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Low-Cost and High-Tech as Opportunities

Dear Reader,

In 2020, for every German employee in the field of research and development, there will be more than five excellently trained automotive engineers in China – which will mean that German car makers and automotive suppliers will lose their global innovation leadership and competitiveness. That is the key statement of a study by management consultants A. T. Kearney. The innovation centres of the automotive industry will relocate from Western Europe to China and India, as they will offer huge development resources with many innovations in future.

India is one of the emerging economies. Tata Motors caused a sensation with its low-cost car, the Nano. But when they were developing the small car, the Indian engineers relied on good and proven technology from Germany, such as a fuel injection system from Bosch.

Our interview on page 12 with vice-president Patrick Pélata, who is responsible for strategy issues at Renault, shows how the French company is meeting the challenge of global competition. Firstly, its Dacia brand provides it with a second range of vehicles that will be successful in emerging countries. In the end, no less than nine cars will use the Logan platform. Secondly, Renault is not ignoring high-tech issues such as batteries. Pélata expects a breakthrough for electric cars on the demanding European market in 2011.

For that reason, we Europeans do not need to be afraid of China and India. Instead, we have to see low-cost and high-tech as opportunities.

Dipl.-Ing. Michael Reichenbach
Wiesbaden, 27 June 2008

Michael Reichenbach
Vice-Editor-in-Chief

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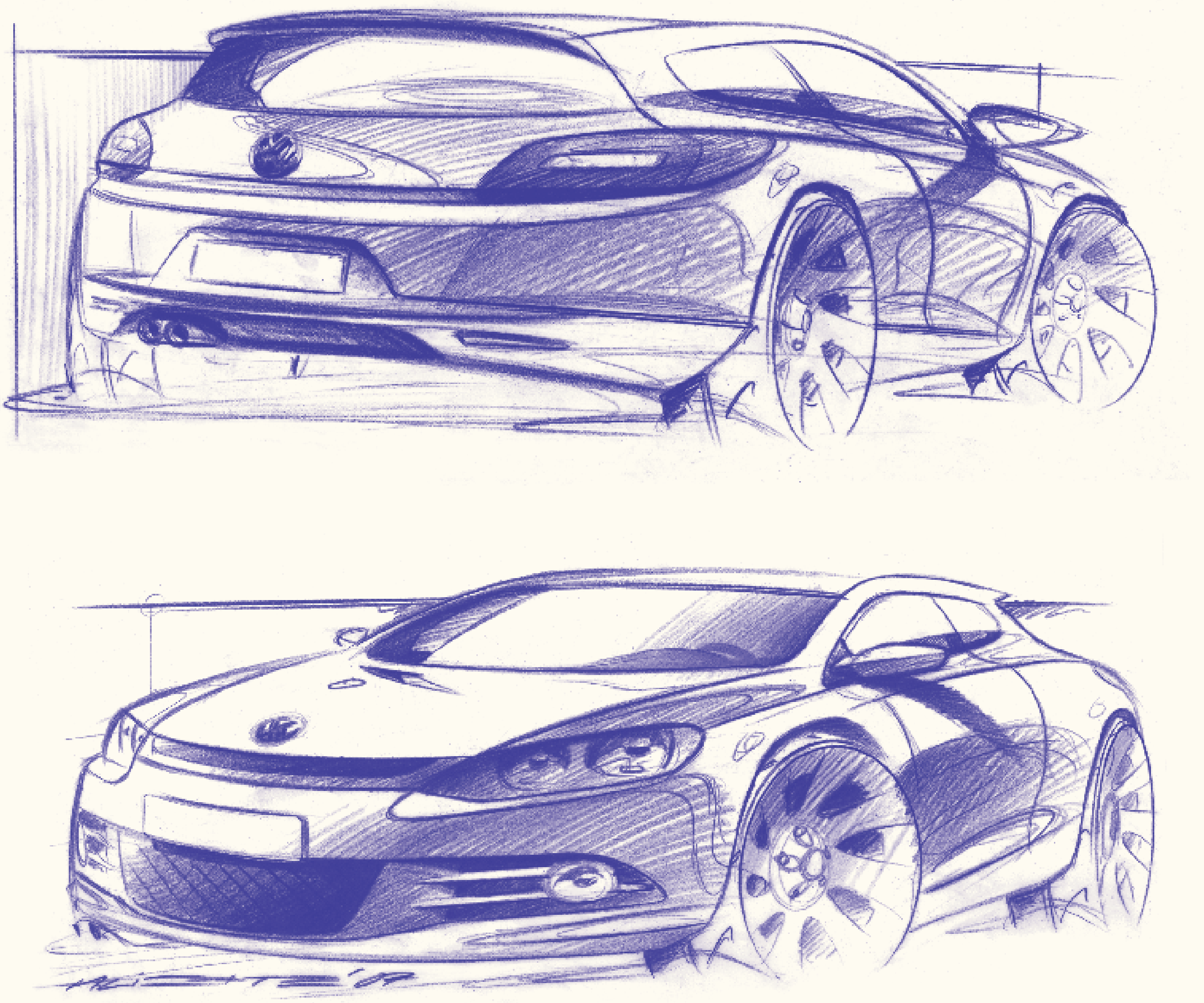

The New VW Scirocco

For the Scirocco comeback Volkswagen uses a shape that is known as the shooting brake among the fans of classic English sports cars. This look is newly interpreted and combined with an emotional design and everyday practicality. As a consequence the new Scirocco is markedly different from the first two generations and communicates its sportive quality via the long roof outline leading into the pronounced rear spoiler.

