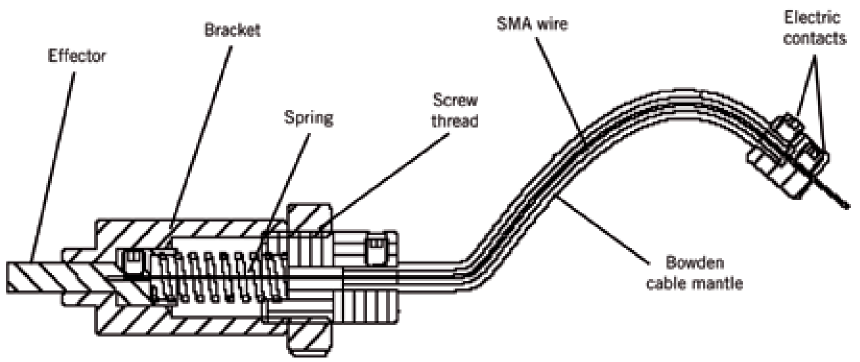
The currently applied compact drive consists of a stepper motor equipped with a multistage gear. It realizes a rotational movement of 45° with relatively low forces. This functionality could be displaced by an SMA actuator. To control the flap opening angle an additional position sensor was necessary. This was realized by a conventional potentiometer mounted on the pivot of the flap. The controller function and the power electronics could be designed by competitive electronic components. The comparison of the two approaches in ③ clarifies the potential of SMAs especially for such systems.

The necessity of an additional position sensor is absolutely acceptable if the sensor is cost effective like a potentiometer. If the application on the other hand requires a linear position sensor the effort can easily exceed the benefits. To overcome this problem Fraunhofer IWU focused on sensor-less drive concepts of SMA actuators. The approaches base on the exceptionally strong length-resistance correlation of SMAs. This enables to realize an indirect position control by measuring the resistance. This approach was successfully implemented in a medical application [7] and showed it's exceeding potential for more cost effective controlled drives.

APPLICATION EXAMPLE: FLEXIBLE SMA ACTUATOR

Implementability of actuators is a determining factor in numerous automotive applications. The available cross section is strictly limited while it's geometry is variable. The application of standardised actuator modules is therefore not possible. To use the available cross sections more effective Fraunhofer IWU developed a novel, flexible SMA actuator module.

The developed module is an independent, easy to integrate component that is



❹ Flexible SMA actuator

especially suitable for applications with high positioning demands and limited cross sections. As shown in ❹ the actuator concept is based on a shape memory wire that is implemented in a flexible Bowden cable casing [5]. The fixed mounting of the casing allows using the stroke of the activated wire at the effector. An integrated spring with a defined stiffness as boundary element guarantees resetting to the initial state and ensures a defined end position. The specific pre stress that is needed for SMA's and the resulting stroke can be set by a thread in the bracket. Furthermore, it is possible to set the actuator properties by the length of the Bowden cable and the SMA wire. The electrical power is applied by two insulated contacts at the end of the actuator. The bowden cable mantle operates as low resistance return contactor.

The design of the actuator considering the mechanical parameters stroke, force, dynamics and reliability is realized by an adequate design of the wires parameters length, diameter and alloy composition, and the design of the pull back spring. Therefore, it is possible to use one and the same module to realize several applications only by changing the spring and the wire.

SUMMARY

Due to intensive research the capabilities of SMAs steadily increased in recent years. Not just the actuatory capabilities, but also the reliability as well as the applicable temperature ranges improved tremendously. Application in cars is therefore not a matter of feasibility; it's just a matter of time.

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REDUCING FUEL CONSUMPTION BY IMPROVED VEHICLE EFFICIENCY

The challenge of fuel consumption reduction has a strong focus in vehicle development. Toyota has evaluated different scenarios of fuel consumption potential based on existing and in near future available technologies. The presented measures of improved vehicle efficiency will be illustrated at a compact vehicle with a hybrid powertrain, which can reduce fuel consumption by nearly the half.

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COUNTER THE NEGATIVE ASPECTS OF VEHICLES

The number of vehicles (excluding motorcycles) in use around the world is predicted to reach 1.2 billion in 2020 and 1.6 billion in 2030, mainly due to increased demand in developing countries [1, 2, 3]. Consequently, there is likely to be growing pressure to counter the negative aspects of vehicles, including traffic accidents and environmental impact. Currently, the issue attracting most attention is the reduction of CO_2 emissions. Although substantial reductions in CO_2 emissions may ultimately depend on the introduction of bio-energy fuels under the carbon-neutral concept or the electrification of vehicles, this paper discusses the prospects of reducing fuel consumption in the future from the standpoint of improving vehicle efficiency.

REDUCING FUEL CONSUMPTION

Even before global warming became the focus of attention, efforts were being made to reduce fuel consumption by improving basic vehicle efficiency. These efforts include improving the efficiency of the engine and drive train systems, and the reduction of vehicle mass and road load (RL). Eq. 1, Eq. 2 and Eq. 3 show the conceptual formulas used to express fuel consumption.

EQ. 1

$$Fc(t) = \frac{1}{\mathrm{P}} \cdot \frac{RL(t) \cdot \mathrm{L} + \Delta k(t) \cdot \eta g(t)}{\eta e_{max} \cdot R\eta e(t) \cdot \eta t}$$

In this equation, $Fc(t)$ is the fuel consumption (cc), P the energy of fuel (J/cc), $RL(t)$ the road load (N), L the driving distance (m), $\Delta k(t)$ the increase in kinetic energy (J), $\eta g(t)$ the kinetic energy regeneration efficiency (–), ηe_{max} the engine maximum efficiency (–), $R\eta e(t)$ the engine efficiency rate (–), and ηt the drive train transmission efficiency (–).

EQ. 2

$$RL(t) = \mathrm{M} \cdot \mathrm{G} \cdot \mathrm{RRC} + \frac{1}{2} \cdot \rho \cdot V(t)^2 \cdot \mathrm{C_D} \cdot \mathrm{A}$$

EQ. 3

$$\Delta \mathrm{k(t)} = \frac{1}{2} \cdot M \cdot (V(t)^2 - V_0(t)^2)$$

In Eq. 2 and 3, M is the vehicle mass (kg), G the gravitational acceleration (m/s^2), RRC the coefficient of tire rolling resistance (–), ρ the air density (kg/m^3), C_D the coefficient of aerodynamic drag (–), A the frontal area (m^2), V(t) the vehicle velocity (m/s), $V_0(t)$ the vehicle original velocity (m/s). (Note: Items in italics with (t) are time variables.)

❶ shows that the fuel consumption of compact cars has been reduced by 40 % in ten years. Furthermore, the hybrid systems, which combine a combustion engine with electric motor to greatly reduce fuel consumption, have become popular [1, 2, 3].

IMPROVEMENT OF POWER TRAIN EFFICIENCY

Targeted is the improvement of the time average of the power train system efficiency to 45 % by hybrid technology. The theoretical upper limit for the thermal efficiency of an internal combustion engine is approximately 60 %. Currently, the highest thermal efficiency for a gasoline engine (ηe_{max}) is between 30 and 35 %. However, in actual driving, thermal efficiency falls as a result of engine speed and load conditions, ❷. As a result, even in driving mode after warm up, the average value for $\eta e_{max} \times R\eta e(t)$ may only be as high as 25 % within standard cycles. As shown in ① and ②, the fuel consumption reduction effect of hybrid technology is obtained primarily by concentrating engine operation in regions of high thermal efficiency. In terms of Eq. 1, hybrid technology enables the time variable $R\eta e(t)$ to be maintained close to 100 % at all times. From this standpoint, the highest thermal efficiency can be maintained if the engine is used exclusively as a generator. Toyota's THS II series-parallel hybrid system achieves thermal efficiency close to this value.

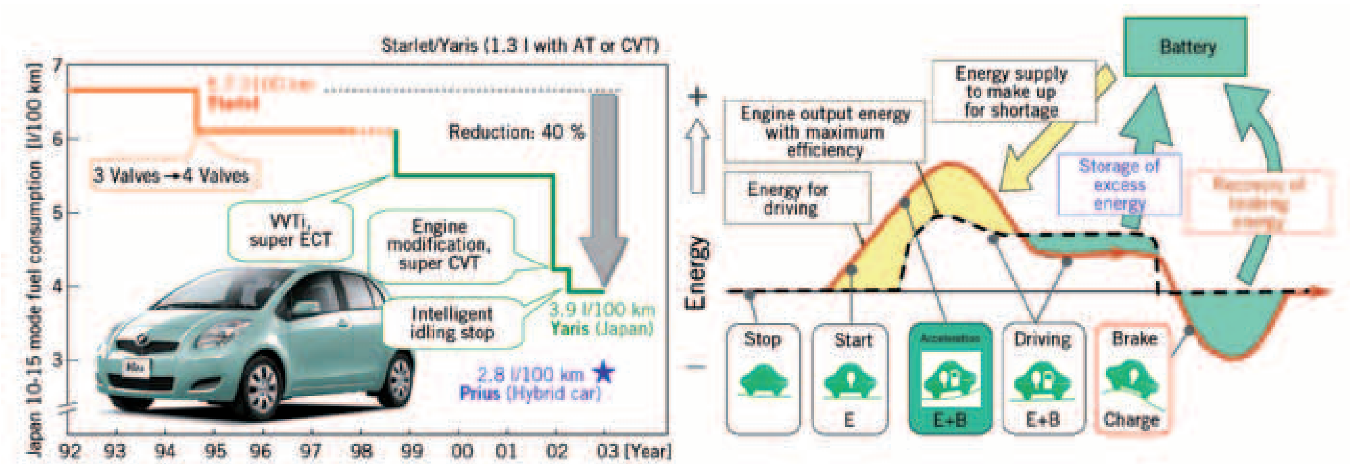
As expressed as $\Delta k(t)$ x $\eta g(t)$ in Eq. 1, hybrid systems save fuel by regeneration of kinetic energy as electricity on braking. Even a micro-hybrid system, which performs as a simple generation control with an alternator, can provide a certain fuel saving effect. Power train system efficiency can be expressed as the product of engine thermal efficiency and transmission efficiency ($\eta e_{max} \times R\eta e(t)$ x ηt). As shown in Eq. 4 and Eq. 5, if the apparent transmission efficiency $\eta t^*(t)$ is calculated, the transmission efficiency $\eta t^*(t)$ of hybrid systems including this regeneration amount is the equivalent of more than 100 %. Then, in combination with improvements in engine maximum thermal efficiency, the time average of power train system efficiency ($\eta e_{max} \times R\eta e(t) \times \eta t^*(t)$) may reach 45 % in the future, ②.

EQ. 4	$Fc(t) = \dfrac{RL(t) \cdot L}{\eta e_{max} \cdot R\eta e(t) \cdot \eta t^*(t)}$
EQ. 5	$\eta t^*(t) = \eta t \cdot \dfrac{RL(t) \cdot L}{RL(t) \cdot L - \Delta k(t) \cdot \eta g(t)}$

LOWER ROAD LOAD

Furthermore, a lower road load by means of reduction of vehicle mass, tire RRC and aerodynamic drag commits to a reduction of fuel consumption.

In Europe where there are greater opportunities to drive at comparatively



❶ History of fuel consumption and energy management of hybrid cars

high speeds, aerodynamic drag resistance makes a larger contribution to total driving resistance. In other countries, however, rolling resistance is relatively more significant. In Japanese urban areas in particular, the average driving speed is fairly low at 20 km/h, which greatly increases the contribution of rolling resistance.

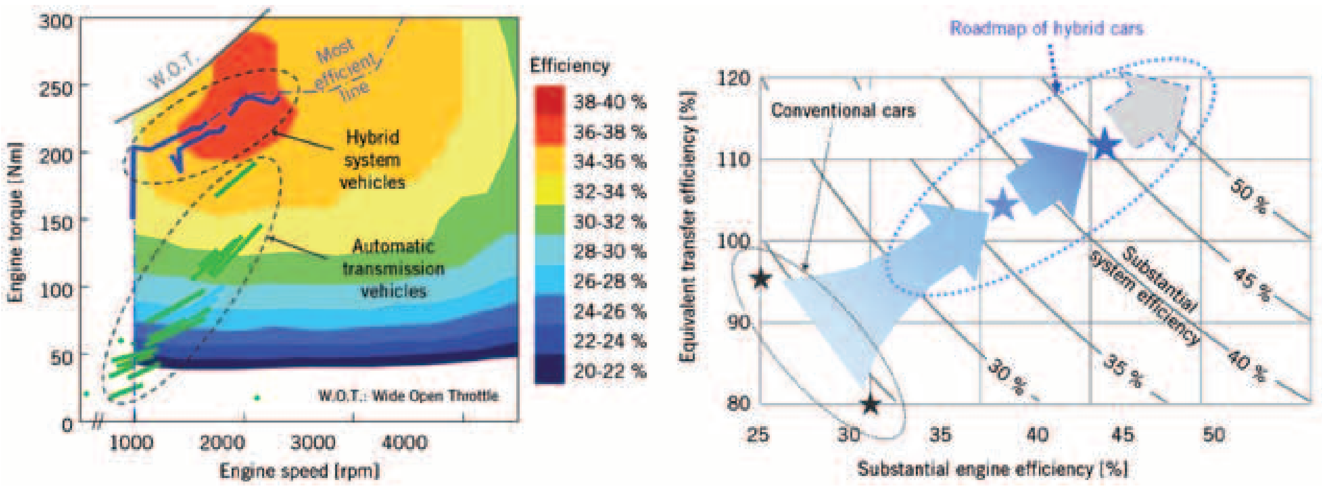
Reducing vehicle mass (M) is a direct way of decreasing acceleration resistance. But it also has positive impact to the rolling resistance. However, it is not easy to make across-the-board reductions in vehicle mass while maintaining today's high level safety and comfort standards. ❸ shows that vehicle mass can be reduced more than 30 % as the result of an iterative cycle whereby a lighter vehicle requires a lighter chassis and a smaller and lighter power train, thereby creating a vehicle with lower fuel consumption, which therefore only needs a smaller fuel tank, and so on.

Tire rolling resistance has also been lowered steadily [1, 2, 3]. Currently, general passenger car tires have a rolling resistance coefficient (RRC) of around 100×10^{-4}, and the technical leaders in the market have achieved an RRC of approximately 75×10^{-4}. It has been reported that further developments are currently under way to reduce RRC to half. However, a reduction of 20 % to around 60×10^{-4} is believed to be more likely for mass-production tires for the time being.

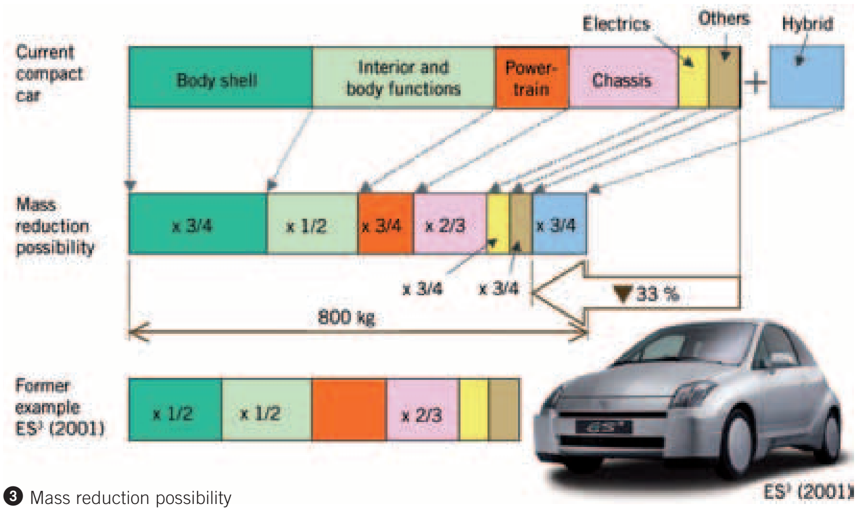
Trends for aerodynamic drag show that most recent compact cars have a coefficient of drag C_D of approximately 0.3. The Toyota Prius and several other cars, developed with a specific focus on fuel efficiency, have already achieved a level of 0.25 and it is likely that C_D is already close to its lowest limit. With respect to frontal area A, there is a moderate trend toward reducing vehicle height. However, this is not likely to become a major trend for practical reasons such as ease of ingress and egress seat position and ergonomics. A level of $A = 2.0\ m^2$ may be seen as a practical figure for a passenger car.

STUDY OF FUEL CONSUMPTION

To evaluate the potential of different fuel reduction measures a comprehensive computer simulation study based on different vehicle variants was conducted. Therefore



❷ Optimized operation of hybrid system and substantial system efficiency



❸ Mass reduction possibility

the powertrain model AVL Cruise was integrated into the simulation environment IPG CarMaker, to generate not only results for classical fuel cycles (NEDC, FTP, JC08 etc.) but rather to compare the results with real 3D public roads (for example auto motor sport fuel consumption lap) and within traffic follow scenarios.

❹ shows the specifications for the base and one studied vehicle, to illustrate the results with one sample. The base case is a current mass-produced compact car in the B segment that includes a hypothetical hybrid power train system. The studied case is an assumed future compact car created using the data described above.

❺ depicts the results and the potential reduction in fuel consumption of the studied case within the New European Driving Cycle (NEDC) as one sample. It indicates that basic efficiency improvements can reduce fuel consumption by nearly half even for a vehicle already powered by a hybrid system. Simulation on 3D public roads and at traffic follow scenarios showed comparable relative results, even if the absolute values are different. These results show that a hybrid system makes a major contribution to improving power train efficiency, and further confirm the importance of technologies that reduce vehicle mass and tire RRC.

REDUCING ACTUAL FUEL CONSUMPTION

Experience shows that vehicles consume relatively more fuel in actual driving conditions (vehicle-driver-environment interaction) than in standard cycle driving, particularly in short distance driving and in winter. The reasons were analyzed, but could not be illustrated in deep in this paper. But, as shown in ❻ in addition to the fuel required for driving the vehicle, fuel is also consumed to warm up the power train, to heat the passenger compartment, and in response to various demands for electrical load. The following section estimates the heat required to warm up the power train and heat the interior, and shows the potential achievements.

Reducing vehicle mass by more than 30 % enables the size and mass of the power train to be reduced, thereby decreasing its thermal capacity. Since waste heat is not generated, improvements can be made to the circulation of coolant, reducing the heat demand by nearly half. As shown in ③, interior mass can be reduced to approximately half, which leads to less demand for interior heating. In addition, adopting high-performance glass with anti-fog and thermo reflection functions, and improving the thermal insulation performance of interior trim should reduce ventilation and external heat transmission losses. This should also minimize the frequency that the engine starts up to meet the demand for interior heat. The same should also be true for the air conditioning.

The increase in fuel consumption in an actual use can be shown conceptually by the sum of the following items:

EQ. 6

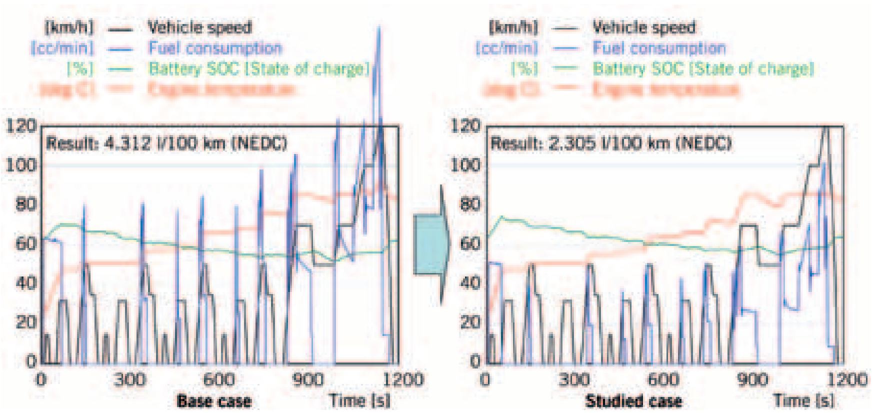
$$Fc^*(t) = Fc(t) + Fcp(t) + Fch(t) + \frac{El(t)}{\eta e_{max} \cdot R\eta e(t) \cdot \eta t}$$

There, $Fc^*(t)$ depicts the actual fuel consumption (cc), $Fcp(t)$ the fuel consumption for warm up (cc), $Fch(t)$ the fuel consumption for heating (cc), and $El(t)$ the electrical power consumption (J). Particularly in winter, the increase in fuel consumption can be reduced by 70 % by thermal management and reducing electrical loads.