1 Introduction – Design

The first two generations of the Scirocco attracted over a half million of customers with the unique and emotional vehicle design based on the Golf. Like its predecessors the new Scirocco crouches on the road, flat and wide. The front-end design conveys another important design message, since this marks the beginning of a new design era at Volkswagen. The emphasis on horizontal elements definitely has a historical background, since the design of the first two generations of the Scirocco also had a horizontal grille connecting the headlights. The upper air inlet with its shiny black frame forms a broad band with the headlights. With their dynamic, slashed design the headlights convey a certain impression of aggressiveness which is borne out by the nimble character of the Scirocco. This theme is mirrored to a certain extent beneath the bumper: An opening which extends into the sides includes the indicators, fog lamps and a generously sized egg-crate grille. The powerful rear with its broad shoulders pushes the car forward. The powerful curves also achieve the desired effect when viewing the rear – they contrast dramatically with the tautly designed core elements of the tail design. Horizontal, flat lamps which have an almost eye-shaped contour are connected by means of a prominent swage line. The clear, reduced form of the rear window stands out clearly from the lower part of the body, resulting in a rear view characterised by a muscular body which crouches on the ground with an air of self-assuredness. The car appears powerful and agile from this perspective as well.

Another counterpoint: The "nipping in" of the bodywork in the middle section resembles a waist. The tautly designed rocker panel, rising slightly, emphasises the changes between clear lines and sensuous forms. Flat side windows, with an elegant upward flourish at the rear, extend the body which is compact from the cab onwards, overturning the proportions of classic sports cars of a short roof to a long bonnet, and are an important element in providing the shape of the Scirocco with the necessary originality and therefore character.

2 Exterior

With a length of 4.26 meters, the vehicle is on par with the Golf. However, thanks to its frameless doors, it is built significantly lower to the ground (1.40 meters) and is nearly as wide as the Passat (1.81 meters), making a large track width of 1.55 meters at the front and 1.56 meters at the rear, **Figure 1**. Combined with the standard 17" alloy wheels or the optional 18" alloy wheels, this also contributes to the Scirocco's dynamic appearance. The passenger compartment can seat four adults comfortably. Even when a 1.90 meter tall driver adjusts the driver's seat

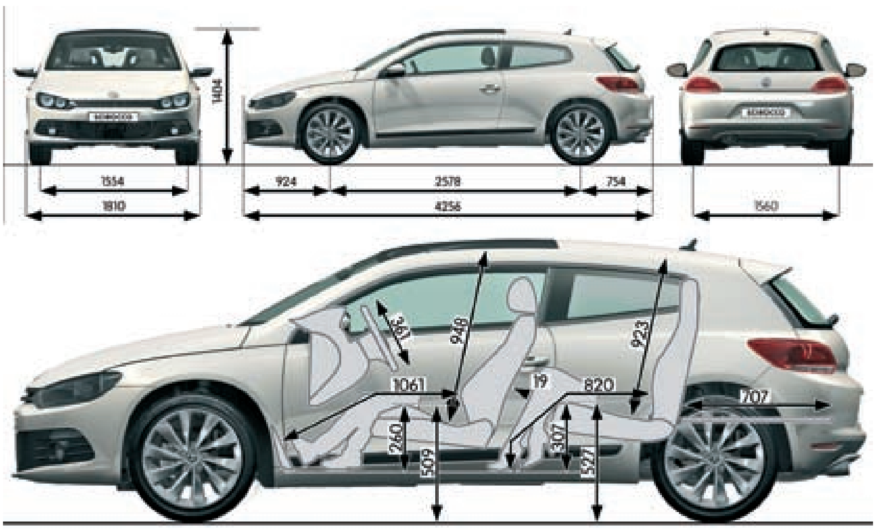

Figure 1: Vehicle dimensions

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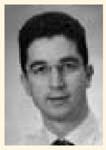

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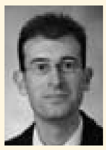

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Figure 2: The lighting concept: standard halogen headlights (top), the optional Bi-xenon lights (middle) and the rear lights (bottom)

(as far back as it will go), there is still knee room (19 millimeters) for the rear sear passengers. Despite its extremely sporty nature, the Scirocco has a cargo area volume of 292 liters. If the seatbacks of the two rear individual sport seats are folded down, the volume increases to 755 liters. There is no problem loading the cargo area up to the roof lining. This new-era Scirocco demonstrates unfettered everyday utility.