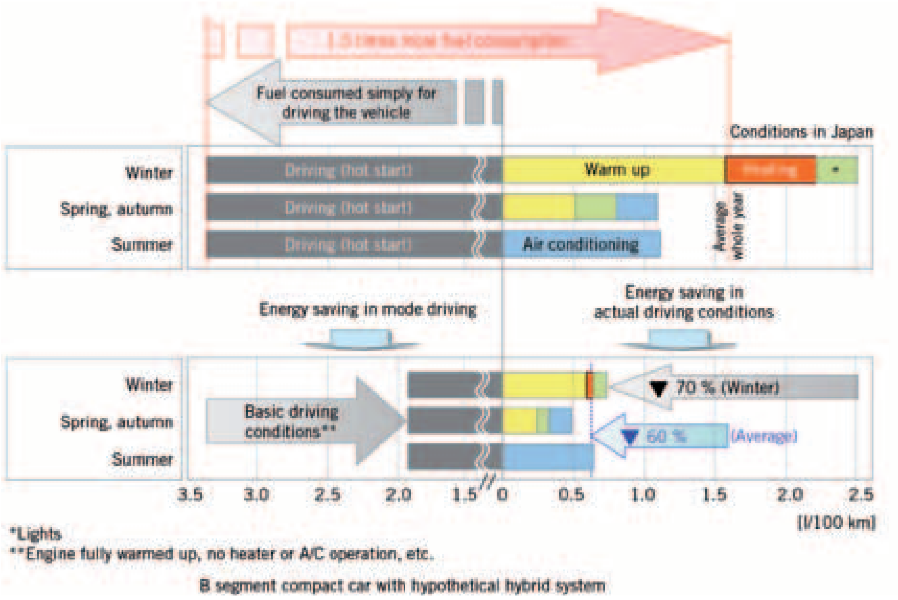
	BASE CASE*	STUDIED CASE	FUEL CONSUMPTION
Curb mass	1200 kg	800 kg	
Gross **mass** with 2 occupants	**1350 kg**	**950 kg**	**–14.6 %**
Tire **RCC**	**100 × 10⁻⁴**	**60 × 10⁻⁴**	**–10.6 %**
Overall length	3785 mm	3785 mm	
Overall width	1695 mm	1695 mm	
Overall height	1520 mm	1435 mm	
Frontal **area**	**0.22 m²**	**0.20 m²**	**–2.7 %**
Coeffizient of aero**drag**	**0.26**	**0.23**	**–2.7 %**
Engine displacement	1496 cc	996 cc	
Transaxle	THS II	THS II	
Averaged system **efficiency** (including hybrid system)	**37.5 %**	**45 %**	**–18.9 %**
Drive configuration	FF	FF	

*The base case is a current mass-produced compact car in the B segment with a hypothetical hybrid powertrain system.

❹ Contributions of automobile basic efficiency to reducing fuel consumption



❺ Simulated fuel consumption from base to studied case



❻ Breakdown of fuel consumption in actual conditions

If progress is made in reducing fuel consumption by improving vehicle efficiency (that is by reducing the amount of waste heat generated), the impact of thermal management on fuel consumption increases in relative terms. Thus, the immediate target should be to meet the heat demand using only the minimum generated thermal energy for warming the power train, interior heating, the ventilation and air conditioning (HVAC) system, and the like.

CONCLUSION

The CO_2 emissions of certain compact cars should fall to approximately 50 g/km at some stage. The mass reduction, energy management, and electrification technologies accumulated in this process will help speed up the switch to alternative fuels and the electrification of power trains as well as improve the efficiency of conventional vehicles. The synergistic effect of these technologies will bring us closer to achieving the ultimate aim of reducing vehicle CO_2 emissions to virtually zero.

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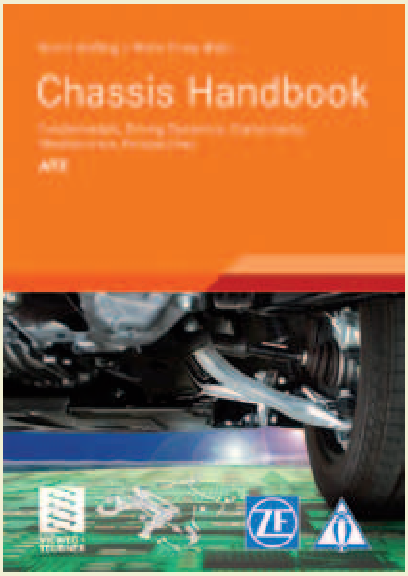
Tyres, wheels, suspension – how comfortable are our cars?



Bernd Heißing | Metin Ersoy (Hrsg.)

Chassis Handbook

Fundamentals, Driving Dynamics, Components, Mechatronics, Perspectives

2011. XXIV, 591 pp. with 970 fig. and 75 tab. (ATZ/MTZ-Fachbuch) hardc. EUR 69,95
ISBN 978-3-8348-0994-0

In spite of all the assistance offered by electronic control systems, the latest generation of passenger car chassis still relies on conventional chassis elements. With a view towards driving dynamics, this book examines these conventional elements and their interaction with mechatronic systems. First, it describes the fundamentals and design of the chassis and goes on to examine driving dynamics with a particularly practical focus. This is followed by a detailed description and explanation of the modern components. A separate section is devoted to the axles and processes for axle development.

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The authors

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Prof. Dr.-Ing. Metin Ersoy completed his doctorate in Design Systematics at the Technical University of Braunschweig and spent more than 30 years at a managerial level at various companies, including 20 years at ZF Lemförder, where his most recent post was Head of Predevelopment. He is also an honorary professor for chassis technology at the University of Applied Sciences in Osnabrück.

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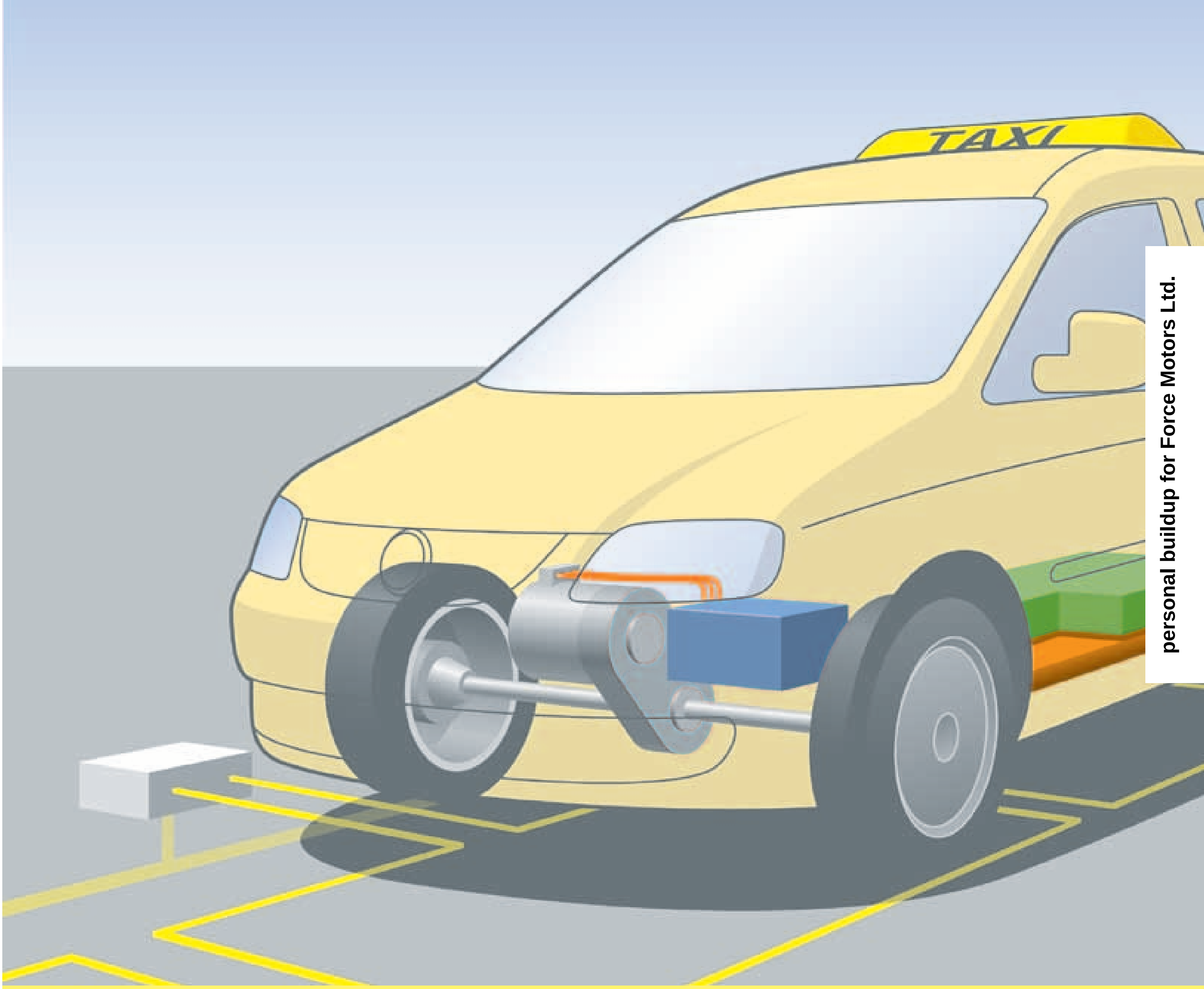

INDUCTIVE ENERGY TRANSFER FOR ELECTRIC VEHICLES

The problem of fast and simple recharging of electric vehicles has still not been sufficiently solved. Cabled systems compete with inductive systems while upright charging pillars are used as an alternative to systems integrated into the road surface. It is even conceivable to recharge the vehicle at traffic lights or while driving. IAV presents an overview of the advantages and disadvantages of all charging systems on the basis of examples. The inductive systems are evaluated as assertive technology, appropriate market opportunities can be conceivable.

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DIFFERENT CHARGING PROCESSES

Electric vehicles powered from regenerative sources, such as wind or sun, produce hardly any climate-changing CO_2 emissions – making them a key component of sustainable mobility concepts. Automotive manufacturers and suppliers across the globe are working flat-out on this new technology.

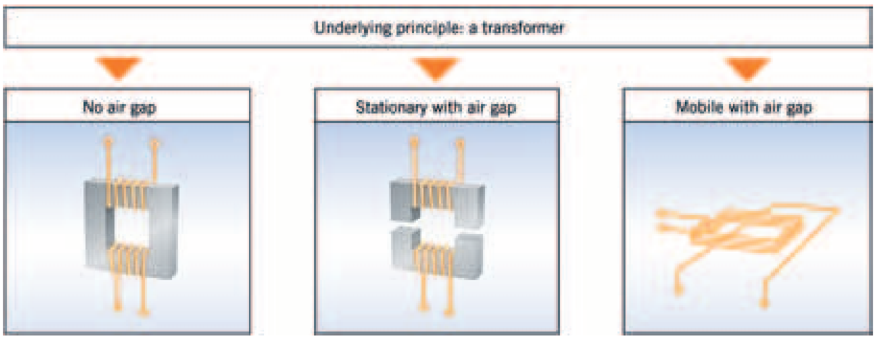
However, e-mobility not only poses a variety of technical challenges – there is also a need to address the misgivings potential users have. This is why projects currently being sponsored are not only examining the purchase price and cruising range issue of electric vehicles but also user attitudes toward the recharging process [1].

Conductive charging of the battery by cable is the state of the art. This is how an electric vehicle can be recharged today with a charging cable fitted with a suitable plug in reach of a power point. Another option is found in contactless inductive charging. IAV evaluates inductive systems as assertive technology for the future, appropriate market opportunities can be predicted. Appropriately configured, this possibility provides the following benefits over recharging by cable:

: automatic connection to the power supply without involving any user action
: no need to carry a recharging cable on board
: free from wear, dirt and weather factors
: easy integration into the townscape
: high degree of protection from vandalism.

The principle behind the technology – electromagnetic induction – was discovered by Michael Faraday (1791 – 1867) in the 19th century. It is from here that Nikola Tesla (1865 – 1943) developed a system for transferring energy using galvanic isolation. The technology is already employed today in a wide range of everyday applications, ranging from induction hobs to electric toothbrushes.

In principle, the energy transfer works in the same way as in a transformer, ❶. Unlike regular transformers with a ferromagnetic core of the type familiar in power engineering, the inductive transfer passes energy across an air gap. The resultant reduction in efficiency can in part be compensated for by making the system resonant. In automated, driverless transport systems, this has made it possi-



❶ Transferring energy using the transformer principle

ble to supply energy to vehicles without the need for actual physical contact. It is now state of the art.

In the case of the electric vehicle, transfer takes place by means of an alternating magnetic field. This is generated by a primary coil in the road with a high-frequency alternating current passing through it from the primary inverter. The secondary coil in the vehicle converts the alternating field back into a high-frequency alternating current, whereupon it is rectified and made available to the vehicle's energy management system. On top of energy, it also provides the capability of transferring data to the vehicle, such as for billing or for internet provision.

EXAMPLES OF SYSTEMS IN USE

Inductive energy transfer is nothing new to electric road vehicles. The EV1 from General Motors, which was built from 1996 to 1999, was recharged by means of an inductive paddle known as "Magne Charge". The WM7200 model from 1998 had a charging power of 6.6 kW [2]. The paddle was inserted into a receiver of matching design on the vehicle – with the EV1, for example, in front of the bonnet. As far as user safety was concerned, this reduced the risk of electric shock, and enabled energy to be transferred regardless of weather conditions. This option, with its defined position and narrow air gap between the transfer surfaces, produces benefits in terms of efficiency, functionality and electromagnetic compatibility (EMC) at the time of inductive transfer [3].

The potential of inductive energy transfer technology is still not fully exploited merely as a result of being able to recharge the vehicle's battery without the user having to plug it in. This can be done by integrating the secondary energy-transfer unit in the front end of the electric vehicle. On the infrastructure side, the primary unit is installed at the same height, with markings being provided to assist and facilitate vehicle positioning. Once the recharging position is reached, charging can start automatically. This is a concept that was demonstrated in 2000 by the Free University of Brussels and Davis Derby Limited. At normal mains frequency levels of 50/60 Hz, it was possible to transfer 3 kW of power. The low frequencies and wide air gap, however, came at the expense of the high weight of the inductive system in the car, which amounted to approximately 30 kg [4].

A recharging position at the front end of the vehicle is also found on the Karabag/Fiat 500e of 2010, this time behind the license plate. Developed in cooperation with both Vahle and Kostal, this solution is designed to make the vehicle just as quick to recharge as it would be from a conventional 230V socket with a 16 A fuse. Resulting from good visibility at the front end, the advantage lies in the ease with which the vehicle can be matched up with the infrastructure side. As a drawback, mention must be given to a restricted use for different vehicle classes and models. If the difference in height is excessively great between two electric vehicles charged inductively at license-plate level, interface alignment can only be ensured by providing mechanical compensation.

With the electric Renault Clio for the Praxitele project in Saint-Quentin-en-Yvelines in 1998, the inductive interface was moved to the front part of the underbody, compensation being made in the form of a raised section on the primary side. This is also an approach currently being pursued by Evatran. In Praxitele, the raised section also serves as a mechanically based vehicle positioning system, limiting the need for compensation through the inductive transfer setup. This being so, inductive recharging was only a means to an end. The actual focus of investigation behind the fleet test was to create a vehicle hire system filling the gap between local public transport and private vehicles [3, 5].

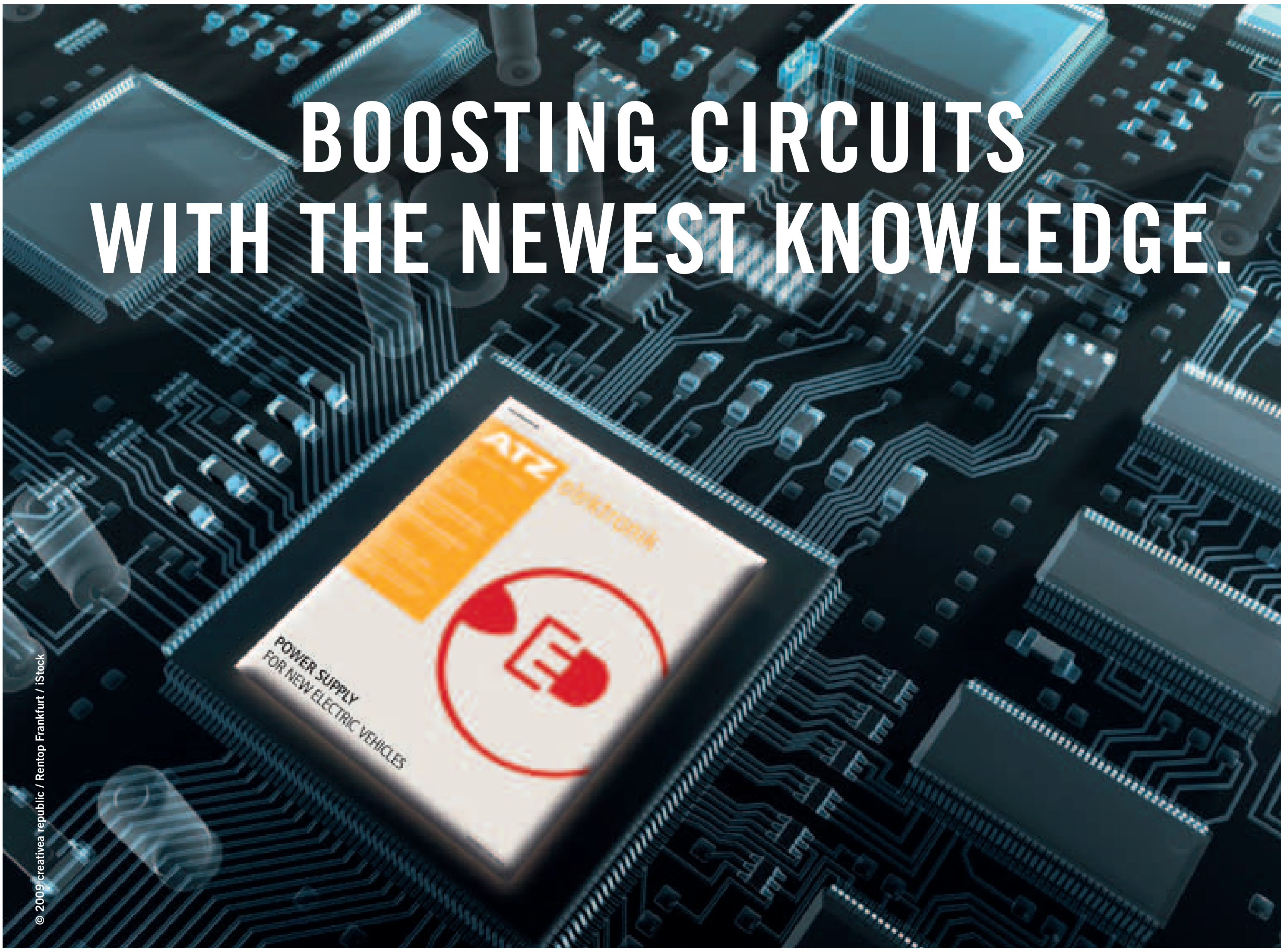
An inductive transfer system without mechanical compensation was featured in Peugeot's Tulip study presented in 1996 at the Paris Motor Show. In the study, recharging took place inductively at the centre of the underbody by means of an asymmetrical system with a larger vehicle coil, providing a greater positioning tolerance. Positioning the vehicle over an in-road structure with primary coil, it was possible to attain a constant level of efficiency with an air gap of between 30 and 60 mm [3].

All of the systems presented have a section raised above road level, be it to accommodate the transfer unit on the primary side or to provide mechanical compensation. These raised elements in general demand a parking position across the direction of travel, are easy prey to vandals and in public spaces present tripping hazards for pedestrians. All told, the full potential of stationary inductive energy transfer has still not been harnessed.

SURFACE LEVEL SYSTEMS

The potential of inductive charging has been better exploited in the fleet test that Conductix-Wampfler and EPT have been conducting with service buses in Genoa and Turin since 2002 [6]. The water-cooled 60 kW recharging surfaces are ideally integrated at street surface level in the parking area of bus stops. The driver positions the bus using an optical system. For recharging, the vehicle's energy-transfer surface is lowered to 30 mm above the surface of the road [7].

With installation at road-surface level and normal vehicle ground clearances of between 100 and 200 mm, it is also possible to dispense with any form of mechani-



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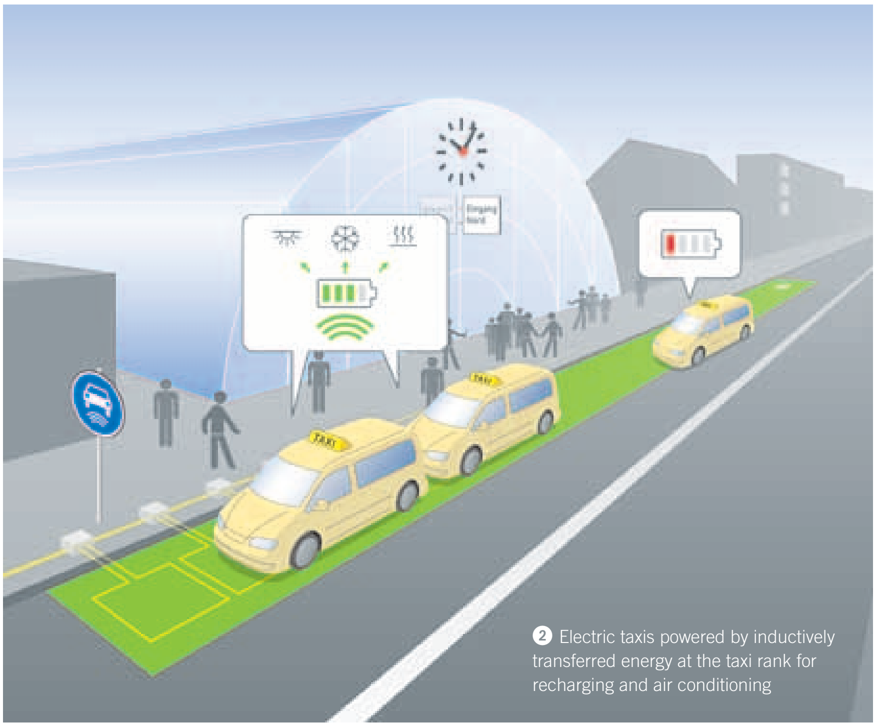


❷ Electric taxis powered by inductively transferred energy at the taxi rank for recharging and air conditioning

cal compensation. This was shown in 2009 by the technology from SEW-Eurodrive at the ecartec fair in Munich.

The potential provided by a system of inductive recharging and energy supply – particularly in the light of the advances being made in semiconductor switching elements and the higher transfer frequencies they permit – has since been acknowledged worldwide. Work is going on in research and development projects to make the technology suitable for use in cars – in Germany in three field tests by Conductix, Indion and W-Charge. These projects maintain an efficiency of over 90 % for inductive energy transfer while meeting the safety standards of the automotive industry in all cases [8].

COMBINED SYSTEMS

At the same time, it is not merely sufficient to optimize efficiency within the various systems. They must – and, needless to say, also at an expected high level of efficiency – work in combination with each other and across all systems in place. This aim is being pursued by a working group at DKE, comprising representatives from automotive manufacturers and component suppliers, manufacturers of inductive energy-transfer systems, research and development institutes, universities and IAV.

One application guideline developed there defines the inductive interface in such way that interoperability must be possible at the greatest possible level of efficiency for the various combinations on the primary and secondary side as well as at the vehicle-make and model level. The guideline aims at realizing a system capable of transferring approximately 3.3 kW of power and suitable for home and in-journey recharging. If the vehicle system is installed at the centre of the x-axis and y-axis and the infrastructure side at the centre of the recharging station, vehicle alignment is irrelevant to diagonal parking. This must be weighed up against the above-described simple positioning capability for systems installed in the front third of the vehicle.

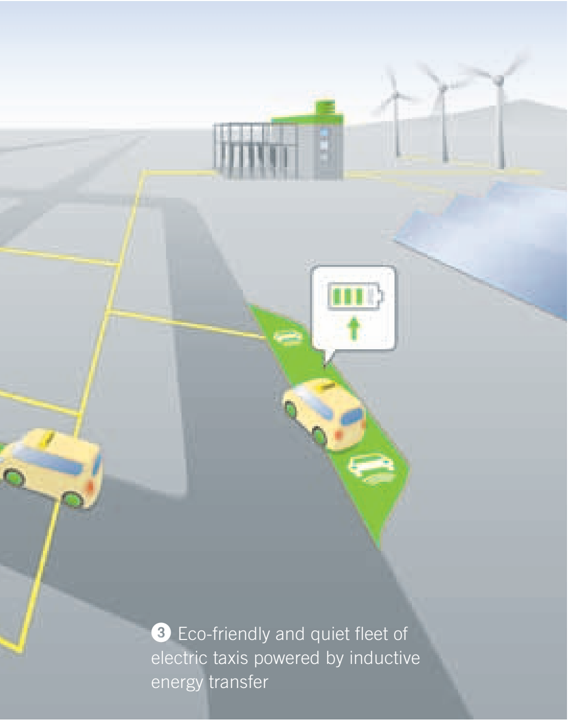
Even today's driver assistance systems can already provide help to position the vehicle or even do this automatically. In future, the primary-side field may be used as a parameter for positioning the vehicle as it approaches. Transfer takes place at a frequency of between 100 and 200 kHz and with an air gap of between 50 and 150 mm across an area of 1 m^2 or less.

ELECTROMAGNETIC COMPATIBILITY

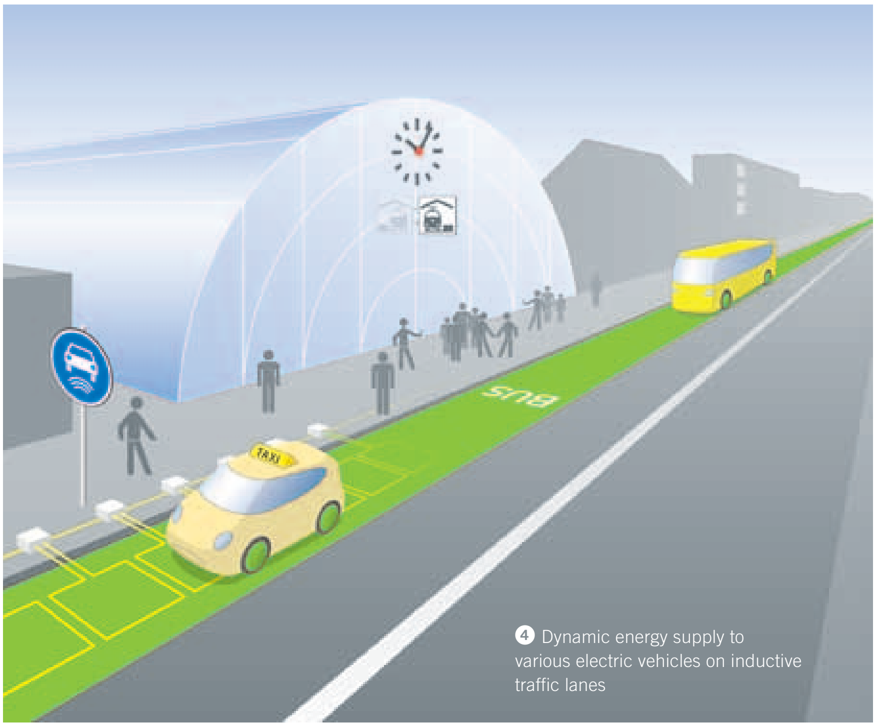
Safety has a key influence on how a charging system is configured, for example with regard to electromagnetic compatibility (EMC). With recharging in public spaces, it is necessary to meet the reference values for magnetic flux density at the particular frequency being used – this being described by the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

Simulations conducted by IAV reveal that this is possible for transferring power of 3.3 kW. The results also show that higher charging power levels in the range of 10 to 20 kW can be achieved without mechanical compensation systems or the need to exceed the reference values in publicly accessible areas. This power range provides the basis for setting up a fleet of inductively charged electric taxis of the type being planned by IAV, ❷.

Even if taxis of this type are recharged incompletely between journeys, sufficient energy can be transferred for the next call-out. Above a critical battery-charge state, power is available for air-conditioning or for heating the vehicle. This ensures permanent, comfortable taxi operation without time-consuming intermittent charging.



❸ Eco-friendly and quiet fleet of electric taxis powered by inductive energy transfer



❹ Dynamic energy supply to various electric vehicles on inductive traffic lanes

And, of course, it is also suitable for applications with similar usage profiles, such as shuttle services.

With a suitably developed network of induction surfaces, it is possible in theory to recharge electric vehicles at every set of traffic lights while they are on red, ❸. Using this technology, the limited cruising range – the e-car's shortcoming currently at the focus of discussion – could be continuously lengthened without any action on the part of the user.

CHARGING ON THE MOVE

Still to be addressed is the potential that today's technology provides for inductively recharging vehicles while they are driving along. This dynamic form of energy supply was demonstrated in the form of a model system at the 2009 Hanover Fair by Braunschweig University of Technology's IMAB Institute, Vahle and IAV, ❹.

The dynamic recharging segment was rated in such a way that sufficient energy was transferred for an entire lap. Dynamic energy supply is currently being investigated by scientists and is already being implemented for low-speed transportation in an initial application in South Korea [9]. Although energy is transferred on a segment basis there too, fitting out bus lanes, main roads or expressway lanes with an uninterrupted supply of inductively transferred energy is also altogether feasible. This would completely resolve the travelling-range problem weighing on electric vehicles.

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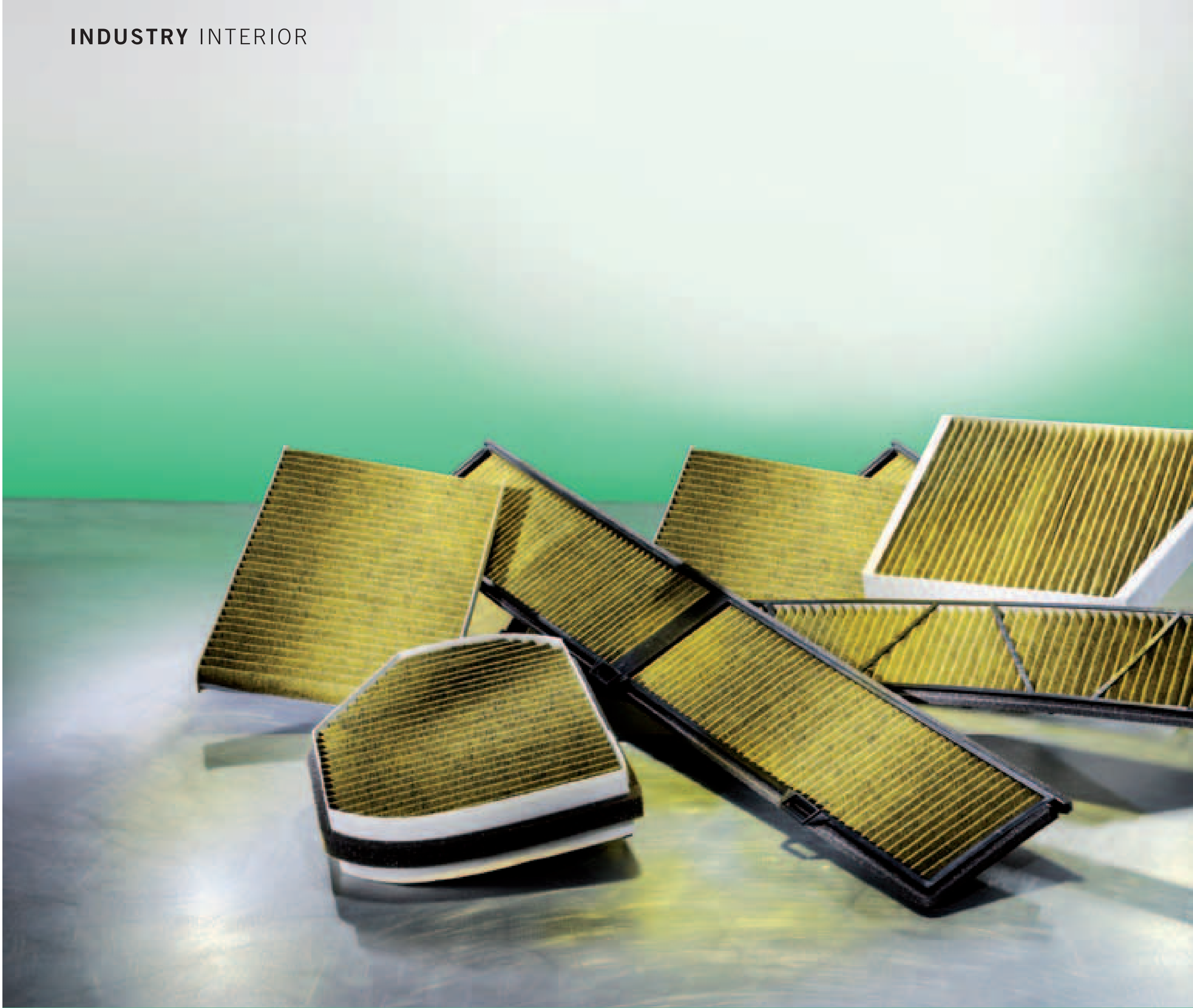

IMPROVED PROTECTION FROM ALLERGENS DUE TO CABIN AIR FILTERS WITH POLYPHENOLS

While the first cabin air filters were designed to protect the components of the air-conditioning system from contamination, modern cabin air filters reliably protect the occupants from hazardous allergens from pollen in the ambient air. Mann+Hummel develops combined filters with layers of activated carbon and polyphenol coating particularly for the Asian market, where customers expect to receive additional health protection. Polyphenols are natural plant substances. Like other anti-oxidants they are said to be anti-inflammatory and antibacterial among other things.

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ALLERGIES ARE GROWING

In recent years, allergies have grown steadily in the population. There are clear regional differences with regard to the frequency of allergies. In general, it can be said that the proportion of people suffering from allergies is particularly high in densely populated and highly industrialised regions. Thus, 59 % of the population in Korea have been treated for allergic complaints, whereas the percentage amounts 44 % in Japan, 28 % in the USA, and 20 % in Europe [1]. In Germany, approximately 20 to 25 % of the population suffer from allergic disorders, with 86 % of allergy sufferers being affected by pollen allergies, around 40 % being allergic to pets, and 14 % to mould spores [2]. The cost of treating pollen allergy sufferers in Germany alone is as high as 240 million euros a year [2]. To date, no effective primary prevention has been developed against allergies, but only symptomatic treatment occurs [2]. Experts believe that the number of cases worldwide will increase by 2 to 6 % each year [1].

By considering the number of vehicle owners in respective markets [3], the figures in ❶ show the number of car owners suffering from allergies in the Europe, North America and Japan. Adding up the number of vehicle owners in the three largest markets leads to a total of around 114 million vehicle owners, for whom protecting the occupants of the vehicle from allergenic pollen is of particular importance.

An air conditioning system pumps large amounts of air into the vehicle interior while the vehicle is in operation. This leads to a significant increase in the concentration of dust particles and pollen inside the vehicle, in the case that cabin air filters are not installed.

CABIN AIR FILTERS RETAIN POLLEN

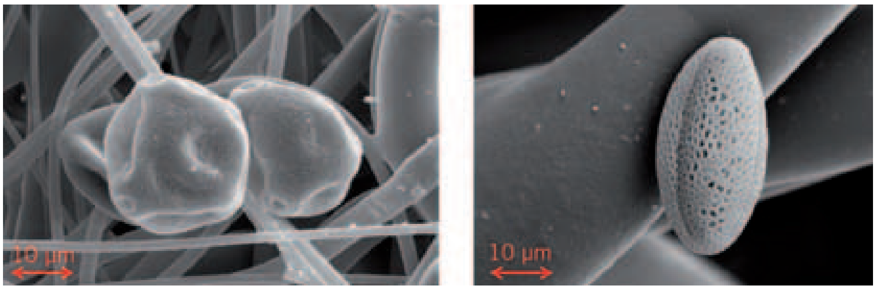
Pollen grains are typically of 5 to 100 µm diameter in size, with the majority being between 10 and 20 µm. Properly designed cabin air filters with efficient filter media have retention rates of more than 90 % for particle sizes of bigger than 1 µm. Therefore, pollen grains can be in principle successfully retained by cabin filters due to their size. ❷ shows scanning electron micrographs of pollen of two different particle filter media. While the birch pollen particles depicted in ② left have an almost round shape, the rapeseed pollen has an elongated flat shape in ② right. The surfaces of the pollen could be relatively smooth and flat, as in the examples illustrated here, but they may also have surfaces covered with verruciform or spiniform structures, such as the highly allergenic ragweed pollen, which is typically spread by the

REGION	NUMBER OF VEHICLE OWNERS [MILLIONS]	ALLERGY SUFFERERS [%]	POTENTIAL MARKET [MILLIONS]
Europe	158	20 %	32
North Amerika	164	28 %	46
Asia	93	39 %	36
Total	**415**		**114**

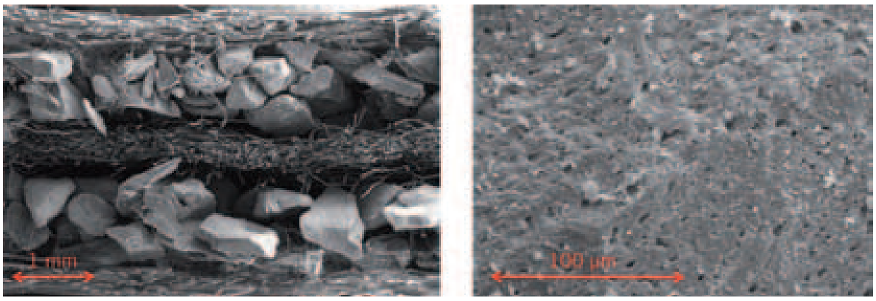
❶ Number of vehicle owners and allergy sufferers in the three large automotive markets European Union, North America and Japan [1] wind from August to October, but which can sometimes still be found in the air as late as December.

The filter medium depicted in ② left in the background has significantly finer fibres compared to the coarse fibre medium in ② right. The pollen grains are retained more reliably by the finer fibre composition.

To provide drivers and passengers with the widest possible protection against allergens and other hazardous substances, Tüv Rheinland has defined a list of criteria entitled with the Toxproof certificate [4]. This involves the filters being tested with reference to the odour and emission behaviour of hazardous substances such as aromatic hydrocarbons and formaldehyde. In addition, their filtration behaviours are tested both with a test dust and with genuine mulberry pollen, which have a relatively small diameter of 10 µm. At Mann + Hummel, fine dust filters were successfully tested in accordance with the Toxproof criteria and have been awarded with the Toxproof quality seal.



❷ Pollen of birch (left, round shape) and rapeseed (right, elongated flat) deposited on filter media



❸ Structure of combination filter media: cross-section through a five-layer combination filter medium (left) and close-up view of an activated carbon particle (right)

COMBINATION FILTER MEDIA FOR COMFORT AND HEALTH

To further increase the comfort of drivers and passengers, combination filters have been developed. In addition to the particle filter layer, those filters are equipped with at least one additional layer of activated carbon. ❸ shows left a cross-section through a high-performance, five-layer combination filter medium with two activated carbon layers and a centrally positioned fine filter layer. This particle layer is designed to retain finest particles, while the carrier media above and below the activated carbon layers fix the particles of activated carbon in place and increase the stability of the composite structure.

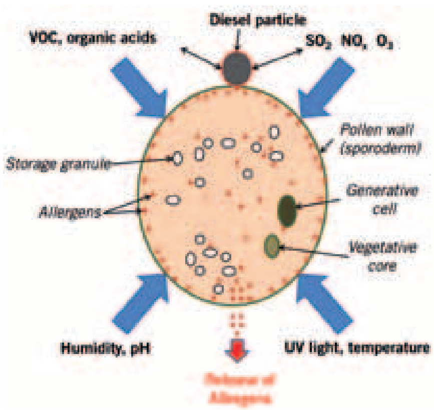
In the magnified image of an activated carbon particle depicted in ③ right, the fine pores are visible in which molecules are physically and reversibly bound by means of adsorption. The activated carbon used for cabin air filters is obtained from coconut shells, on account of its favourable adsorption characteristics and high mechanical stability. The activated carbon adsorbs harmful gases such as sulphur dioxide (SO_2) and nitrogen oxides (NO_x), but also aromatic hydrocarbons and other hazardous chemicals from exhaust gases. In addition, odours produced by agriculture, for example, can be adsorbed, meaning that combination filters not only protect the health of the passengers, thus they also contribute to a further increase in their level of comfort.

INTERACTIONS BETWEEN POLLEN AND FINE DUST

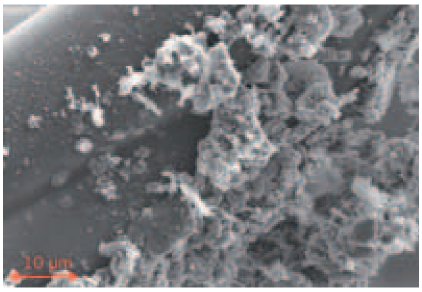
Based on the previous observations, it might be expected that even coarse cabin air filters would provide adequate protection for vehicle occupants against allergenic pollen. The pollen, however, is only the carrier for the allergenic proteins (allergens). Recent studies (over the past 15 years or so) have shown that pollen can also interact with fine dust like diesel particles [5, 7]. ❹ represents a schematic overview of these interactions and environmental influences on a pollen grain and the associated release of allergens [6]. For example, pollen can burst open in wet conditions [7]. In addition, fine dust particles can accumulate on the surface of pollen, resulting in an increased release of allergens.

The released allergens can in turn attach themselves to fine dust particles and thus be transported over long distances [5]. One were able to demonstrate experimentally both the presence of allergens on starch granules between 0.5 and 2.5 µm in size and the binding of pollen allergens to diesel soot particles [7].