Lights: Halogen and Bi-xenon Headlights

The Scirocco comes as standard with halogen headlights with dipped and main beam lights. Position and indicator lights are integrated in a functional unit in the bumper. The optional bi-xenon headlights combine dipped and main beam light in one functional unit. In addition, static corner lights and separate daytime driving headlights are integrated. The flat, horizontal tail lights with their almost eye-shaped contour shape the rear, **Figure 2**.

3 Interior

The driver and front passenger in the vehicle experience a sporty and sophisticated ergonomic environment. Pleasing to the touch and appealing to the eye are the complex designs of the interior door trim. In addition, instruments and gauges have been laid out intuitively and clearly. In particular, the centre console with its controls arranged at a high level exhibits a refreshingly clear layout, **Figure 3**.

Arranged directly beneath the two central air vents is the audio system. The latest equipment generation (RCD 210 to RCD 510) is being used on the Scirocco. The equipment packages always include an MP3-capable CD player or changer. In parallel, there will be two audio/navigation systems. The top model, the RNS 510, includes such refined features as a 6.5-inch touch screen and an extremely fast 30-gigabyte hard disc.

3.1 Seats

The Scirocco is a fully fledged four-seater. Here "fully fledged" means that two adults can be seated comfortably in the rear. Similar to the new Passat CC, ideally-contoured ergonomic individual seats are used in the back of the Scirocco. Providing a high level of safety are the headrests that are permanently mounted to the seatbacks in the rear. The front sport seats include an Easy Entry function as standard for easier entry and exit of the rear seat passengers. When the seatback of a front seat is unlatched, the seat moves forward; afterwards it automatically returns to its preset position. The height adjustment system of the front sports seats also comes as standard.

3.2 Dynaudio Sound System

Since the initial launch of the high-end sound system, Dynaudio, in the Passat, Volkswagen is now offering this system in a very similar form in the Eos, Touareg, Multivan and Tiguan as well. In order to satisfy customers' desire for decent sound quality in the compact class, the engineers have managed, in collaboration with their Danish colleagues, to transfer this high-quality sound system to the A class segment as well. The sound system will be used for the first time in the new Scirocco within its class.

The system is based on speakers with the characteristic innovative Dynaudio technology. The four 168 mm woofers - consisting of a membrane made of magnesium silicate polymer, a very light 74 mm oscillation coil and an inner magnetic construction in a rigid plastic basket – in the doors in the front and in the side panels in the rear of the car, provide a precise and powerful bass with high pulse fidelity. The 60 mm and 50 mm tweeters – with a 28-mm or 25 mm woven fabric dome with a special coating and powerful magnets – in the recesses of the door and side panel trims – guarantee transparency and detailed design.

The treble reproduction, the homogeneous radiation of all frequencies, the realistic-looking stage above the instrument panel and the powerful bass reproduction, ensure that the listener will be able to enjoy a faithful quality of sound.

The loudspeaker system is driven by the newly developed digital 300-Watt power amplifier comprising eight Class AB amplifiers.

3.3 Panoramic Vent Roof

The panoramic vent roof is an optional extra. Tinted glass and a fabric sunshade guarantee a pleasant climate and good protection against the sun. The roof can be raised by 39 mm for ventilation purposes. The supporting framework, which serves to accommodate the entire system and to guarantee the vehicle's rigidity, is made from a glass-fibre reinforced polyurethane system (long fibre injection, LFI), **Figure 4**.

As a special design feature it should not go unmentioned regarding the constructional design of the front and central roof cross-members that these have been designed in a dual shell form and only the upper shell is controlled depending on "full roof" or "panorama vent roof" application. The front area of the roof between the windscreen and the panoramic vent roof has been integrated into the module. Made from an injection moulded film made of PC-ABS (polycarbonate and acrylonitrile-butadiene-styrene), it has a shiny black design. Thus, the entire roof projects the image of a continuous visually adapted area as far as behind the B pillar, thus visually extending the windscreen and contributing to the Scirocco's sporty design claims.

A manual sunshade system is used as protection against the sun, which, in terms of the demands made, represents a complex further development of all of the current sunshade systems. The following technical outline conditions have therefore been taken into consideration and implemented in this shade system:

- use of opaque sunshade fabric to increase the degree of shading
- continual adjustment of the sunshade independent of the opening position
- side-controlled sunshade to guarantee fabric tension
- additional front sunshade engagement device
- sunshade shaft provided with a transverse curvature (strake), adjusted to the body design, to maintain the required head clearances.

In addition to the advantages of the roof module already described, mention should also be made of the tinted, heat-insulating glass roof (transmission light 8.2 %, UV radiation 2.8 % and heat rays 6.9 %) used and the fact that the system meets the statutory requirements of an anti trap control system.

4 Chassis

The Scirocco's chassis offers driving pleasure without compromises with a sporty-dynamic design and the right

Figure 3: Interior design of the Scirocco

Figure 4: The panoramic vent roof's glass pane is embedded in a plastic frame made from fibre-reeinforced PUR

Figure 5: The Scirocco chassis is based on modules from the Volkswagen modular kit

amount of comfort. It therefore comes up to the high expectations created by the sporty appearance of this new coupé from Volkswagen. An excellent driving experience is possible thanks to the deliberate selection of chassis components from Volkswagen's module construction kit and committed precision work during tuning, **Figure 5** and **Figure 6**.