Scanning electron micrographs of the fibres of a cabin air particle filter used in a vehicle under real conditions give an insight into the particles which are typically retained by from the filter. ❺ shows the fine dust particles deposited on a fibre. It can be clearly seen that many particles have a size below 2.5 µm. These particles penetrate deep into the alveoli of the lungs and increase the risk of diseases of the respiratory tract [8].



❹ Interaction of a pollen grain with environmental factors (simplified view based on the work of [5])



❺ Air dust deposited on a single fibre of a cabin air filter

It is therefore very beneficial to use high-efficiency filter media in cabin air filters, thus enabling the removal of very fine dust and soot particles, which act as potential allergen carriers, in a highly reliable way.

EFFECT OF POLYPHENOLS

While the deactivation or denaturation of a complete pollen particle is not practical, there are ways of denaturing the allergens released from pollen and of thereby inhibiting their allergenic effect. Polyphenols, for example, can be used to deactivate the allergenic proteins, ❻.

Polyphenols are secondary metabolites of plants (metabolites = intermediate products in most biochemical metabolic processes). The flavonoids, a subgroup of the polyphenols, include a large proportion of flower pigments. Health benefits have been attributed to polyphenols, leading them also to be used as food supplements [9, 10]. Polyphenols are antioxidants and have even been reputed to reduce the risk of cancer and cardiovascular diseases [9]. Some polyphenols, such as the catechins, which contribute to the flavour of black tea and cocoa, have an antimicrobial effect [11]. Polyphenols can also bind with proteins. These reactions are often undesirable in the food industry, as they can lead to turbidity, e.g. in beer, but on the other hand they can also be used to bind allergens deposited on the fibres of cabin air filters, thus rendering them harmless.

FILTER MEDIA EQUIPPED WITH POLYPHENOLS

The polyphenol coating of Mann + Hummel cabin air filters is designed to achieve the effects described before. Particularly in the Asian market, customers expect to receive additional health protection, especially from allergenic substances and microorganisms. These filters are designed as combined filters, on which the carrier layer is equipped with a polyphenol coating, thus giving it additional functionality.

The polyphenol coating of these filters can be seen from the outside on account of its yellow-green colour. Immunochemical studies have shown that allergens are effectively deactivated by the polyphenol coating. Under the selected test conditions, over 90 % of the allergens of cedar pollen could be deactivated after only 10 min.

SUMMARY AND OUTLOOK

Modern cabin air filters offer a high level of comfort and protection for drivers and passengers. With a innovative polyphenol coating, as Mann + Hummel use it, natural plant extracts can be used to provide an additional anti-allergenic protective function.

Future developments in cabin air filters will focus on a significant reduction in allergenic pollen and fine dust particles (diesel soot) inside the vehicle and on enhancing the comfort of occupants. Constant efforts will be made to improve filtration efficiency, in order to increase the separation of fine dust. This will require a structure which allows very high air permeability and consequently a low loss of pressure, but which also has an excellent dust storage capacity, thus ensuring a long service life for the filter.

Further progresses are aimed at increasing the adsorption capacity of activated carbons, the use of alternative adsorbent materials for specific odour removal and a reliable way of protecting dust-laden filters from microbial growth. On account of the many different tasks performed by a cabin air filter, it is advisable to change it at least once a year or every 30,000 km, in order to maintain its positive functions and protective effects.

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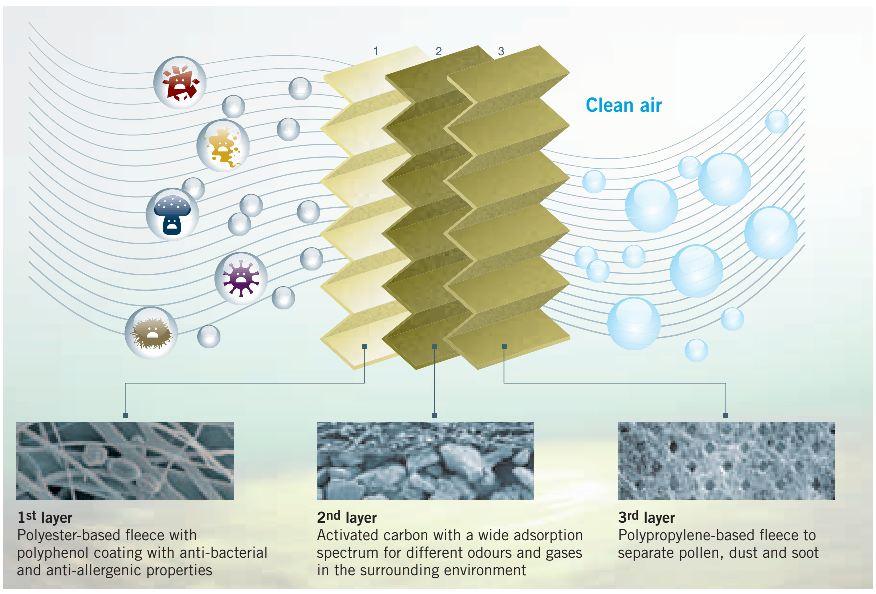

❻ Effective health protection through three filter layers – the first layer consists of a polyphenol coated non-woven material

THIN FOIL ENHANCES INJECTION MOULDED PARTS

With a new thin foil, Benecke-Kaliko AG is introducing its new decorative foil for back injection moulding of products used for applications such as doors, seats and consoles. The foil presents a low-cost alternative to uncoated injection moulded surfaces in car and commercial vehicle interiors. It upgrades traditionally designed, unpainted injection moulded parts substantially.

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BACKGROUND SITUATION

Manufacturers rely heavily on injection moulded surfaces in particular for compact and high-volume vehicles. While this cuts costs, it also presents many disadvantages. The main drawback is the lower-quality impression that injection moulded parts convey in terms of appearance and feel to the touch. The components are often excessively glossy, and the surface is susceptible to scratches. Furthermore, the possibilities for surface designs are very limited.

The problem can be partially solved by subsequent painting. This is, however, an additional costly process that does not lead to optimum results in all regards. Besides additional logistical expense, it requires substantial investments in plant technology and industrial hygiene.

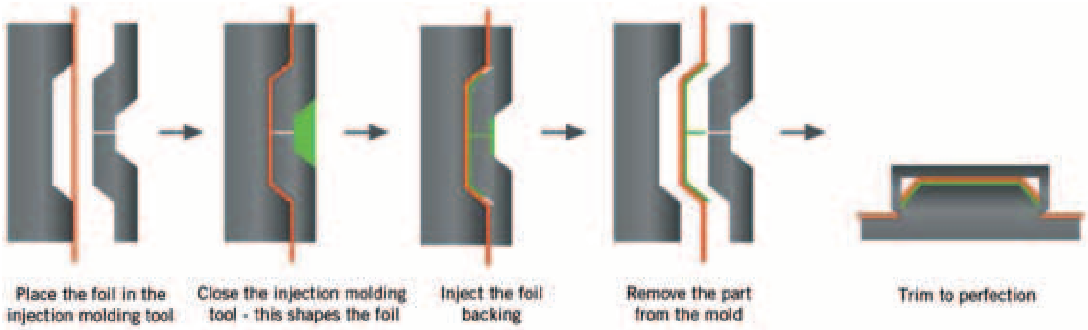
With “DecoJect”, a new TPO-based thin foil that is only 0.2 to 0.5 mm thick, Benecke-Kaliko is going in another direction. The aim is to offer an improvement in scratch resistance compared to polypropylene injection moulded surfaces while at the same time enhancing the qualitative appeal of the components. This makes the foil especially suitable for components that are subjected to high stress due to wear and scratching in day-to-day use, such as doors and door sills.

PROCESSING

The foils were designed for the back injection moulding process. Due to their thin nature, the grain structure can be imparted in the decoration surface by the foil backing tool. In this process, the thin foil, pre-heated as needed, is fixed firmly in the foil backing tool and then injection moulded on the back typically with polypropylene-based thermoplastic masses. The grain structure is in the negative mould on the tool side of the foil backing tool. The tool side with the grain is now pressed onto the foil by the injection of the carrier material onto the back of the foil. Due to the pressure and the injection temperature of the mass, which exceeds 200 °C, the grain information is transferred precisely from the tool to the decorative foil. When it comes to the surface, nearly everything is possible, from a leather look to technical grains. The grain looks good even if the radii are very small, as there is nearly no stretching of the grain structures transferred to the foils, ❶.

This means that the component manufacturer need make only a relatively small investment for an adjustable injection mould. As a rule, no additional pre-moulding step is required. Only extreme geometries may require that the foil be pre-formed to ensure exact grain depiction and shaping, also in areas where it is otherwise prone to distortion.

The thin foil makes it possible to match the colour and gloss of the decorative surface to other components. Furthermore, the foil opens up new design possibilities for vehicle interiors thanks to its broad range of colours. The colour carrier is generally the TPO-based foil material. The paint coating on it serves primarily to adjust the degree of gloss as well as the haptic quality, ❷. In addition to these haptic adjustments provided by paint, further designs are also provided by patterns and special effect paints that Benecke-Kaliko offers optionally, ❸. Even metallic effects are possible.



❶ DecoJect itself has no surface structure of its own, its structure is applied in the back-injection process

Like the good grain stability, the high scratch resistance is a result of the foil construction as well as the formula of the decorative foil. Whereas some PP injection moulded surfaces have a scratch resistance of only about 2 N (measured with the Erichsen hardness test pencil 318), the new thin foil boasts 4 N or more, depending on the surface and grain structure, ❹.

Due to its scratch resistance, the foil is ideal for seat buckets, doors and centre consoles, as well as on the map pocket, on the bottom of the pillars, the back of the headrests, on the rear shelves and the bottom of the instrument panel. In addition, the foil is well suited for parts that have previously involved injection moulding, even in the case of high-quality vehicles, and that can be easily scratched. Door sills and trunk loading sills are two good examples. Furthermore, in the storage space there are also many injection moulded parts that can be upgraded and made more resistant to scratches by using the thin foil.

The thin foil is made of lightweight polyolefinic materials, which ensures that the parts are not any heavier than injection moulded surfaces. The recyclable halogen-free interior foils do not require plasticizers, as the necessary flexibility is created solely by their composition. When it comes to the paint finish, Benecke-Kaliko relies on a PUR-based paint system. Other paints are possible as well and can be assessed on request.

COLOUR CHANGES

For the processor, one special benefit of the foils, compared to the traditionally-manufactured injection moulded surfaces, is colour changes. Each time the colour of an injection moulded surface is changed, the injection moulding line must first be run until it is empty and be started up again with the material of the new colour. This results in waste and lost time every time in order to attain the required colour consistency. Typically, one colour change can quickly lead to 50 kg of waste material as well as an hour of tooling time. This can be avoided with the thin foil, with which the component can be produced constantly with one back injection material despite a change in the surface design. The colour, gloss, haptics and effect of the surface are determined solely by the foil. Furthermore, typical flaws from the injection moulding process, such as seams, colour and gloss deviations on support components, can be disguised, thus helping to achieve a uniform surface quality. Even expanded substrates can be used with surfaces that would usually not allow them to be used as decorative material. The resulting combination of less waste and lower component weight translates to the conservation of valuable resources and thus a favourable impact on the environment.

AREAS OF APPLICATION

The fact that decorative surfaces can be changed easily means that the foils are in

❷ The colour carrier is the TPO material itself, and the paint coating on it serves primarily to adjust the degree of gloss (Sample part from IAC Group and Benecke-Kaliko)

❸ Patterns open up additional design possibilities

THICKNESS [mm]	WEIGHT [g/sqm²]	SCRATCH RESISTANCE
0.2	185	4 – 5 N
0.3	280	4 – 5 N
0.4	375	7 N
0.4	375	4 – 5 N
0.5	465	4 – 5 N
0.5	465	7 N

❹ The thin foil is much more scratch resistant than painted injection moulding

COLOUR FASTNESS TO LIGHT (NOTE)		DIN EN ISO B06	1 cycle ≥ 7
COLOUR FASTNESS AND AGEING TO LIGHT (RATING)		DIN EN ISO B06	5 cycles ≥ 4
COLOUR FASTNESS TO RUBBING (RATING)	Smooth foil	DIN EN ISO 105X12 DIN EN ISO 20105 A 03	
	Dry		100 strokes ≥ 4.5
	Wet		10 strokes = 5
AMINE RESISTANCE (RATING)		PAPP PWT 7329	≥ 4.5

❺ The resistance properties of the foil have been confirmed in numerous tests

keeping with the trend towards individualization of car interiors. What is more, they can be used to produce small quantities of specific surface designs at no significant additional expense.

In addition to compacts and small cars, decorative foils are also well suited for use in the commercial vehicle sector, where drivers spend a great deal of time in the passenger compartment and where interior trim materials are subjected to heavy wear and tear. For commercial vehicle drivers, the driver‘s cab is like a second living room, which they often use more frequently than their actual home. Accordingly, the demands placed on interior designs are increasing, with the focus shifting from pure functionality more towards aesthetics. At the same time however, the wear and tear that surfaces must deal with in this vehicle segment must not be neglected. At present, injection moulded surfaces are predominant in commercial vehicle interiors as well as in the entire light truck segment. With the new thin film, vehicle interiors can be upgraded substantially with respect to haptics and appearance.

When developing the new foil, Benecke-Kaliko’s engineers took on four goals at the same time. They wanted to achieve optimum grain depiction by varying the formula and the thickness, to improve the scratch resistance over PP injection moulding, to ensure grain stability even at hot temperatures, and to enable as great a variety of designs as possible. When it came to constructing moulds, tests showed that it is very important that the tool and the foil match.

In the meantime, the foil has undergone basic testing in cooperation with mould builders, diverse Tier 1 suppliers and various car makers. One German manufacturer has already subjected the film to component testing in which its colour fastness, heat stability and ageing resistance were confirmed, ❺.

FIGURE © Porsche

ASPECTS OF LIGHTWEIGHT DESIGN WITH DOOR FRAMES AS AN EXAMPLE

For a number of premium-class vehicles, George Fischer Automotive manufactures innovative door inner frames and door frames using aluminium and magnesium pressure diecasting methods. Since different boundary conditions applied in each case at the start of the project, the process steps leading up to the weight-optimized components also differed. Three examples at Mercedes-Benz, Aston Martin and Porsche demonstrate that a rear door frame, for instance, can be about 30 % lighter than a comparable sheet-steel component.

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COST AND BENEFIT OF WEIGHT REDUCTIONS

Lightweight design is regarded as a tried-and-proven method of reducing fuel consumption and, along with it, the CO_2 emissions of passenger cars. According to a rule of thumb, every 100 kg of vehicle weight reduction results in savings of between 0.3 and 0.5 l of fuel every 100 km. This corresponds to a reduction of between 8 and 11 g of CO_2 per km. Weight reductions are possible on practically all of the vehicle's components, albeit with varying degrees of cost and benefit. The vehicle's bodywork, chassis and powertrain are regarded as those areas with particularly promising weight-saving potentials.

Georg Fischer Automotive is a supplier of components and system solutions in all three of these areas, and as such makes decisive contributions to reducing vehicle mass and environmental impact. In addition to its product know-how, the company also has wide-ranging process expertise in development, materials optimization and casting processes, as well as in the fine-finishing of its products. This comprehensive competence portfolio is imperative if a company is to provide the optimum answers needed to solve the challenges inherent in a project. After all, for a given task – for instance, the production of a door structure – a wide range of results are possible.

Essentially, the selection of the materials and the production methods depend upon the number of units to be produced and the technical requirements. Taking as examples the door inner frames for the Mercedes-Benz S-Class, the Aston-Martin DB9 or Vantage, and the Porsche Panamera, George Fischer demonstrates what influence these inputs have in practice. The results are in each case tailor-made door frames featuring minimum mass, economic efficiency and high functionality.

QUESTIONS ON MATERIALS AND PROCESSES ANSWERED AT DAIMLER

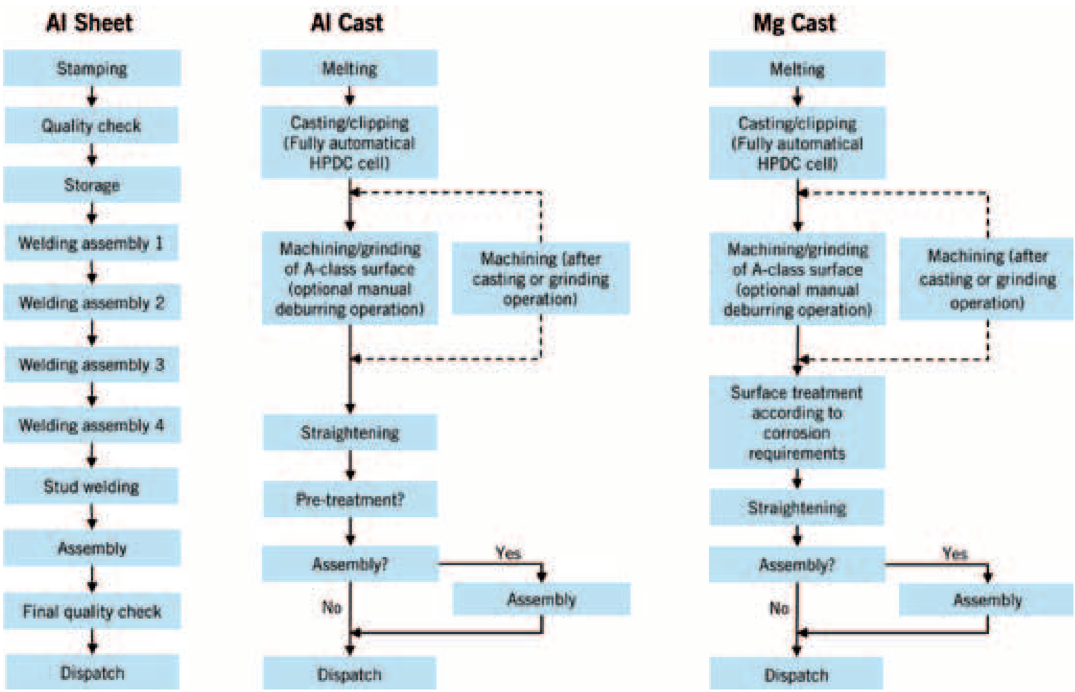
Georg Fischer developed and manufactures the aluminium door inner frames of today's Mercedes-Benz S-Class (W221, V221). Compared to the predecessor [1], at the start of the development phase, both the series-production aluminium diecast part and the sheet-metal parts of aluminium and steel as well as pressure diecast components of magnesium were investigated. Since its drawing depth and drawing angle are limited, and the components are heavier, aluminium sheet was rejected. Apart from this, such a frame would have had to be constructed from a number of separate parts and from the production-technology viewpoint would therefore have been highly complex. Although magnesium diecast components demonstrated similarly good properties as the aluminium diecast parts, these would have caused high costs for corrosion-proofing and joint engineering. The cost of steel-sheet inner frames would be slightly lower, but they would not have been so functionally efficient, as well as being considerably heavier, ❶.

An upper frame section comprising an aluminium profile is welded onto the one-piece aluminium diecast frame. The few MIG welding seams that are needed result in minimum component distortion and thus very tight tolerances. This facilitates the assembly work and promises efficient inner-frame sealing between the door's wet and dry compartments.

Georg Fischer selected $AlMg_5Si_2Mn$ as the material for the door inner frame. This is a special aluminium alloy which is also used for other components. Aluminium alloys can be optimized to fulfil a variety of different material requirements, for instance with respect to elongation, tensile strength and deformability (ductility), ❷. The experts for light metal at Georg Fischer decided on the "naturally hardening" alloy because it does not require heat treatment. With this alloy, the hardening effect results from the grain refinement due to the magnesium. The alloy thus permits a ductile yield of about 8 % in the relevant areas of the component.

HIGHLY COMPLEX CASTING PROCESS

Whereas this material proved to be ideal for the design engineers, it posed considerable challenges for the diecasting engineers: in particular, the distortion optimisation of the cast-on B-pillar and the material's problematic shrinkage behaviour. This problem was solved following a very intensive analysis of the melting process, as well as of the mould filling,



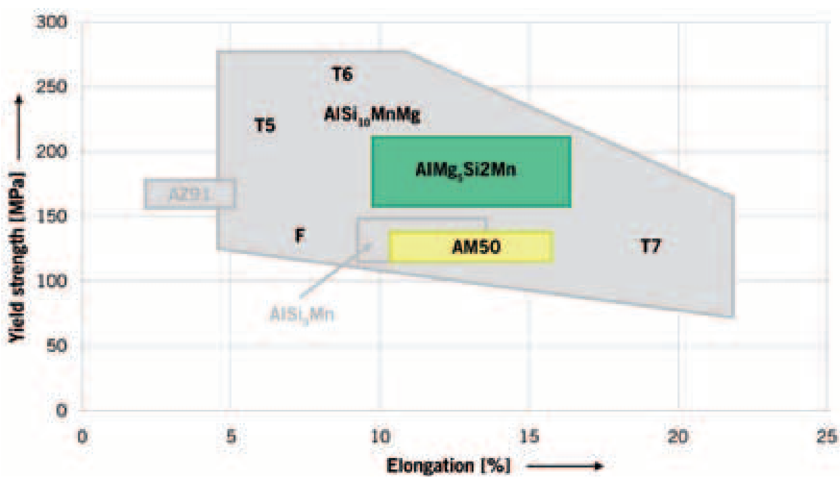
❶ Production process of the various manufacturing methods for door frames when aluminium sheet, aluminium castings and magnesium castings are used

the ventilation and the solidification. The design of the mould was also analysed.