4.1 Axle Concept and Chassis Tuning

The Volkswagen PQ35 platform, with its McPherson front axle and four-link rear axle, provides all the necessary ingredients for a compact sports car's chassis. Springs, dampers and stabilisation have been adapted to the vehicle's lower sitting position and to the vehicle's specific weight distribution. Hub carriers made of aluminium are used on the rear axle to increase the wheel track and reduce the unsprung masses. A generally lowered stance improves aerodynamics and emphasises the vehicle's sporty appearance. With its extremely agile driving behaviour, the tuning of the chassis is designed such that the Scirocco offers an extremely high degree of stability and driving safety. The tyres have been specially designed for the sporty character of the Scirocco and optimised to provide high lateral dynamics and short braking distances.

4.2 The New Adaptive Chassis Control DCC

In the new Scirocco Volkswagen's adaptive chassis control DCC is available as an option for the first time in an A Class Volkswagen, making possible a further, clearly noticeable improvement in driving dynamics and comfort. The system consists of four adjustable dampers, three sensors each for wheel position and body acceleration as well as an electronic control unit. In addition to controlling the dampers of front and rear axle, the system also influences the characteristics of the electromechanical steering. The movement of the wheels and the vehicle body is continually measured by the wheel position sensors and the body acceleration sensors. The signals of these sensors are processed in the control unit with other CAN data from the steering, engine, transmission and braking system. Depending on this input, the damping for each wheel is continuously adjusted by electric control valves according to the prevailing road and driving conditions, using a new control algorithm designed from scratch by Volkswagen.

In addition, the driver is able to adjust the control parameters to his personal preferences in three modes (Comfort - Normal - Sport) by the press of a button in the center console. During the development phase of the system it has been possible to significantly reduce the development cycles thanks to model-based software development and automatic code generation, and to provide the system with the Volkswagen hallmark.

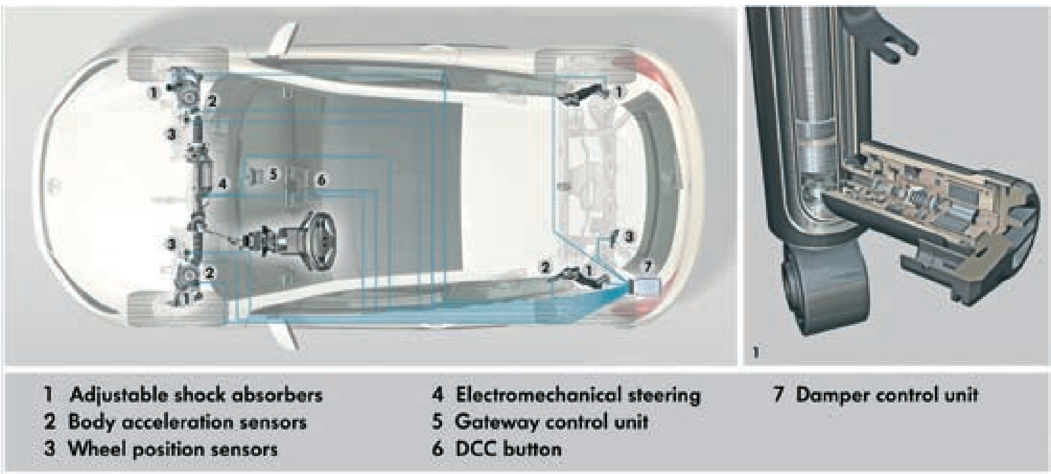

Figure 6: DCC: Adjustable dampers facilitate an adaptation of the damping forces according to the instantaneous road and driving condition

4.3 Innovations in the Steering System

In the Scirocco, the electromechanical steering gear (Electromechanical Power Steering, EPS) can fully display its system-related benefits such as speed-sensitive power steering assistance and extensive suppression of disturbances. A new generation is being used for the first time: the steering angle sensor, which is used by both the electromechanical steering and by ESP, has been integrated as a worldwide first in the pinion housing and can therefore be omitted from the switch module of the steering column, resulting in an increase in sensor quality and reliability. The steering column has also been redeveloped: Crash behaviour and rigidity have been improved and, at the same time, it has been possible to reduce the weight. The Scirocco is equipped with attractive leather steering wheels, optionally with multifunction buttons, and – in conjunction with a DSG-gearbox – also with Tiptronic (manual automated gear shift).

4.4 Optimised Braking System

The vehicle is fitted with powerful floating-calliper brakes with large brake discs and an enlarged brake master cylinder, making it possible for the brakes to respond quickly as well as allowing short pedal travel, and highlighting the sporty character of the Scirocco.

A new ESP generation is used as standard in the Scirocco, in which the sensors for yaw rate and lateral acceleration have been integrated into the hydraulic system's control unit. As a result, the previously separate sensor cluster in the passenger compartment can be dispensed with.

5 Passive Safety

The Scirocco has the same high level of safety as the Golf and Passat. The basis of this is a body structure with great rigidity (sturdy passenger cell), energy-absorbing deformation zones all around and a protection system fine-tuned to these characteristics. The combination of the high rigidity of the body structure and specifically designed deformation zones form the basis of its good crash performance. A design with lightweight, profile-intensive construction using form-hardened, highest-strength sheet steel was chosen for the Scirocco. The shell construction of the steel body also offers the occupants optimal protection under even the worst crash conditions, **Figure 7**.

The basic structural requirements have been very quickly and purposefully attained through the extensive use of digital simulation methods. As a result, it was possible to reduce the number of modifications to the hardware to a minimum during the product creation process. The need for pedestrian protection was also given high priority from the very first stages of developing the Scirocco. All relevant components at the front of the vehicle were engineered with this in mind. The interior sheet metal structure of the bonnet was, in particular, optimised for pedestrian protection. The hinge area represented a particular challenge. A specially designed soft foam body is installed behind the bumper cover. Together with a support beneath the bumper transverse beam, this is primarily intended to reduce pedestrian leg injuries.

5.1 Systems for Protecting Vehicle Occupants

The use of simulation methods in designing body structures and restraint systems opens up the possibility of evaluating and optimising a variety of designs in the shortest possible time.

The simulation methods, the CAE infrastructure and processes are constantly being further developed based on experiences from previous developments. In the design model of the Scirocco, in addition to the restraint systems, the complete passenger compartment structures were illustrated as structural mechanical models. It is therefore possible to adjust

Figure 7: Form-hardened, highest-strength sheet steel increases chassis strength and rigidity

Figure 8: The airbag system includes driver and front passenger airbags, head airbags and side airbags

all of the system parameters to a variety of different crash conditions. Optimising the complex functions of a restraint system is no longer conceivable without recourse to occupant simulation.

The "virtual prototype" milestone was embedded in the development process of the Scirocco. Long before the first experimental members were available, all of the essential functions of the restraint system could be evaluated and optimised with the aid of simulation.

The strengths of occupant simulation lie not only in the functional design and forecasting, but it also assists experimental evaluation during advanced development. The virtually unlimited visualisation possibilities aid understanding of the test results considerably.

The front airbag system provides optimal restraint for the driver and front passenger during a frontal collision, with minimum risk of injury. The front passenger airbag is installed in the top of the instrument panel and can be disabled via a key switch. The status is indicated to the driver via a display, enabling a rear-facing child seat to be mounted safely in the front passenger seat. Child safety is completed by standard Isofix anchorage points for the rear seats. Standard head airbags and side airbags integrated in the seat backrests, thus ensuring that they are always correctly positioned, add to the all-round safety of the Scirocco, **Figure 8**. A rear-end impact is detected by means of the two acceleration sensors integrated in the airbag control module, which are aligned with the car's longitudinal direction. In addition to triggering the protective restraint systems, tensioners and airbags, the airbag triggering system also communicates with other control modules, ensuring that the hazard lights are activated, locked doors are unlocked, the interior lights are switched on and the fuel pump is switched off.

6 Engines and Transmissions

Volkswagen will be offering the Scirocco as the world's first sports car with charged engines only, **Figure 9**. The three TSI petrol direct-injection engines output 90 kW/122 PS, 118 kW/160 PS and 147 kW/200 PS. The TDI offers a similar range of performance: The highly advanced

Figure 9: All Scirocco engines are highly charged: the choice includes three TSI engines and a TDI

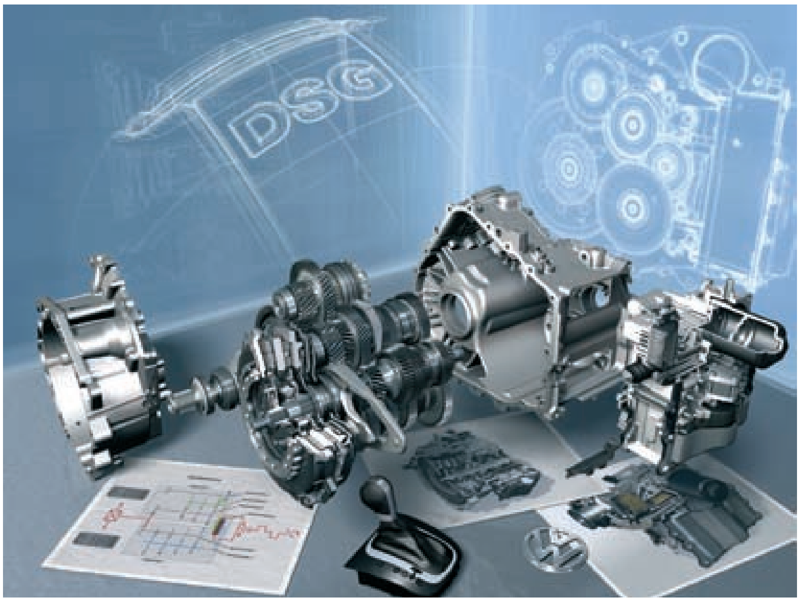

Figure 10: For the Scirocco the world's first dry 7-gear DSG is available in a series production car

common rail engine develops 103 kW/140 PS. All Scirocco models will feature six-speed gearboxes as standard. A 7-speed DSG will be optionally available.