Georg Fischer, for instance, applies inductive processes to melt the alloy, whereby the resulting swirl motion efficiently mixes the melting bath and as a result also the microstructure. For better dosage, the alloy quantity required is scooped out of the crucible, which means that it can be treated in such a way that oxide and hydrogen inclusions are practically eliminated, and the material's elongation and welding suitability improved. The casting blank is immersed in the cooling basin with a previously specified speed and direction. All in all, 135 parameters are registered and documented in the casting process. Subsequently, full automation is applied in the further treatment of the blanks.

Excellent production properties result from these highly complex casting and processing procedures. The aluminium alloy $AlMg_5Si_2Mn$ with 5 % magnesium and 2 % silicon and manganese content is easy to stamp and weld. In contrast to conventional aluminium alloys, even without heat treatment it displays high levels of elongation and strength. In the casting process, the required depths in excess of 10 cm are complied with. The diecast inner frame for the front doors, which is longer than 90 cm, maintains tolerance in the 1/10 millimetre range. Wall thicknesses of only 2.2 to 3.5 mm result in a component weight of only about 3.7 kg.

The specialists from GF Automotive in Herzogenburg (Lower Austria) put a one-piece diecast aluminium door inner frame into series production. It is not only the size of this component with a diagonal dimension of about 1.5 m that is an innovation, but also the fully automatic further processing of the casting blank as a series-production part. In contrast to multipart door inner frames, there is no longer any need for complex and difficult welding work. Without heat treatment, the material displays high elongation and strength, and is a good starting point for the economically efficient manufacture of light components featuring high levels of passive safety. Even for its size, the component complies with all demands for high ductile strength, weldability and excellent dimensional accuracy as stipulated by Mercedes-Benz for its S-Class. In the meantime, the factory has already produced more than 1 million doors for today's S-Class.



❷ With regard to elongation, tensile strength and yield strength, light metal alloys have many advantages

Among other things, the inner frame's economic efficiency results from the moderate number of units produced. The figure here is just under 1500 inner frames produced every day. This means that the unit cost for the aluminium diecast part is lower than that of a new aluminium-sheet component and practically the same as that of a comparable sheet-steel part.

LOW PRODUCTION VOLUMES AT ASTON MARTIN FAVOUR THE USE OF MAGNESIUM

The numbers of door inner frames produced by George Fischer were even smaller for the premium models Aston Martin DB9 and Aston Martin Vantage. It was the relatively low numbers produced for both models that was decisive for the choice of magnesium. Compared to sheet-metal parts from aluminium or steel, using diecast magnesium is economically more efficient where small lot sizes are concerned. For instance, only a single tool set is required during the complete production run. This fact reduces costs considerably.

With their length of a maximum of 1281 mm, the inner frames are above-average in size, ❸. Notwithstanding this fact, it was possible to have a wall thickness of only 2.5 mm. This limits the Mg component's weight to 6 kg, which is about a third less than that of a comparable aluminium diecast component. The substitution of the reinforcement sheets in the hinge and lock areas was particularly complex. The solution chosen here was to use special wall-thickness reinforcements.

Since the deviations from dimension and shape were not to exceed a figure of only 0.5 mm, extensive quality-assurance measures are in force during and after the casting process. Therefore, a multipoint measurement tester is used, ❹. Initially, the blank is measured in a gauge. The experts then use this data to optimize the important manufacturing parameters. This applies in particular to the spray period of the separating agent and the tool temperature. The aim is to keep the distortion to a minimum. Finally, coarse burrs are removed, holes bored and the gating removed. This is followed by a cooling-off phase in a cooling tower, during which time the casting cools down to between 24 and 40 °C. Further holes are then bored, and fine burrs and unevenness removed by grinding, ❺.

❸ With a length of maximum 1281 mm, the Aston Martin door inner frames made from magnesium are of above-average size

❹ Multipoint measurement tester for quality assurance

❺ Mechanical processing using a robot

❻ Georg Fischer produces the front and rear door frames for the Porsche Panamera using the aluminium pressure diecasting method

Since, for instance, there are no chill cracks that need grinding, the surface quality of the magnesium is very good. This is an important factor, as some areas of the frame are visible from inside the vehicle. The casting must not display any sinks, roughness or other defects that may possibly necessitate reworking.

Considering the fact that only small quantities are produced, and that there are only two versions, it was important for Georg Fischer that the setting-up times for the pressure diecasting machines were kept to a minimum. Since the components concerned are very similar to each other, apart from the differences in their sheared edges, interchangeable tool sets are used. It is possible to exchange 16 complete sets in about 1 h.

PORSCHE DOOR FRAMES WITH TWO INNOVATIONS

Georg Fischer delivers all four door frames, ❻, of the Porsche Panamera [2]. These are aluminium pressure diecast frames, which are subsequently fine-finished in a number of process steps. One door frame has dimensions of 1110 × 852 × 261 mm (L × B × H) and is made of the alloy $AlMg_5Si_2Mn$. Among other things, a reinforcement plate is attached in the door-sill area by means of Deltaspot welding. The Panamera door thus becomes the first series-production casting in the automotive industry in which spot welding has been used.

The advantage of this process lies in the absolute reproducibility of every welding seam. This is attributable to the circulating process belt, which guarantees a virtually unused electrode for each welding seam. A variety of materials with different thicknesses can be joined together in a reliably controlled process. This also applies to multi-plate joints. Surface splash is practically ruled out. In the Porsche Cayenne factory in Leipzig, a magnesium diecast window frame, which is also manufactured by Georg Fischer, is screwed to the door frame during final assembly.

A further Georg Fischer innovation is the laser cutting process, which for the first time in the automotive industry determines the door frame's precise outside geometry. Since the metal sheet of the outer skin and the module holder on the inside are attached to the door frame, very high tolerance and styling specifications apply for the joints, the fitting dimensions and the overall appearance. On the outside edge of the component, one of the Porsche stipulations called for a 90° flange referred to the flange surface. This is intended to improve the appearance after the flanging process. These stipulations are complied with by the laser cutting process, since this improves the cant quality considerably compared to stamped castings.

Wall thicknesses of only 2.0 to 3.5 mm are a further characteristic of the door frames. This comes very close to the limits of the wall-thickness/flow-length ratio. For instance, with its weight of 3.6 kg, the rear door frame is about 30 % lighter than a comparable sheet-steel component. Such extremely lightweight design together with flexible wall thicknesses and the integration of add-on components is only feasible using aluminium diecasting processes. Light-metal sheeting does not feature the required deep-drawing properties, as well as causing higher production costs. On the occasion of the 2010 Aluminium Pressure Diecasting Competition, the jury of Verband der Aluminiumrecycling-Industrie (VAR) (Association of the Aluminium Recycling Industry) honoured this innovative performance from Porsche and GF with the First Prize in the “Structured Components” category [3].

SUMMARY

Projects at Mercedes-Benz, Aston Martin and Porsche are used as examples to demonstrate that there are various forms of lightweight body design. On the one hand, the question concerning the optimum material must be answered. On the other hand, the precision characteristics of the product mean that the production and fabrication processes used for a component provide the opportunity for utilising further lightweight design potential.

With its extensive expertise in the sectors of product development, materials science, casting processes and metals processing, Georg Fischer makes important contributions to the reduction of vehicle weight. A particularly important role is played by aluminium and magnesium pressure diecastings for door frames, which is further underlined by their high levels of functional integration, resulting in to fewer individual parts, lower costs and tailor-made product characteristics.

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THE ELECTRIC STEERING SYSTEM FOR THE NEW FORD FOCUS PLATFORM

Ford has continued the global introduction of electric steering systems with its electro-mechanical rack type steering gear on the new Ford Focus platform. This concept decision is seen as the basis for future assistance functions. A modular design guarantees synergy effects between several platforms.

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MARKET SITUATION

Changing market conditions and customer needs led to a change in technology at Ford for the steering system on the new Focus platform. As a result of the technological improvements in EPS systems in recent years, the possibility of implementing a full electric power steering system arose. A number of EPS technologies were initially available for selection for Ford‘s new global compact class. These included – in addition to the familiar electro-hydraulic steering system (EHPS) – steering column mounted electric power steering (column EPS), which is primarily being used in the small car segment, the established pinion mounted electric power steering system (pinion EPS) and electro-mechanical rack mounted power steering (rack EPS), which is currently the most advanced of the three. After detailed consideration of the pros and cons of each, Ford’s new Focus platform started production at the end of 2010 with a new rack EPS system.

The Focus platform is conceived as a global platform and serves as a basis for all compact vehicles in the Ford/Lincoln portfolio. Already introduced on the platform are the Focus and the C-Max, and upcoming models based on the platform are the new Kuga in Europe, the Escape and a Lincoln variant of this for the USA, plus a number of other variants which will also use this C-platform technology in the compact segment.

The new C-platform will be manufactured in Europe, North and South America, South Africa, Russia, Australia, China and further ASEAN states.

REQUIREMENT PROFILE

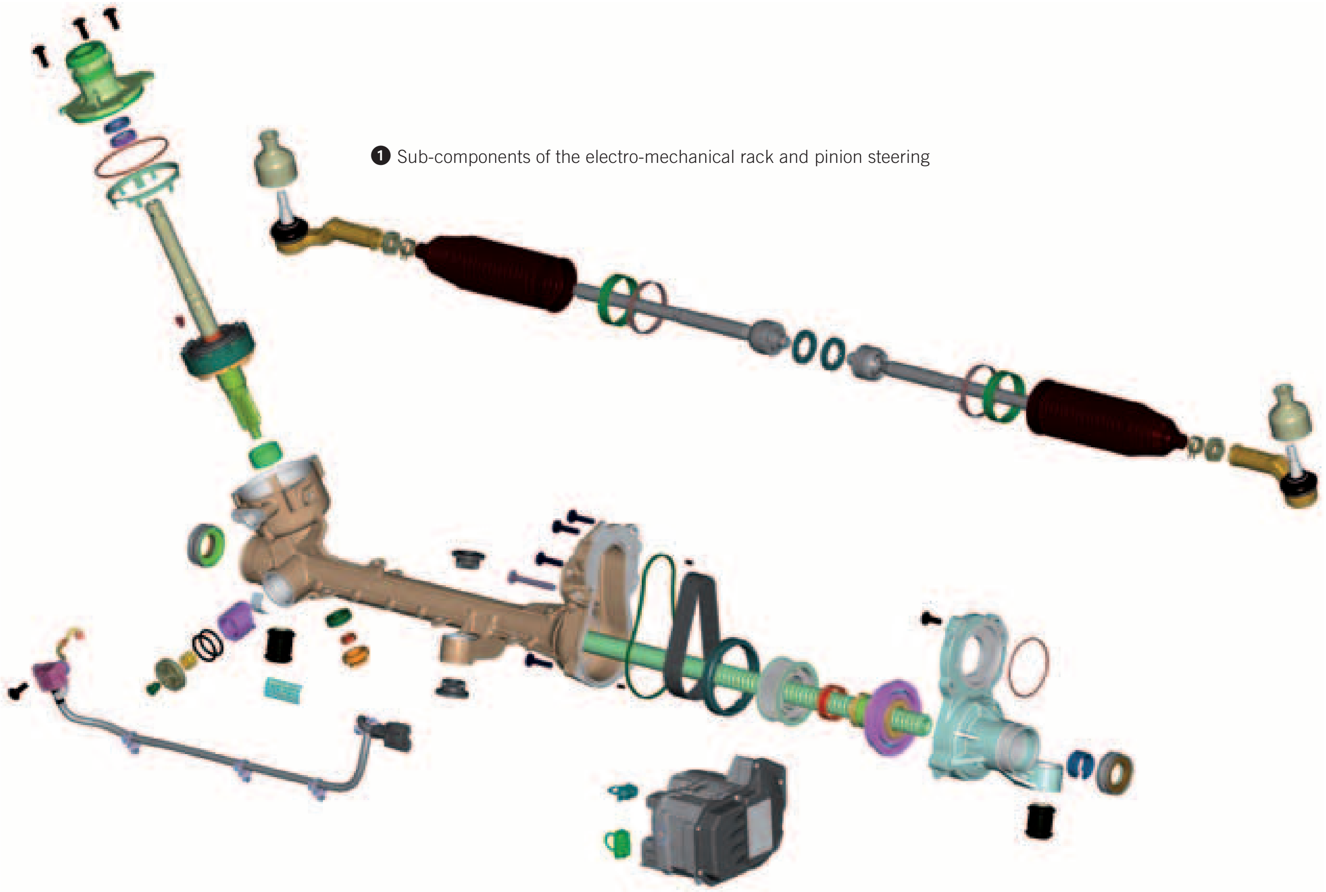
A primary design criterion for a steering system is rack force, which is determined by the maximum front axle weight and chassis geometry. In case of a maximum front axle weight of up to 1230 kg, the maximum rack force is as high as 9.5 kN. This dictates the requirement for a high level of static assist during parking manoeuvres, also with high ambient temperatures in the engine compartment. Furthermore, the maximum angular steering wheel velocity that can be applied during an evasive manoeuvre determines the power demand of the steering system on the basis of the available on-board voltage. The specification defines a steering dynamics requirement of at least 900 °/s without the presence of significantly increased torque (catch-up) at the steering wheel.

The steering characteristic, which describes the steering feel of a Ford vehicle objectively, is fixed in the so-called Ford “steering system DNA”. The vehicle agility and the on-centre response are considered as the most important elements of this DNA. Among other things, these attributes are affected by the overall steering ratio in combination with a high rigidity steering column. This resulted in a chosen gear ratio of 60 mm/revolution as a design factor. Furthermore the torque feedback is very important, and this is significantly affected, apart from the actual boost characteristic, by steering and chassis friction. Consequently, the development focused on achieving the lowest possible mechanical friction within the steering system, the target being to achieve the same or higher level of feedback and steering feel as with a traditional hydraulic system. The demand for quiet operation and customer requirements for increasing comfort and safety-related features round off the primary requirements of the steering system.

Besides steering assistance, the EPS is also able to act as an actuator for new safety and comfort features.

EPS contributes primarily to increased requirements for the reduction of CO_2 emissions, specifically due to low current consumption during operation. Furthermore, a CO_2-saving stop/start strategy for the internal combustion engine can be achieved simply with the implementation of an electric steering system, without suffering any loss of comfort and driving safety. Also, the application of an EPS steering system in the future-planned hybrid and battery-electric vehicle powertrains on this platform is ensured.

EPS also offers the vehicle manufacturer system-inherent advantages in logistics, production and recycling. For manufacturing, it is advantageous that filling with hydraulic oil is now unnecessary. The total time for the assembly of EPS is also significantly reduced in comparison with traditional to hydraulic steering systems.



❶ Sub-components of the electro-mechanical rack and pinion steering

DESIGN AND SUBCOMPONENTS

For the electric steering system of the Focus platform, Ford together with TRW Automotive developed a belt-driven rack and pinion steering gear with a circulating ball nut (BNA – Ball Nut Assembly). In its design, the rack EPS used in the platform does not differ substantially from the well-known systems on the market. The torque sensor installed at the steering gear determines the torque applied by the driver during a steering wheel movement. Pulse width modulated torque signals are then sent to the power steering controller. The controller computes from the manual torque, vehicle speed and further internal parameters the necessary current and the direction of rotation of the servo motor, which transmits rotation through the belt and the circulating ball nut. This provides rack travel linearly in the desired direction.

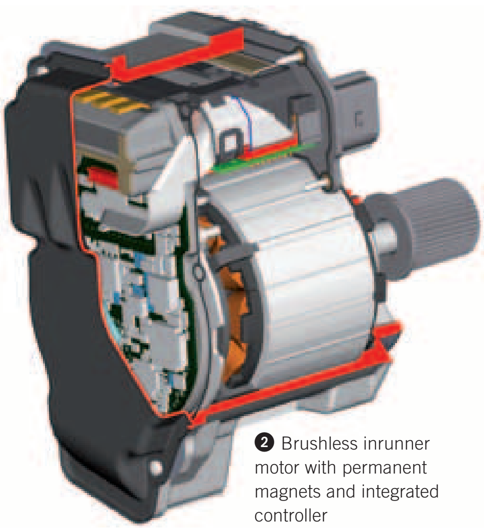
The servo motor is mounted parallel to the rack but shifted towards the passenger side in order to guarantee sufficient clearance to the catalytic converters of different powertrains. All power assist components are integrated into the steering gear, so that the assembly effort in the vehicle assembly plant itself is reduced to mounting the steering gear to the sub-frame, attachment of the electrical connections and fastening the connection between the steering gear and the steering column and the outer ball joint to the knuckle. ❶ shows an overview of the rack EPS components.

A key element of the assistance force control is the inductive torque sensor. It measures the torque applied at the steering wheel and conveys this signal to the EPS controller. The steering wheel torque is measured between the input shaft and pinion, in which a torsion bar of 2.5 Nm/° stiffness is mounted.

The signal processing and current supply to the sensor, the controlling of the EPS motor and communication with the vehicle via the high speed CAN bus is performed by the EPS controller. This ECU calculates the necessary auxiliary torque with an algorithm and drives the servo motor accordingly. The ECU is integrated into the EPS housing, ❷.

The motor is a brushless inrunner motor with rare-earth permanent magnets in 9 stator coil/6 pole topology. The maximum input current at 12 V is limited to approximately 85 A. Two motor sizes are used in order to cope with the different front axle weights and the associated necessary steering assist forces. The exchangeable, modular motors differ in rotor length. They are split into a motor with 5.2 Nm of torque for the high front axle loads and one with 4.5 Nm of torque for the light variants.

The belt drive has the primary task of transferring the torque from the motor pulley to the circulating ball nut, and additionally provides a transmission ratio of Eq. 1 between the motor and the circu-



❷ Brushless inrunner motor with permanent magnets and integrated controller lating ball nut, ❸. The belt is manufactured from glass-fibre reinforced hydrogenated nitrile butadiene rubber (HNBR) and is coated with PP. It is 28 mm wide and has a helix angle of 5° in order to eliminate running noise. For tensioning the belt in production, the motor is held in an off-centre ring and is rotated in such a way that the belt tension is optimally adjusted.

EQ. 1	$i_R = 2.4$

The circulating ball nut converts the rotation of the servo motor into a linear motion to the rack and, according to its ratio, converts the input torque into the rack-force. With a BNA ratio of Eq. 2 and a C-factor of Eq. 3 the total ratio accordingly results in Eq. 4.

EQ. 2	$i_{KGT} = 7\frac{mm}{revolution}$
EQ. 3	$C = \frac{60\,mm}{revolution}$
EQ. 4	$i_{ges} = \frac{C}{i_{KGT}} \cdot i_R = \frac{60\frac{mm}{revolution}}{7\frac{mm}{revolution}} \cdot 2.4$ $= 20.57$

In the TRW rack EPS, two different circulating ball nuts manufactured by two different suppliers are used. One system has an external ball feedback with two separate ball tracks. The second application uses an internal ball feedback with four independent ball tracks, ❹. Both BNAs have identical interfaces to the steering gear housing and the same mechanical characteristics and are thus modular. Independent of the construction, both are rigidly fixed in the housing of the respective steering gear without any absorbing rubber elements in order to make the steering system very responsive in the centre position.

The aluminium housing of the steering gear is split in two parts, so that the circulating ball nut assembly and the belt drive can be installed. To support the large mass of the EPS motor and controller, the housing is equipped with a third mount in the centre. For the improvement of the on-centre feel of the steering system and in order to minimize the deflection of the housing, the centre mount is implemented rigidly, while the two outside mounts are fastened with flexible rubber bushes onto the sub-frame.

MODULAR APPROACH

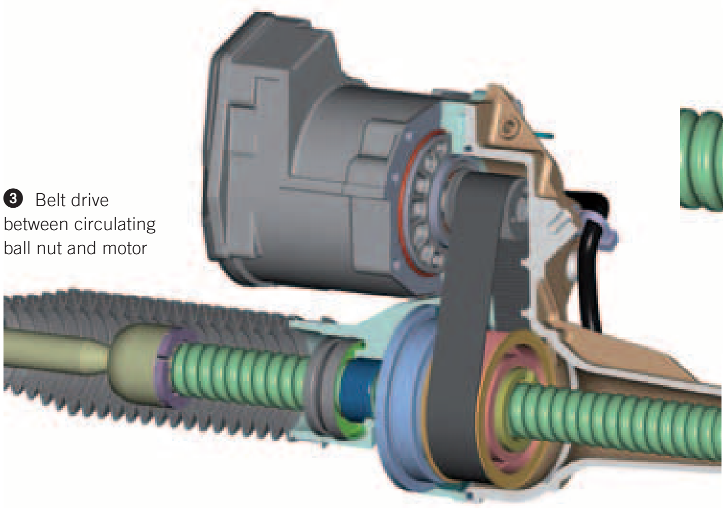
The EPS for the Focus platform from Ford has to cover at least seven vehicle derivatives. Complexity drivers are, apart from left and right hand drive vehicle variants, the high variance of front axle loads, different rack travels and the steering gear ratios.