6.1 Gasoline Engines

6.1.1 TSI with 90 kW

Maximum power with minimal consumption – within a very short period of time this property has made the TSI four cylinders synonymous with a new generation of fuel-efficient and, at the same time, sporty Volkswagen engines. Representing the entry level into the world of these multiple award winning engines is a 90 kW/122 PS strong TSI (at 5,000 rpm). In the Scirocco, the four cylinder engine develops its maximum torque of 200 Newton metres at a low 1,500 rpm. The TSI takes the car to a top speed of 200 km/h. The122 PS Scirocco handles the classic 0-100 km/h sprint in 9.7 seconds. Its average fuel consumption of 6.1 litres Premium Unleaded per 100 kilometres makes it one of the most economical sports cars in its class.

6.1.2 118 kW TSI with Turbo Charger and Supercharger

This TSI engine is a four cylinder, turbo- and supercharged engine, with 118 kW/160 PS (at 5,900 rpm). Like all of the TSIs, this engine is exceptionally economical (average fuel consumption: 6.5 l/100 km) and high-torque (maximum of 240 Newton metres at just 1,750 rpm) too. This TSI takes the Scirocco from rest to 100 km/h in 8.0 seconds; its top speed is 217 km/h. As an option, the 160 PS TSI may be paired with the first 7-speed DSG in the world that is transversely mounted.

6.1.3 TSI with 147 kW

At the highest power level, the Scirocco comes with a powerful 147 kW/200 PS (at 5,000 rpm) TSI. It too has a turbocharger, and it also shines with very good torque and fuel economy. Per 100 kilometres this 280 Newton metres (from 1,700 rpm) four-cylinder engine consumes just 7.6 litres of fuel. Yet it can still deliver a top speed of 235 km/h. The highest performing Scirocco of all times completes the sprint to 100 km/h in 7.2 seconds. As on the Golf GTI with an identical engine, for example, this engine can also be ordered with an innovative 6-speed dual clutch transmission on the Scirocco.

6.2 Turbo Charged Diesel Engine with 103 kW

At its market launch in Europe, the vehicle will already be available with a clean and high-torque 140 PS TDI (103 kW at 4,200 rpm). This highly advanced common rail diesel is especially quiet. It develops its maximum torque of 320 Newton metres starting at just 1,750 rpm. The Scirocco completes the 0-100 km/h sprint in just 9.3 seconds with this TDI. Its top speed of 207 km/h contrasts with an average fuel consumption of just 5.4 litres per 100 kilometres. Volkswagen offers an optional 6-speed DSG with this engine too.

6.3 Transversely Mounted 7-Gear DSG

As one of its outstanding design characteristics, the world's first 7-speed DSG DQ200 for volume models possesses two dry clutches, the pressure of which is hydraulically regulated. The engine power is transferred to the dual clutch via the crankshaft by means of a dual mass flywheel, **Figure 10**. Clutch 1 serves the odd gears, while clutch 2 serves the even ones plus reverse. The clutch management ensures that there is no more interruption of traction power during shifting. Consequently a dynamic and at the same time smooth shift feeling with a high degree of comfort is conveyed. The entire shifting process is completed within just a few hundredths of a second. ■

Patrick Pélata
Executive Vice President for Product Planning and Programs, Renault

"We Want to Have Most of Our Growth in Growing Markets"

Now that people are willing to pay more for better efficiency, Patrick Pélata sees no problem in achieving 130 g/km with improvements in the pipeline such as stop/start and turbocharged petrol direct injection engines. However, Renault's Executive Vice President also sees an electric-car breakthrough coming in 2011 that could become a market of 2.5 million battery-powered cars in Western Europe, Pélata said to ATZ.

ATZ What does Renault need to do to meet Europe's 2012 goals for CO_2?
Pélata We are quite confident that we will meet the goals without burning money. What we see is that the current value of a gram of CO_2 saved has been rising. This allows us to put more technology into the car, because the customers are ready to pay more for more fuel efficiency, or they are ready to buy a smaller car with a better fuel efficiency and make a different trade-off between space, comfort and utility. These technologies are not that expensive, and they are already in the pipeline. They will be ready to achieve 130 g/km of CO_2. This is more of a 'kaizen' kind of continuous improvement. Diesel engines, transmissions, downsized petrol turbo engines, electricity management in the car, thermal management in the car, start/stop systems with supercapacitors for bigger cars, and things like that. Besides that, we are preparing other breakthroughs, for example electric vehicles.

ATZ What is the basis for your breakthrough?
Pélata All the technologies for a CO_2 breakthrough are shared with Nissan. We work together and divide the workload. Nissan was the first car company to choose lithium-ion, and about four or five years ago, the engineers at Nissan started to say, "the batteries will be safe," but the cost was still extremely high. When I left Nissan in 2005, we could not make any business case, but when I came back to Renault, we discovered that if the battery price came down a little bit, there were potential business cases in Europe, for example for postal delivery services, where vehicles make the same round trip every day. So we said to Nissan engineers, when would you be able to make a battery below a certain cost? Six months later, there was a big surprise to all of us in the alliance board meeting when they said, "Yes, we can. By 2012." And that changes the story. Carlos Ghosn met the Israeli President Shimon Peres in Davos (Switzerland) just three months after that significant event, and Perez asks Ghosn, "Would you make electric vehicles for us in Israel?" Of course, he said yes.

ATZ And how does the story continue?
Pélata A few weeks later, I started to discuss the project with Shai Agassi, who is the American-Israeli founder of Project Better Place. So we are probably the first ones to have a real business case, the mass production of batteries and cars and a market, as well as somebody to operate the network. And when we began to see these economies of scale, we got more ideas on how to reduce the cost of the electric motors, etc. The Nissan engi-

"We feel challenged by Tata with its 3000 US dollar car" neers have been working and the cost of batteries has gone down, and now we are starting to see other potential business cases in Western Europe.

ATZ What will be the next step?
Pélata The automotive market is still very much customer-driven. With Project Better Place, we are learning a lot of things, an amazing quantity. You do not operate an electric car in the same way. A lot of things are changing in the car. We need to take the time to learn, instead of saying in an arrogant way, "I already understand everything."

ATZ Will you be working on a platform adapted to electric traction for other markets in 2012? How big can the market be?
Pélata For current batteries and for the heavy car we are doing for Israel, to get the energy with current photovoltaic cells, you need 15 m^2 of photovoltaic cells to fill the cars with all the energy it needs for 15,000 km a year.
How many people in Europe can accept a car that can do 150 km a day, or 100 km using air conditioning, etc? We find that one sixth of the market is like that. One sixth of the market represents cars that are second cars, which are never used to go to the country house more than 100 km from the main home, never used for holidays, just used for commuting, going shopping, or taking the children to school. These amount to 2.5 million cars, based on conservative assumptions and assuming that nothing changes in our habits for using the car.

ATZ Is 150 km the limit?
Pélata We can make cars better than that. We can make the car smaller, we can make the engine better, we can make the battery better. The starting point is not that bad.

ATZ What are the trends for Renault's traditional cars and traditional markets?
Pélata Renault has two businesses: we compete in one mature market, which is Europe, where we have our Megane and Laguna, and we try to do niche cars like the Koleos. And we have a second business, in which Renault is successful, in emerging markets like Argentina, and the Logan is designed for these markets. We have been adding new body types on the same platform, and in the end we will have eight or nine cars on this platform. We want to continue to fight on the refined and more expensive European market, but we want to have most of our growth in growing markets.

ATZ How will Renault react to the Tata Nano in India?
Pélata We feel challenged by Tata with this 3000 US dollar car, and we are putting the best of our engineers to work with Bajaj to find a solution that would not be just a "me-too" car. We want a car going in the same direction, but with some differentiation.

ATZ Mr. Pélata, it has been a pleasure talking to you.

Interview conducted by Bill Diem, correspondent ATZautotechnology.

Patrick Pélata

was born on August 24, 1955. He is a graduate of two engineering schools – École Polytechnique and École Nationale des Ponts et Chaussées – and has a PhD in socioeconomics from the École des Hautes Etudes en Sciences Sociales in Paris. He joined Renault in 1984 as a shop foreman in body-in-white assembly at the Flins plant. He designed the architecture for the Twingo chassis and became boss of platform architecture and chassis equipment. Then, in 1998, Pélata was named Senior Vice President for Vehicle Engineering, and in 1999 he joined Carlos Ghosn's team at Nissan as Executive Vice President for Corporate and Product Planning, Design and Programs. When Ghosn came back to Renault in 2005, he brought Pélata with him, as Executive Vice President for Product Planning and Programs.

R744 A/C Systems
Test Stand and Field Test Experience

For 14 years now, Behr has been investigating and developing refrigerant circuits operating on the alternative refrigerant R744 (CO_2). During this time, extensive staff and technical resources have been built up for the development, testing, and validation of these circuits in A/C (air conditioning) systems. These include a number of circuit and component test benches, test labs, climatic and acoustic chambers as well as a modern climatic wind tunnel. Also counted are simulation tools and the capability for industrialization and initial application of the refrigerant circuits in motor vehicles. Extensive field trials were carried out in conjunction with automobile manufacturers. These revealed that the performance, efficiency, vehicle integration, and reliability of R744 refrigerant circuits have attained a level that corresponds to, and in some cases even exceeds, that of present-day R134 systems. In addition, initial experience in the manufacture of R744 components was gained through small-scale production runs.

1 Introduction

On January 31, 2006, the European Union (EU) made the decision to ban refrigerants with a global warming potential (GWP) of over 150, which also includes the currently used R134a refrigerant, which has a GWP of 1,430. Accordingly, as of 2011, all new vehicle models in the EU must be equipped with eco-friendly climate control systems, and, after 2017, all new vehicles.