The main components have a modular design and have standardized interfaces to permit their use over all variants on the platform. Due to global orientation of steering system technology planning, it was possible to share the standard components of this rack EPS with further platforms from the Ford product portfolio that have the same supplier, TRW. This leads to a reduction in development costs and variable costs due to economies of scale. Because of modular approach, the pinion/input shaft, torque sensor, motor concept, the ECU including software and the belt and circulating ball nuts are virtually identical to the North American models Ford Fusion and Lincoln MKZ. The individual housings and their attachment points guarantee that the requirements and special attribute specifications for the individual vehicle lines can be incorporated into the different applications.

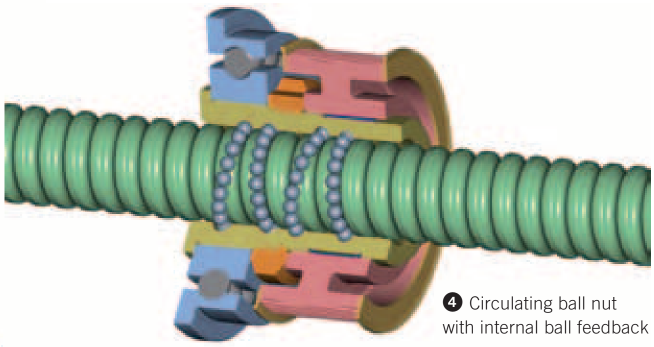
The motor‘s rotor length and the circulating ball nut diameter are scalable, so that these components can also be used in the models Ford Taurus, Ford Flex, Ford Explorer, Lincoln MKS and MKT. With appropriate adjustments, the sensor, the ECU with its software and the belts can be carried over from the modular system too.

SUMMARY

Ford has consistently continued the global introduction of electric power steering systems with the electro-mechanical rack and pinion steering on the Focus platform. The concept guarantees fulfilment of the highest dynamic requirements with high front axle loads. The modular concept of the rack EPS permits high synergies between several platforms, which make a cost-optimized EPS introduction possible in the compact platform segment. The discussion about customer-relevant driver assistance functions continues to become more and more important and the electric power steering system takes over a key role as an actuator for the implementation of these driver assistance functions.



❸ Belt drive between circulating ball nut and motor



❹ Circulating ball nut with internal ball feedback

FUEL CELL HYBRID CONCEPT VEHICLE FOR EMISSION-FREE MOBILITY IN CITY TRAFFIC

With its fuel cell hybrid concept vehicle based on a production vehicle from the BMW 1 Series, BMW Group Research and Technology demonstrates a new development in emission-free, urban driving. It is based on hybrid technology developed in the framework of EfficientDynamics in conjunction with the use of hydrogen. Apart from a petrol engine, the research vehicle has an electric drive supplied with power from a small fuel cell. Double-layer capacitors buffer the power peaks for acceleration and store electric energy from regenerative braking.

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TASK

The transforming social environment places new demands on individual mobility [1]. The worldwide trend towards urbanisation has resulted in the focus of development efforts being placed increasingly on urban traffic.

With hydrogen as the energy source, emission-free traffic would be easier to implement, especially in urban areas: relatively few filling stations would be required to cover these areas [2] and the infrastructure dependence would therefore be reduced.

Apart from the zero emissions, with its high energy density compared to electric storage systems, hydrogen offers a relatively long range as well as the advantage of fast refuelling to which drivers are accustomed.

CONCEPT

Today‘s passenger cars have a driving power of approximately 100 kW to satisfy the all-purpose requirements of the user. However, urban traffic can be mastered with an average of 5 % of this installed capacity. To exploit the related potential for consumption reduction in this area, specialists from BMW Group Research and Technology have provided a second drive train that is specially optimised for urban traffic and which, at the same time, makes emission-free driving in town centres possible.

This second drive system consists of a small fuel cell in conjunction with an electric buffer storage (EBS) and an electric motor. To minimise additional costs, the fuel cell is dimensioned in such a way that it only supplies the average power required for urban traffic. The electric motor and the EBS are designed to cover

power peaks that occur, for example, during acceleration.

Journeys with higher continuous power demand, in particular at high speeds, are accomplished in the usual manner with an internal combustion engine. At the same time, the electric drive system can support acceleration and also has a fuel consumption-reducing effect through regenerative breaking.

As the existence of a comprehensive network of hydrogen filling stations is unlikely in the short term, the internal combustion engine will initially run on conventional fuel. In 2006, BMW Group already proved the suitability for mass production of hydrogen internal combustion engines with the series introduction of the BMW Hydrogen 7 [3], ❶.

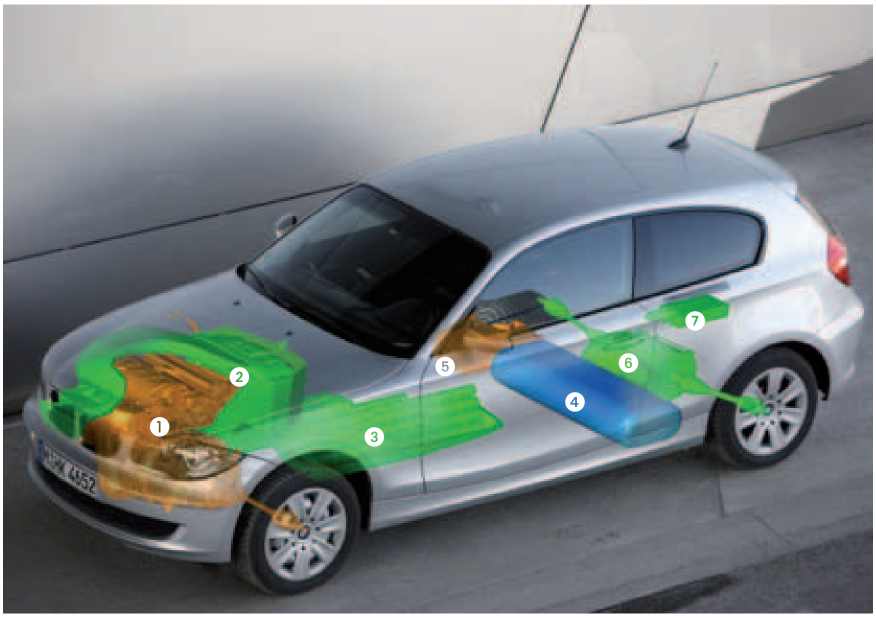
DEMONSTRATOR

The research vehicle has a 6 kW fuel cell, which supplies an 82 kW electric motor that acts on the rear wheels. The electric buffer storage of 810 kWs has been dimensioned to cover an FTP-72 driving cycle limited to 70 km/h. An 88 kW internal combustion engine designed for overland travel drives the front wheels.

A vehicle from the BMW 1 Series was selected as the experimental vehicle. To integrate all components of both drive systems, extensive modifications to the body shell were necessary.

The complete drive train of the Mini Cooper, including the front axle, was integrated into the engine compartment instead of the BMW standard rear wheel drive. This arrangement left sufficient space for the integration of the fuel cell system behind the transversely installed internal combustion engine.

❶ The concept of the fuel cell hybrid vehicle allows the step-by-step introduction of hydrogen-based mobility without an area-wide infrastructure



❷ Experimental vehicle package: ① transversely installed internal combustion engine with corresponding chassis; ② hydrogen fuel cell; ③ electrical buffer storage (EBS); ④ hydrogen cylinders; ⑤ petrol tank; ⑥ electric motor with transmission; ⑦ power electronics

The transmission tunnel accommodates the electric buffer storage. 148 double-layer capacitors are arranged in nine different modules to optimise space. Due to its very low electrical resistance and associated minimal heat development, the EBS does not require any cooling or ventilation. It is protected against humidity and dust by a sealed housing made of fibre-glass-reinforced plastic.

The electric drive system is integrated into the rear axle, while the complete power electronics of the electric drive train are installed directly above. The hydrogen supply and petrol tank are located under the rear bench seat. The complete prototype has an overall weight of just over 1500 kg, ❷.

FUEL CELL

Since 1997, BMW Group has been researching into low-temperature PEM (Polymer Electrolyte Membrane) fuel cell technology. The system operates at low excess pressure and does not require a compressor. Because of its simple design, it is very robust and has a service life of more than 5000 h in normal car driving conditions. The system efficiency is 58% over a wide power range, ❸.

Due to a clever cell design, external humidification of the gases is not required, so that the vehicle can already be supplied with energy after 30 s even after a start in freezing conditions [4].

DC/DC CONVERTER

The DC/DC converter transforms the output voltage of the fuel cell (33 to 44 V) unidirectionally to the variable voltage level of the EBS. The nominal output is 7 kW at a maximum efficiency of 93%. Furthermore, the galvanic separation between the fuel cell and EBS, as well as the insulation monitoring for the high-voltage system, are integrated in the DC/DC converter.

ELECTRIC BUFFER STORAGE

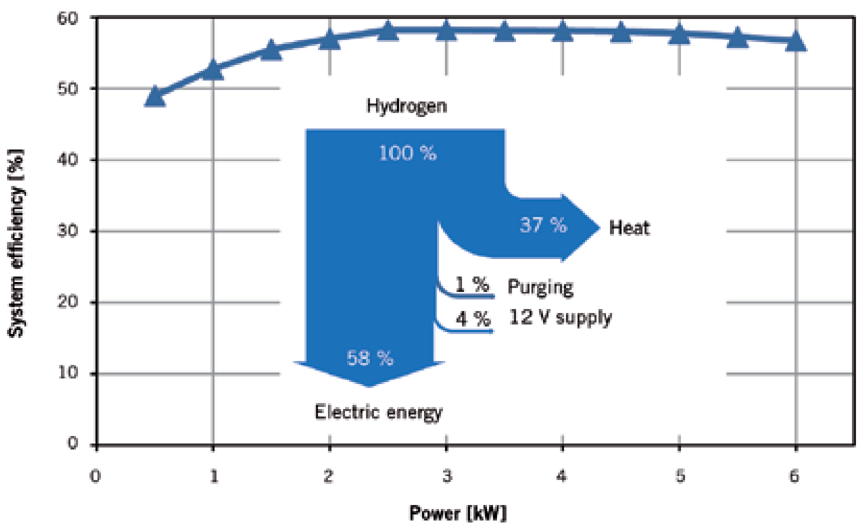
The 148 double-layer capacitors connected in series, ❹, have an individual capacity of 2000 F each. Besides the high charging/discharging efficiency, they are characterised by a power density of 13 kW/kg and a long service life [5]. The individual cells are balanced by means of separate electronics [6] installed directly on the cell. The total electric buffer storage operates from 200 to 400 V.

ELECTRIC DRIVE UNIT

The electric drive unit is a hybrid synchronous motor with a reduction gear and differential. The nominal torque is 223 Nm and the speed is limited to 11,000 rpm [7]. The gear unit is permanently engaged; the fixed reduction ratio of 10.2:1 represents a compromise between electric acceleration capacity and permissible maximum speed. In internal combustion engine operation, the research vehicle is electronically regulated to a maximum speed of 120 km/h.

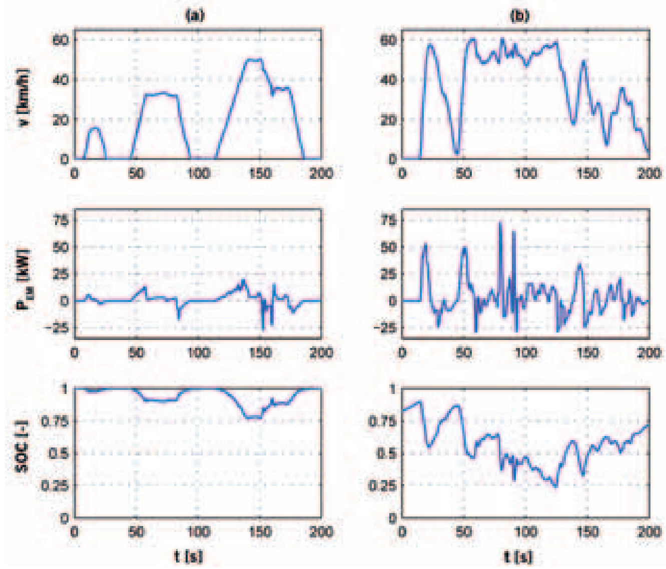
RESULTS

The functionality of electric, and thus emission-free, driving in urban areas with



❸ Efficiency characteristic curve of the fuel cell system

❹ Electric buffer storage consisting of 148 double-layer capacitors



❺ Speed, electric motor performance and EBS state of charge (SOC) during (a) a drive in the European Urban Driving Cycle (UDC) and (b) a real urban trip

a small fuel cell was verified in several test and presentation drives. The drive system, which generally reacts very spontaneously in vehicles with electric power systems, impressed with acceleration figures of up to 4 m/s². Acceleration from 0 to 50 km/h takes 3.7 s. The cruising speed, i.e. the speed when travelling using 6 kW, is 55 km/h.

Even with highly dynamic driving, the combination of the 6 kW fuel cell and the 810 kWs electric buffer storage proved to be sufficient for all urban driving scenarios up to v = 65 km/h. ❺ illustrates the state of charge of the electric buffer storage while driving in the urban share of the New European Driving Cycle (UDC – Urban Drive Cycle) and during a dynamic, customer-typical urban trip.

The efficiency was determined after four completed UDCs. The vehicle consumption level was 0.94 MJ/km and, with an operational strategy optimised to the driving cycle, as low as 0.79 MJ/km. This is equivalent to approximately 2.4 l/100 km petrol consumption.

It is not just the absolute consumption figure that is significant, but also the efficiency chain. The Sankey diagram in ❻ clearly demonstrates the high average efficiency of the energy converters and energy storage unit. If the mean power required to overcome rolling friction, acceleration resistance and drag is correlated to consumption, 56 % of the fuel energy content is used for driving. It should also be noted that fuel consumption in the UDC can be reduced by 25 % thanks to the regenerative braking energy.

OUTLOOK

The test results confirm that the low power output of a small fuel cell system is sufficient for driving in urban traffic. Emission-free mobility using hydrogen fuel cells is therefore – at least in city traffic – economically feasible.

With further optimisation of the prototype with regard to the package, weight and component efficiency, ranges of up to 400 km in city traffic are conceivable.

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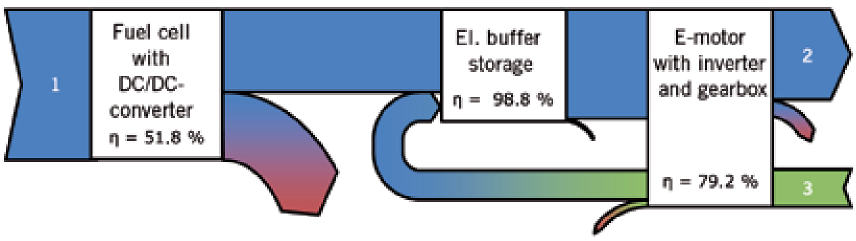

❻ Sankey diagram of the average performance of the fuel cell hybrid concept vehicle in the European Urban Drive Cycle; 1: hydrogen consumption; 2: driving performance for overcoming frictional and acceleration resistance and drag; 3: regenerative braking performance; the power losses are shown in red

THE NEW VW GOLF CONVERTIBLE

Driving with the roof down in the new VW Golf convertible gives you a sensation of freedom. The first version was launched on the market in 1979. The torsionally rigid vehicle in the 2011 model year is characterised by its greater elegance, softtop opening in 9.5 s, the longest interior length in its class as well as modern petrol and diesel engines. The four-seater dispenses with the famous “handle” because two overroll protection modules are deployed via the central airbag triggering unit in case of a roll-over.

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HISTORY AND STYLING

There is a long tradition of four-seater convertibles at Volkswagen. The classic Beetle convertible was the founder of the legend. And ever since 1979, the VW Golf convertible has been a legitimate successor and continues to write further chapters in the success story.

Now, the new VW Golf convertible in the 2011 model year features a fully open shape without an overroll bar. Together with the more steeply raked windscreen and the flatter softtop, the convertible is significantly more elegant and dynamic than its predecessors. It is unmistakeably based on the "Golf", of course [1]. Surfaces and lines unobtrusively embody the ideal of "semplicità": The clearly drawn lines and controlled tension correspond in an exemplary way with levels of quality, value and precision that are convincing in this class, as well as the already legendary attention to detail. By cutting out inessentials, dispensing with superfluous and purely decorative elements, the design of the VW Golf convertible once again stands for long-lasting quality – and as a result it prepares the ground in the best possible way to be the next classic in the stable of compact convertibles.

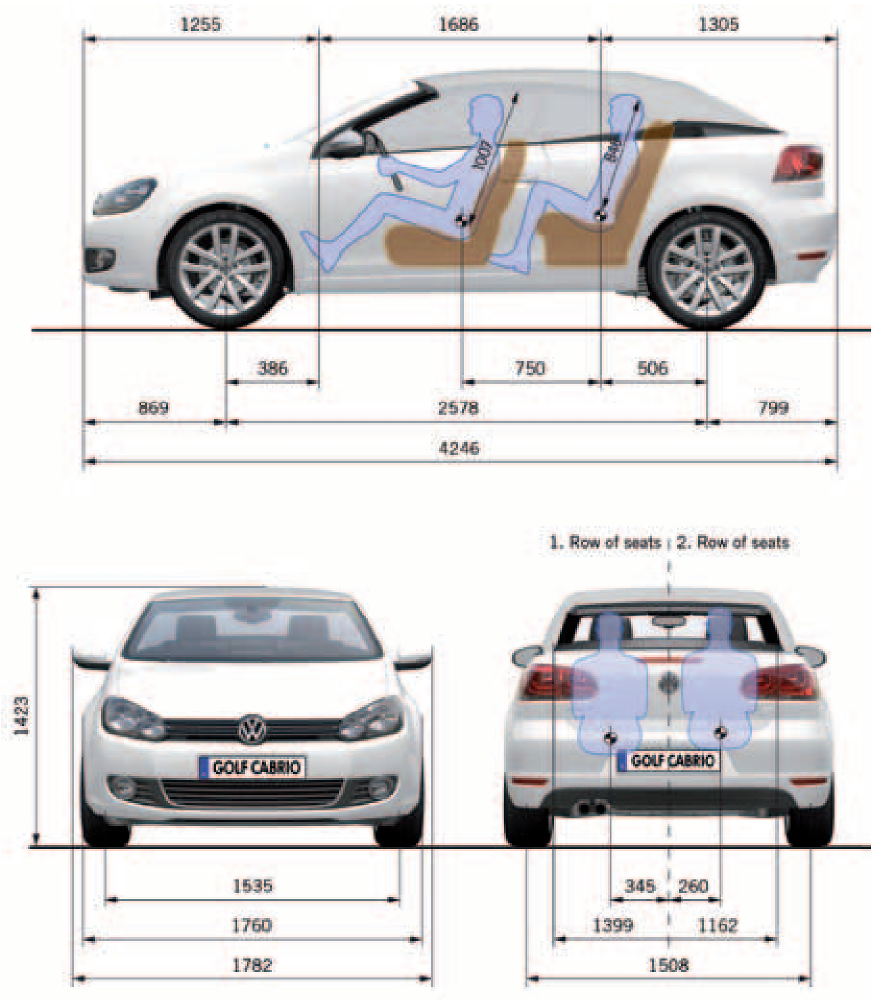
CONCEPT

The new VW Golf convertible is based on the platform of the current VW Golf VI. One of the principal goals in designing the vehicle concept concerned ensuring that the interior would be as roomy as possible in relation to the compact exterior dimensions, ❶.

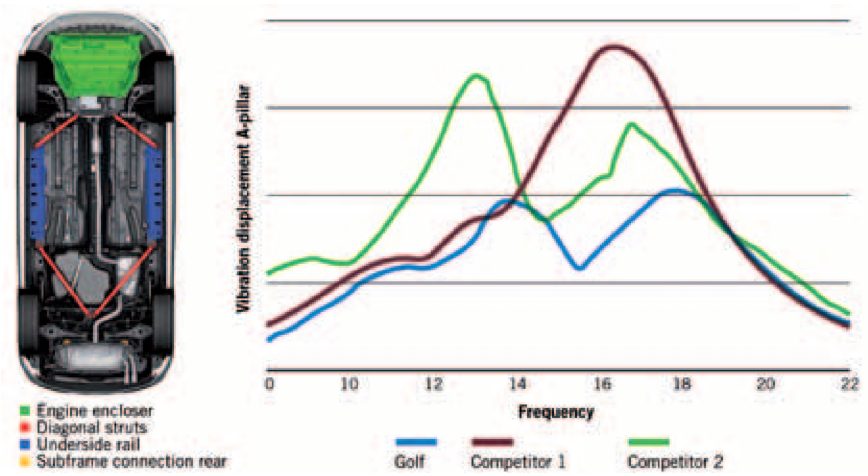
Result: the vehicle has the longest interior length in its class. The roof frame is positioned further away from the occupants, compared to the competitors. This achieves an excellent feeling of spaciousness which is typical of VW and makes it easier for the customer to get in and alight. The convertible even offers excellent seating comfort in the rear, in spite of the retractable overroll bar and a luggage compartment volume that is generous for a car in this class, including through-load facility.

BODY RIGIDITY

Torsional rigidity is particularly relevant for the impression of stiffness given by



❶ Silhouette: side view (top) and front/rear view (bottom) with dimensions in mm



❷ Body with significant structural reinforcements in the under floor (left); qualitative diagram showing the vibration amplitude of the A-pillar of the VW Golf convertible in comparison to competitors (right)

convertibles, and represents the main emphasis of any convertible development. In order to achieve a high standard of driving comfort in the VW Golf convertible, the first torsion eigenfrequency for the trimmed body has been set to more than 17.5 Hz, and the eigenfrequencies of the running gear and the body have been matched to one another very effectively – this not least as a means of reducing the forces input into the body via the running gear to a minimum, ❷. Furthermore, sections and add-on components with a structurally reinforcing effect were developed specifically to improve the already high static and dynamic rigidity of the basic platform even further.

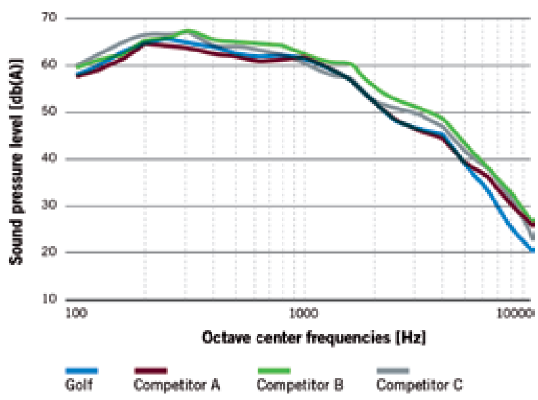
The aluminium engine cover and its mounting holders led to an optimum reduction in relative movement between the front subframe and the tips of the front longitudinal member. This movement represents a dominant parameter of front-end movements in convertibles. At the same time, the diagonal struts and the rear subframe connections not only increase stiffness but also significantly reduce amplitudes of the body structure and eliminate vibration.

The characteristic value of torsional rigidity is more than 13,500 Nm/° – a very good value for an open vehicle. The eigenfrequencies of the body in white are > 26 Hz for the first torsion and > 29 Hz for the first flexure. High static body rigidities form the basis for a safe driving feel. The objective in developing the vibration properties is to minimise the torsional vibration that is usually encountered in convertibles. An important tell-tale in this case is the vibration amplitude of the A-pillar in the transverse direction of the vehicle, ②.

The body itself only has slight inherent damping properties. As a result, corresponding countermeasures have to be taken to reduce reverberation, for example after driving over an isolated obstacle. The engine/transmission mountings used by Volkswagen in vehicles with transverse engines allow the engine/transmission assembly to be used as a vibration absorber. The engine mountings for each engine/transmission combination have been designed individually in terms of optimum vibration comfort. As a result, no additional and weight-intensive dampers are required.

AERO-ACOUSTICS

It has also been possible to develop the aero-acoustics of the new VW Golf convertible to a significantly further extent. Specifically, experience from previous



❸ Wind noise (sound pressure level) of the VW Golf convertible in comparison to competitors

projects was analysed under aero-acoustic aspects to discover which synergy effects can be leveraged. In addition to tuning the engines and transmissions attention focussed on integrating the necessary new parts. It proved possible to achieve a low noise level without neglecting the economic and technical objectives.

For example, a successful compromise was made in the selection of the softtop fabric between the thickness of the insulating mat and the quality of the softtop fabric. In this area, the VW Golf convertible is located on about the same level as the competitor A with acoustic top, see the 200 to 1000 Hz frequency range in the diagram in ❸.

The noise level in the frequency range above 5000 Hz, on the other hand, was significantly improved by revising the seal concepts in the areas of the door and roof crossmember, ③. The short travel concept implemented for the door windows also makes a significant contribution to noise comfort due to the extremely short response time.

The results of the measurements taken using technical means and subjective assessments of the acoustic comfort make it clear: systematic processing of the parameters defined initially made it possible to achieve a very good wind noise level. In particular, the high-frequency ranges (above 5000 Hz) were included in the investigations and have a major effect on what is referred to as the articulation index. This provides information about how well occupants can make themselves understood to one another whilst driving at different speeds. The VW Golf convertible sets new standards for the acoustic interior.

SOFTTOP CONCEPT

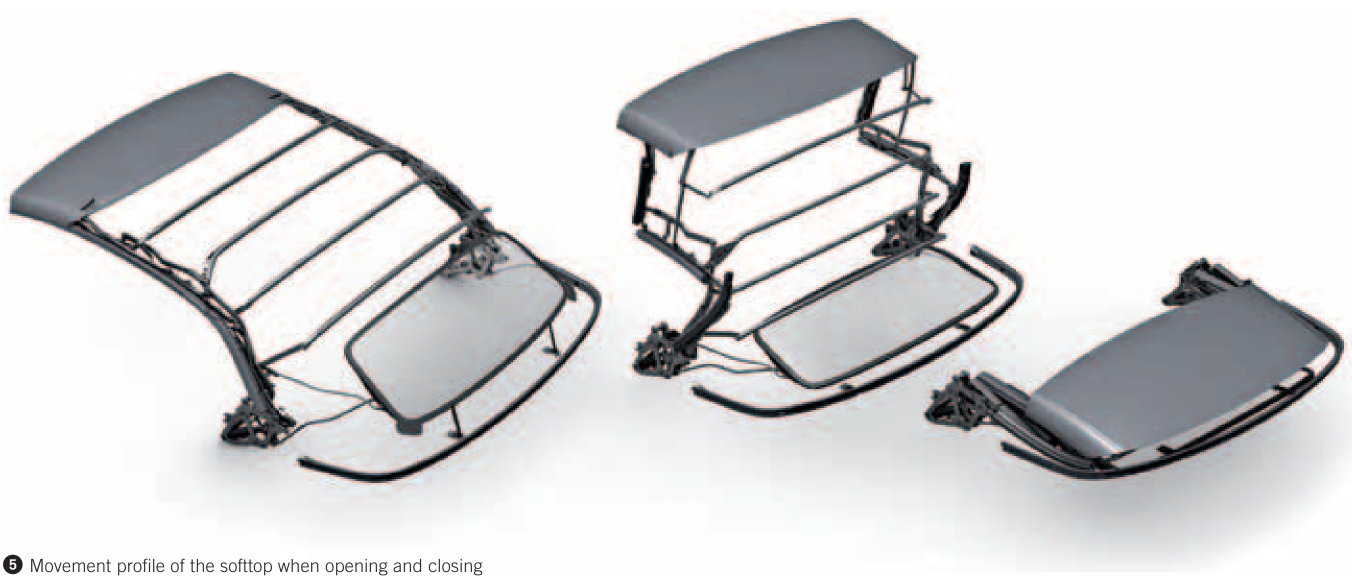
The roof consists of a Z-folding fabric roof which is firmly connected to the rear of the body opening. The upper side of the front roof bow covers the area of the softtop compartment from above over a large area when the roof is down – this is advantageous in particular because it means no additional softtop compartment cover is required, ❹.

The roof is opened and closed fully automatically by the hydraulic drive and the front lock when the push/pull button in the centre console is operated. The significant features of the roof concept are:

: rapid roof opening (9.5 s)
: softtop can be operated whilst driving up to a speed of 30 km/h
: short package in lengthways direction of the vehicle
: large-format front roof bow covers the softtop when it has been lowered; no need for an additional softtop compartment cover (less weight, costs, etc.)
: front approach to the cowl panel approximately in the Z-axis direction to ensure optimum seal compression and eliminating seal abrasion
: optimised size of glass rear window
: softtop status indicator integrated in the instrument cluster.

The softtop linkage consists of the following main components: main bearing, main pillar with mobile fabric retaining bracket, main link, lateral roof frame, front roof bow, control links, four

❹ Opened (left) and closed (right) softtop



❺ Movement profile of the softtop when opening and closing

round-profile roof bows and rear window link.

The softtop is locked by an electromechanical lock system. The electrohydraulic drive system ensures the softtop linkage functions reliably. This moves a laterally installed four-joint kinematic system by means of the rotary motion link, with the limit positions (roof opened and closed) being interrogated by two microswitches, ❺.

The softtop covering is made up of a centre panel and two side pieces. The lengthways seam is configured in such a way as to serve as an additional rain channel. A round cord embedded in the side piece also carries out this function. The covering is connected to the roof bow tubes by means of screwed-on fabric holding strips. The connection to the roof bows prevents excessive ballooning. The heated glass rear window is connected to the covering by means of high-frequency welding.

The functional unit comprising the electronics and the drive system also has a hydraulic pump. Additional equipment includes the rear window heating, the wiring harness and the sensors. The softtop wiring harness carries the current of the electrical and electronic units in the softtop to a central connector that is connected to the vehicle wiring harness. There is an additional connector for the hydraulic pump on the drive system.

The drive system for the softtop operates electrohydraulically. A hydraulic pump generates the hydraulic operating pressure and the flow rate. The hydraulic unit is enclosed in sound insulation in order to improve the acoustic properties.

INFOTAINMENT

The VW Golf convertible uses updated radios and navigation systems with extended functions. The range includes the RNS315 and RNS510 navigation systems as well as the RCD210, RCD310 and RCD510 radio variants, ❻. The infotainment equipment is supplemented in an intelligent way by mobile phone preparations and multimedia interfaces.

The new devices have additional languages for the displays and for voice control. The navigation software is state of the art and has been supplemented by additional useful functions such as waypoint indications, personal points of interest, a travel guide and “green route”. The Optical Parking System (OPS) is expanded into a 360° display in conjunction with the Park Assist function. The harmonious visual impression is completed by the screen display in RCD210 and RCD310 radios being changed over to white text, as in the instrument cluster. The latest

❻ Infotainment with navigation systems and radios

❼ Chassis with normal or sports suspension as well as leather steering wheel with sun-reflective coating

audio formats for MP3 players and Apple iPods optimise the pleasure of listening to music, while the mobile phone preparations are suitable for mobile phones currently on the market and the audio streaming function from the telephone has been expanded to feature title display on and control from the radio.

ENGINES AND TRANSMISSIONS

The drive range from the Golf family which is also used for the VW Golf convertible includes the full range of modern engines and transmissions with TSI, TDI and DSG technology [2] that are used in the Group. Selected engine/transmission combinations feature, in some cases as standard, in others as options, BlueMotion Technology, the stop/start system, an energy recuperation function (braking energy recovery) and longer gear ratios.

The range of petrol engines includes highly turbocharged 1.2 l, 1.4 l and 2.0 l TSI engines with direct injection and covers the power range from 77 to 155 kW. They are designed to run on regular unleaded (95 RON) which is less costly than super unleaded.

As far as diesel engines are concerned, 1.6 l and 2.0 l TDI units are used (with 77 and 103 kW maximum power). These feature second generation common rail injection technology and four-valve injection. This second generation features even greater economy, dynamic performance and reliability.

The range of transmissions includes the familiar manual and automatic transmissions from the Golf saloon version. In addition, there is the seven-speed dual clutch transmission DSG (DQ200), which was the first transmission of this kind for front transverse installation and with a dry clutch [3].

CHASSIS

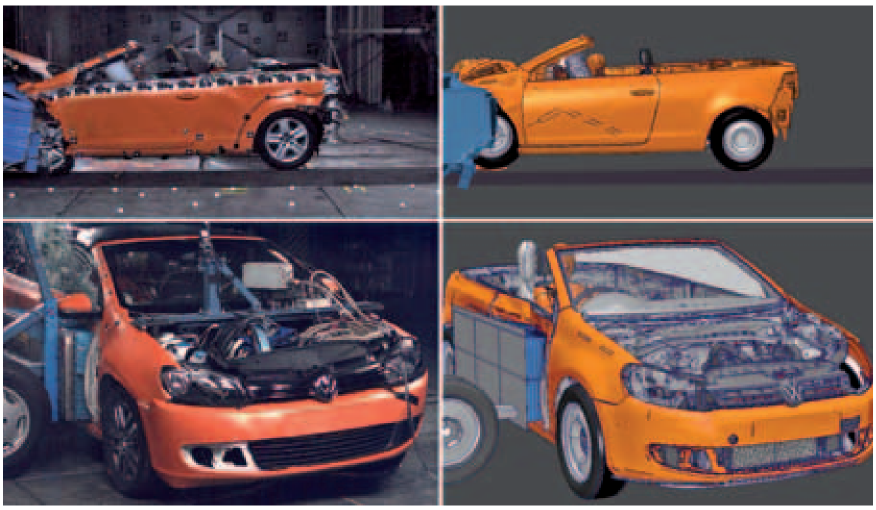
All models of the VW Golf convertible have been planned as front-wheel drive, although a normal suspension and a sport suspension lowered by 15 mm are available, ❼. The suspension is based on the PQ35 (Golf V) platform which meets all requirements for driving dynamics and comfort.

The McPherson front axle features stabilisers with optimised efficiency for high lateral rigidity and longitudinal flexibility, ensuring excellent rolling comfort. The multi-link rear axle has separate longitudinal and transverse dynamic functions, dampers with a precise response as well as a track variation curve with a slight understeer effect to assist in achieving the desired steering agility and to increase stability when braking.

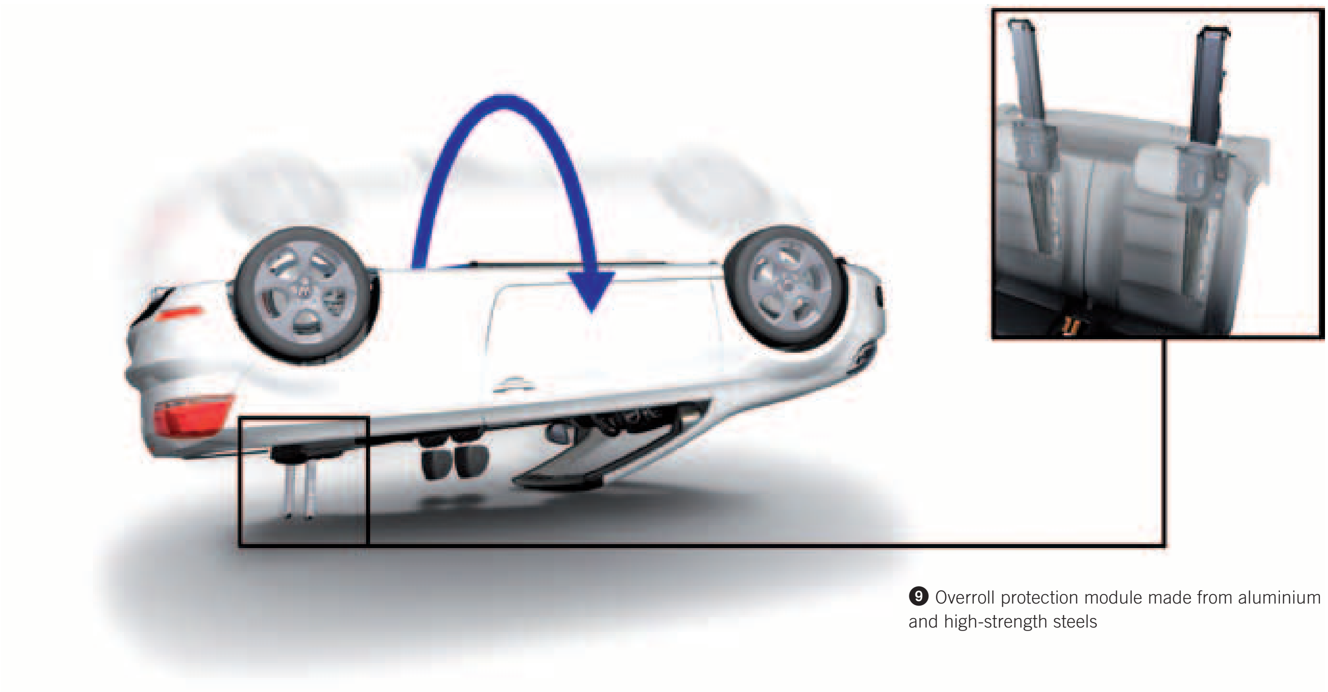
16, 17 and 18-inch wheels are available for the VW Golf convertible which is equipped with the electronic stability programme (ESP) as standard. The tyres are environmentally friendly and have undergone continuous development to reduce their rolling resistance.

The optional leather steering wheel is always manufactured in the “Cool leather” material variant in which the additional application of a reflective coating (pigmentation) reduces heating of the nappa leather when exposed to direct sunlight.

The optional adaptive chassis control (DCC) achieves a further significant improvement in driving dynamics and comfort compared to the previous convertible. Electrically adjustable valves on the shock absorbers adjust the damping forces to the particular carriageway and driving situation.



❽ Tests (left) and simulations (right) for front and barrier side crash according to EuroNCap



❾ Overroll protection module made from aluminium and high-strength steels

SAFETY

The innovative, tried-and-tested front-end concept of the Golf VI has been carried over to the new VW Golf convertible. The pedestrian protection measures for protecting weaker road users have been transferred from the saloon version without changes.

In other areas of the vehicle, the body has been specifically developed to meet the requirements of a convertible. These include a sturdy tube in the door waist rail and load-bearing sill profiles. This equipment means that the convertible also offers an effective safety cell for the vehicle occupants and provides the best possible protection in case of a frontal collision.

In terms of side protection, the B-pillar, the floor crossmembers and the doors represent the most important structural components. Taken together, these components absorb the main loads in case of a side-on collision as is checked during the EuroNCap test, ❽. Taking over the door concept that has proven its worth in the VW Eos and using ultra high-strength steels have resulted in an efficient structure in terms of weight and performance. In addition, the head/thorax airbags integrated in the seat backrests provide a side-impact protection package that has a harmonised range of functions.

The safety equipment of the new convertible is as fully featured as in a saloon car. The standard equipment includes driver's and front passenger's airbags, head/thorax airbags for the front seats as well as the knee airbag on the driver's side.

In combination with the seat belt, a knee airbag absorbs the energy from the pelvis area and the legs, resulting in reduced strain on the occupant. The knee airbag integrates the driver in the deceleration of the vehicle from an early stage via his or her thighs and pelvis. The precise torso rotation initiated in this way means that the head and chest of the driver are caught and supported at a favourable angle by the driver's airbag.

All seats are equipped with three-point automatic seat belts. Belt tensioners on the two front seats and belt force limiters on all seats ensure that the occupants are linked to the vehicle at an early stage, thereby providing effective restraint and protection. The seat belt fastening reminder for the driver and front passenger is a standard feature. Isofix anchoring points on the two rear seats round off the equipment of the new VW Golf convertible with regard to child safety.

A state-of-the art active overroll protection system has been developed to provide safety in case the vehicle rolls over, ❾. The weight has been reduced significantly by using aluminium and high-strength steels. The new, compact design of the overroll protection system comprises two extending modules and is connected to the vehicle in a concealed position in the rear behind the rear seat backrests. This allows a through-load dimension of 526 × 381 mm to be achieved from the luggage compartment into the passenger compartment. As a result, it is possible to transport large items when the roof is closed. The two overroll protection modules are activated by the central airbag triggering unit in case the vehicle rolls over. In this way – together with the sturdy A-pillars – they provide effective protection for the occupants within a few milliseconds.

INTERIOR EQUIPMENT

The highest levels of quality, value and appeal are also achieved inside the VW Golf convertible, ❿. The beautiful surfaces of the door and side trims underline the high standards set by the vehicle. However, great emphasis has also been placed on useful functions. For example, a storage compartment for a 1.5-l bottle has been added, and the integration of the high-visibility tabard holder in a side crash element of the door trim allows the occupants to access the tabards directly when required.

Comfort and ergonomics were the priorities in seat development. For example, an easy entry system is used as standard. This makes it easier for the rear passengers to get in, because the front seats move forward a little.

❿ Interior

Differentiation between the Comfortline and Sportline equipment lines is achieved by different cushioning contours, finishes and covering materials. The following are available: fabric, “Alcantara” and “Cool Leather” partial leather trim.

The VW Golf convertible is a fully featured four-seat car. The rear seat backrests can be folded down separate using a remote unlocking function in the luggage compartment. A torso angle of 23° for the rear seat backrests provides good seating comfort. L-shaped headrests are used for reasons of comfort and safety. They are height adjustable and offer an unobstructed view to the rear when not in use. The blow moulding concept of the rear seat backrests contributes to the lightweight construction.

The luggage compartment is characterised by a pleasant feel, through-load facility, and convincing convenience of operation. The volume of 250 l is available even with the softtop down.

As far as the vehicle’s climate control is concerned, a feature of particular importance is the different Climatronic settings for operation when the roof is up and down, with the settings for each position being stored. When the sensors detect that the roof has been opened, the air conditioning system responds to the increased exposure to sunlight or, if the heating is switched on, directs additional heat to the occupants’ upper bodies.

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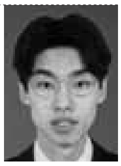

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COOPERATIVE TRAJECTORY PLANNING BASED ON CAR-TO-X COMMUNICATION

Modern cars offer assistance to the driver for many of his tasks. Especially, the sophisticated active lane keeping and automatic lateral guidance assistance systems have a high potential to increase the traffic safety. Basis of these systems is always the information about the vehicle environment. This article from the University of Duisburg-Essen and the Rhine-Waal University of Applied Sciences shows how the modern Car-to-X technology improves the gathering of information in comparison to the traditional on-board sensors and enables a cooperative trajectory planning for the lateral guidance assistant.

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1 INTRODUCTION

Since 1970, the number of casualties of the urban traffic has steadily decreased [15]. While this decline was initially caused by passive safety systems, in recent years greater emphasis has been placed on active systems. These have already shown their great potential and contribute significantly to traffic safety. A frequently discussed approach to assistance is the lateral vehicle guidance, which has entered the market as so called lane keeping assistance. There also is a great variety of approaches that pursue the goal of helping the driver in emergency maneuvers (e. g. evasion).

A crucial point in such an assistance system is the path planning. It must determine a suitable trajectory. For this purpose, information is needed about the vehicle environment [3]. Present systems focus on gathering information mostly on the basis of on-board sensors. This can only survey the environment to a limited extend. The technique of Car-to-Car or Car-to-Infrastructure (Car-to-I) communication enables a completely new approach to the task of information retrieval and the following path planning. Possible cooperative trajectory planning leads to significant safety increase as well as the driver's acceptance for the system.

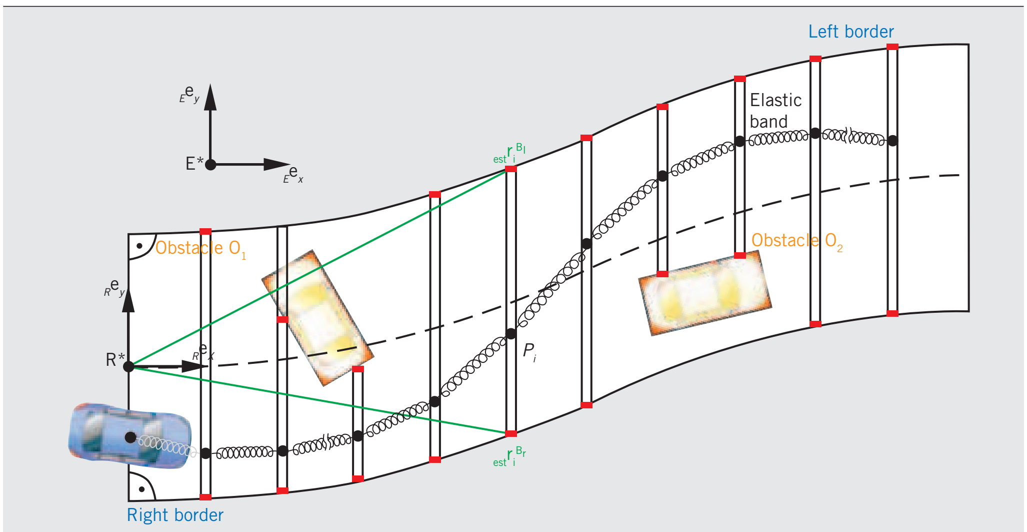
2 TRAJECTORY PLANNING

Development of active assistance and safety systems, which is driven by the desire for better traffic safety, has led to the development of different lateral guidance systems for vehicles. The desire to assist the driver during the vehicle lateral guidance causes the planning of a suitable target trajectory. Various concepts are discussed in the literature. In principle, there are several target trajectories possible at a given time. In the context of the project "Have it", the trajectory is selected from the multiplicity of possible ego-vehicle trajectories, by finding the optimum in terms of safety, comfort, consumption and the traffic regulations for the maneuver [6]. In [1, 2], the reachable sets of all road users for all possible ego-vehicle maneuvers can be estimated. Based on this, the trajectory with the minimal collision probability is proposed. An overtaking maneuver is determined during the project Proreta [8,13]. This can be used as an emergency evasion trajectory. In addition, approaches based on the rapidly exploring random tree (RRT) method [9], which was already successfully applied during the Darpa Grand Challenge. In the context of this article, a trajectory planning approach is applied according to [3] based on elastic bands, which is shown schematically in ❶. This approach is already applied in [5,10,16] to trajectory planning. Despite various trajectory planning possibilities for assistance or emergency systems, the sensing of the vehicle environment is still the basis of all these approaches. Without a secure knowledge of the vehicle environment, a suitable trajectory cannot be planned.

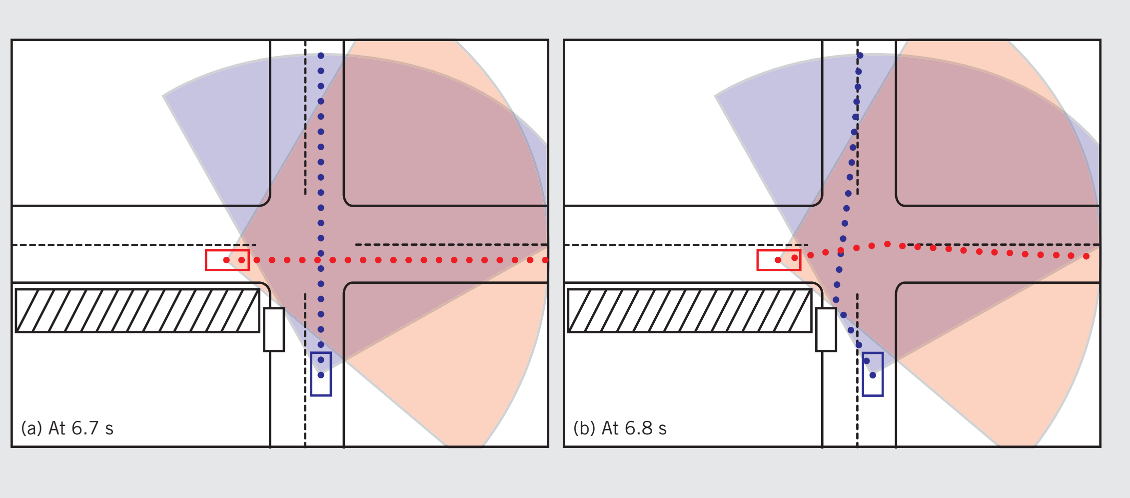
In [3], Brandt has applied the approach based on elastic bands, which has been proposed in the field of robotics, to vehicles. A possible vehicle trajectory is described by an elastic band, taking the road border and obstacles into account. The elastic band consists of nodes with constant intervals in the direction of the road. As shown in ①, the nodes move laterally and are linked by virtual springs. The described approach is a local trajectory planning method and therefore can determine different collision-free trajectories.

3 ON-BOARD SENSOR BASED PLANNING

Nowadays, the combination of various sensors already allows the implementation of driver assistance systems such as collision avoidance systems into modern vehicles. Systems based on cam-



❶ An equilibrium of the elastic band [3]



❷ Sensor based trajectory planning

eras or on radar sensors are already implemented in the new generations of vehicles and have improved the driving safety [17]. Although the modern sensors provide good measurements in many traffic situations, they still do not work in some situations.

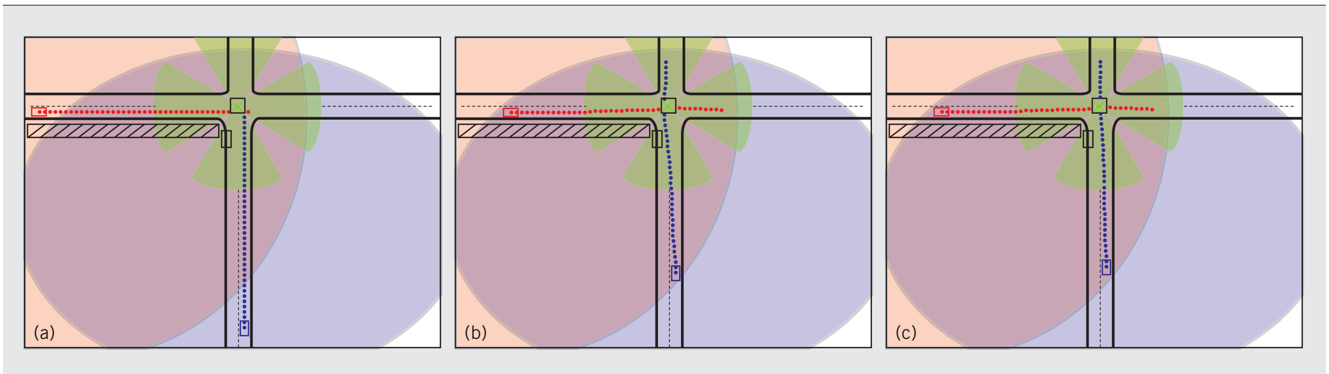
❷ (a) – (b) show two vehicles, which – each of them with a separate trajectory planning module – enter an intersection scenario almost at the same time. The trajectory planning is based on the information delivered by the on-board sensors. During the simulation, the range of the sensors remains constant and an ideal transfer behavior is assumed.

Because of the building and parked vehicles next to the intersection, the two vehicles cannot be perceived by the driver of the other vehicle. For the same reason, radar sensors and camera systems of both vehicles do not provide the information about the other vehicle for the driver and the assistance system. Thus, the resulting planned trajectory is not different from a trajectory without any obstacle, ② (a). At the moment in which both vehicles can be perceived by each other, ② (b), a possible collision free trajectory is immediately planned. However, this planning of the trajectory is very late, and demands a sudden direction correction, which is impossible to be realized by the driver under normal conditions. Despite planned evasion trajectory, the collision between the two vehicles cannot be prevented in this situation.

4 TRAJECTORY PLANNING VIA CAR-TO-CAR COMMUNICATION

The problem of a system based on on-board sensors can be partially solved by Car-to-Car communication. As soon as two vehicles are within reach of each other, information can be exchanged, while the obstacles are probably not recognized by the onboard sensors yet. If there are no such information sources within the communication range, the regular sensor information is used to obtain the familiar settings. The sensors can also be used in addition, in order to enrich or verify the information of the other traffic participants. In ❸ (a) – (c), an intersection scenario is shown, taking the Car-to-Car communication into account.

The circle around each vehicle represents the communication range. ③ (a) shows a situation when both vehicles only rely on their on-board sensors. The planned trajectory is not different from the above presented simulations. In ③ (b), both vehicles are within the communication range. Therefore, information about their own position and orientation can be exchanged. The collision free trajectory for each vehicle is planned immediately. In this situation, the on-board sensors would not detect the other vehicle as already shown. Moreover, the information content of the transferred data is higher than that of the sensors, because the vehicle internal states can be shared. However, the trajecto-

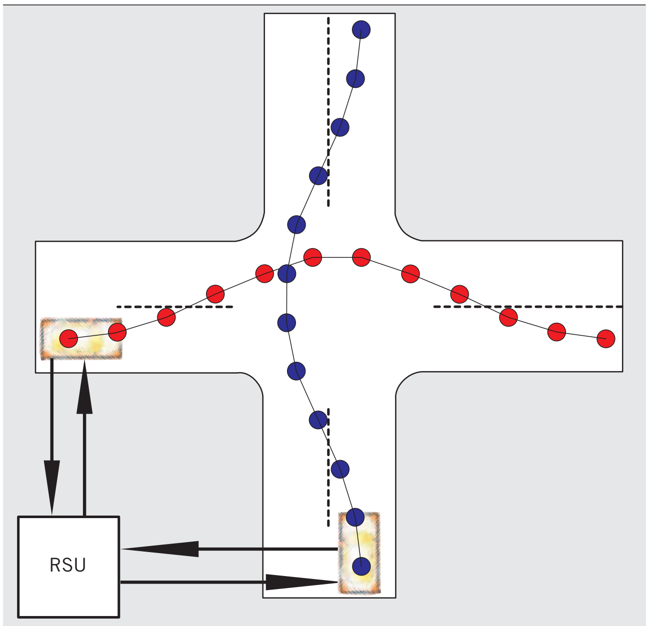


❸ Trajectory planning based on Car-to-Car communication ries are still planned individually for each vehicle. Since the planning of the trajectories are still vehicle specific and the motion of the corresponding obstacle vehicle is only considered by means of an extrapolation of the actual position and speed, abrupt changes of the planned trajectory cannot be excluded. Both vehicles change their course according to the proposed elastic bands and influence the hazard map of the other vehicle. This effect can sometimes even lead to oscillations of the planned paths. ③ (c) shows how much the trajectories do change between two successive time steps, ③ (b), (c). Since the continuous re-planning of the trajectories produces differing trajectories, it is almost impossible for a driver to ride along the proposed path. It can even confuse the driver and therefore cause a hazardous situation.

5 CENTRAL OPTIMIZATION OF THE TRAJECTORY PLANNING VIA CAR-TO-INFRASTRUCTURE COMMUNICATION

In order to avoid the problems associated with individual trajectory planning, a central optimization unit could be used, as described in [5]. In the area of a complex intersection or a dangerous place, a stationary unit could be used. Appropriate infrastructure such as cameras enables even non-motorized road users to be incorporated into a trajectory planning. Trajectories for all traffic participants are calculated and optimized according to a rule base. While [5] has considered only autonomous driving, the driver is an important component in real vehicles. In the increasingly complex systems, the driver must be considered in an appropriate manner and involved in the design of the system.

In ❹, the cooperative trajectory planning is shown. A fixed central unit is applied to collect information on various traffic participants and to determine an optimal trajectory for each vehicle according to the information. The vehicle and node data of the present elastic bands are sent to a central unit (e. g. roadside unit) by the Car-to-I communication. In the central unit, the trajectory is optimized in terms of drivability, safety, and the driver intention, which is crucial for a good working assistance system. To determine the driver's intention methods based on Bayes nets can be used as proposed in [14]. It can be prevented that a trajectory (and the according assistance) conflicts with the manner of driving desired by a driver. The optimized node data will be sent to the corresponding vehicles again by the Car-to-I communications. Thus, the trajectories are determined which not only prevent a collision but also can be followed by a random driver.

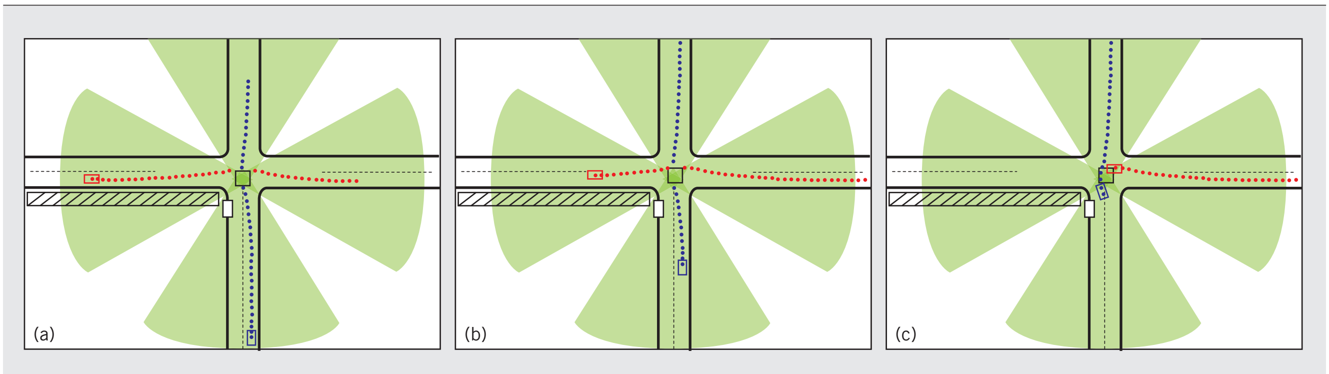


❹ Central optimization of trajectory planning

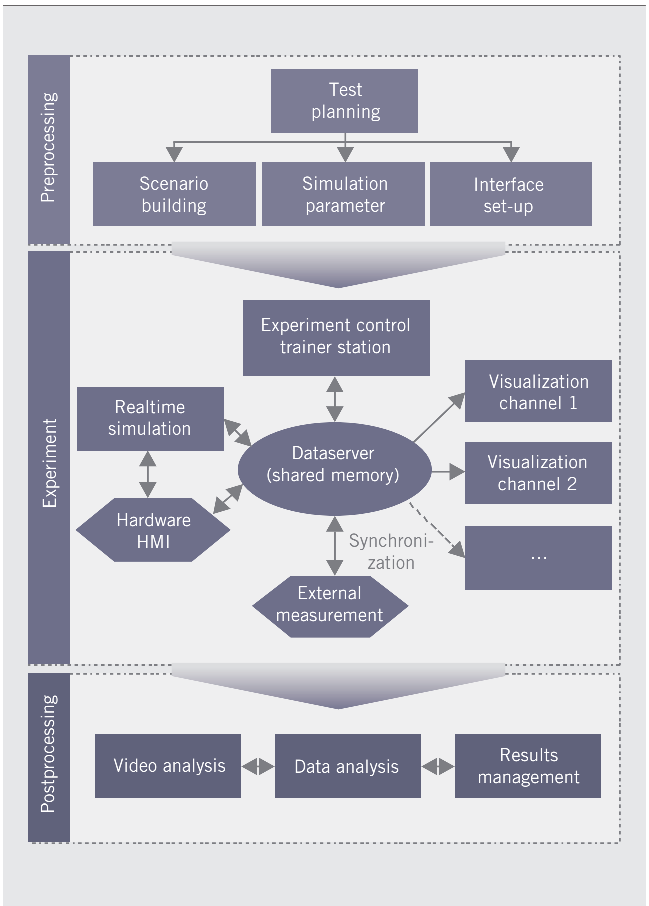
❺ shows that a trajectory for both vehicles is determined directly after both vehicles enter the green-marked transmission range of the RSU (Road Sind Unit). This trajectory prevents a collision and can remain unchanged over the whole range of the maneuver.

6 DRIVER IN THE OVERALL SYSTEM

Even with the ideal knowledge of all ambient information, the proposed vehicle trajectories could be insufficient due to the human factor. For this reason, the driver influence on the trajectory planning must be taken into account. Otherwise, the proposed trajectory planning might not be accepted by the driver and the cooperative trajectory planning could even lead to a collision due to the individual behavior. The proposed assistance is based on a hapic feed-back via the steering wheel. In the event of the system being active the driver is alerted be the additional torque applied to the steering wheel and therefore the level of attention increases. The proposed system might however be critical in an



❺ Results of a central cooperative trajectory planning



❻ Network structure of each client [4]

event when the driver is not able to detect the cause of a proposed trajectory, since possible obstacles are not always in sight. In this case the driver has to have a very high level of confidence to the system. The interaction of such a system with the driver remains to be examined.

The human factor can be considered in the above shown approach at various points of the planning process. In particular, the driver's request is considered at the starting solution in the trajectory planning algorithm [3]. Once the vehicle trajectories are planned, it must be communicated to the driver by an appropriate manner. Such complex human-centered mechatronic systems can only be studied analytically limited. They mostly require an experimental validation of the system properties. For this reason, the driver assistance system with the trajectory planning algorithm and the driver must be tested [17]. As indicated in [4, 7], the driving simulator "Drivassist" is well suited to analyze the effectiveness of driver assistance systems taking the human factor into account.

To conduct a study of human-centered cooperative systems, two Drivassist Driving simulators have to be linked, so that they are available in one scenario, as shown in ❻, a central data server, which is comparable to the RSU used in the cooperative trajectory planning, manages all scenario-relevant data. The various clients (individual vehicles here) can access the server. Effects due to central planning or the individual behavior are shown and the planning strategies or rule bases can be established.

7 SUMMARY

Modern vehicle guidance systems contribute to improving the road safety. Today's systems are mostly based on on-board sensors as the single source of information. The limits of these sensors restrict this functionality of the overall system.

Car-to-X communication can be used in addition to the existing sensor systems. Because of the application of the communication technology, it can be intervened earlier and safer in many scenarios. Hereby, a significant safety gain can be achieved.

A central cooperative planning of various assistance systems is also possible due to the application of Car-to-I communication. The simulations in this contribution have shown that such a planning has distinct advantages compared to individual assistance systems in the respective vehicles. The point of the human-machine-interaction can be affected positively, because the systems can operate with full knowledge of the complete scenario early, thoroughly, and comprehensibly. This is coupled with a high degree of the system acceptance on the part of the driver.

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