Following intensive testing of all alternative refrigerants, the German automotive industry was the first in the world to decide to utilize the particularly eco-friendly R744 refrigerant in future A/C systems. In order to achieve this goal, they are accompanied by the development partner Behr based in Stuttgart, Germany, which has extensive experience with the R744 refrigerant, and has carried out series-production projects through to the design validation phase additionally with fleet tests.

2 Objectives of the Fleet Tests

For the reason of in-house testing, and for trials conducted by automobile manufacturers, 20 vehicles were equipped with R744 circuits. To do lifecycle testing some fleet vehicles were also converted and endurance-tested. Altogether, components for 100 vehicles and vehicle bodies were delivered. Objectives of the fleet tests were:

- testing the performance and efficiency of the R744 A/C system
- testing the pressure and leak resistance of the refrigerant circuit
- gaining manufacturing experience through small-scale component production
- studying the integration of the refrigerant circuit into the vehicle
- derivation of specifications from actual driving operations for component validation
- testing and application of the R744 servicing unit.

3 Testing and Validation Resources

Behr has great experience in testing and a big number of test benches for R744 [1–4]. In the following test benches and run times, simulation tools and thermal dummies, climatic wind tunnel and the vehicle fleet are discussed.

3.1 Test Benches and Run Times

First of all, refrigerant circuit test benches were developed. Subsequently, to meet the growing demand for air conditioning systems, test stands were also constructed for individual components. Even after the deactivation of one older test stand, there are still three refrigerant circuit test benches in operation for the R744 fleet trials. The run time accumulated up to March 2008 was approximately 20,000 h. The component test stands for compressors, evaporators, gas coolers, and accumulator IHX (Internal Heat Exchanger) units were in use for 3000 h. An acoustic chamber is available for noise measurements. The fact that the operating time of the refrigerant circuit test benches is much higher than that of the of the component test rigs is due to the fact that many findings about the components had already been obtained on the refrigerant circuit test benches, **Figure 1**.

The results from the test bench investigations and fleet trials were used to develop the R744 technology as well as upgrade the test benches themselves. So not only A/C circuit performance was measured on the refrigerant circuit test benches, but also the efficiency of the A/C circuit that means the power take-up of the compressor at different cooling outputs (and various boundary conditions) in the vehicle. Modern measurement technology enables an accurate determination to be made of fuel consumption. In this way, additional potential increases in air conditioning efficiency can be investigated, which will ultimately reduce its fuel consumption demand.

3.2 Simulation Tools and Thermal Dummies

Simulation tools, such as Behr's own "Behr Integrated System Simulation" (BISS), were also continuously upgraded. Today, complex circuits, such as the heating up and cooling down of vehicle cabins, can be reliably modelled with BISS. Even air conditioning systems with two evaporators, as found in truck cabs or luxury vehicles, can be simulated.

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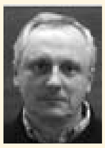

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Figure 1: Climatic chamber for simulating the vehicle environment during the measurement of R744 A/C circuits; the climatic chamber is part of the R744 system test facility

Figure 2: Cooldown measurements in the climatic wind tunnel: with the help of the adjustable solarium, every possible type of solar radiation into the vehicle cabin can be simulated

Additionally, real and virtual thermal dummies are used to evaluate vehicle climate comfort. These dummies mimic the behaviour of human skin, **Title Figure**. Depending on the air temperature and air motion, and the solar radiation temperature, the sensors on the measurement surface yield a temperature that correlates with the comfort perceived by test subjects. This comfort correlation is also used in three-dimensional flow simulations (CFD). Through the use of this virtual thermal dummy, initial statements regarding passenger comfort in the vehicle can already be made in the early development phase.

3.3 Climatic Wind Tunnel

With the climatic wind tunnel, installed only a few years ago, Behr's development engineers, as well as the OEMs, have one of the world's most advanced facilities of its kind at their disposal. The wind tunnel is distinguished by several special features, primarily its superior air flow quality and low noise level. These properties enable a uniform air flow onto the vehicle as well as acoustic optimization of the interior noise. Additional special features include a movable solarium, **Figure 2**, and the fitting of the climatic wind tunnel with two powered and brakeable pairs of rollers. The solarium is equipped with a shutter system to simulate cloud formation and other shade conditions.

Dynamic cycles are run in the climatic wind tunnel. The dynamics and flexibility of this tunnel are highly advanced, because environmental and driving conditions can be quickly altered. In addition, different climatic extremes (tropics, desert, Arctic) can be input in quick succession. The temperature can be reduced from +50 to −20 °C in less than 2 h. The lowest attainable temperature is −30 °C. The input temperature is controlled with a precision of ±0.5 °C throughout the entire measurement chamber and test duration.

The relative humidity can also be input very precisely and varied quickly, on the one hand through the continuous flow of extremely dry air, and on the other through the controllable injection of water vapour. The maximum attainable relative humidity is 95 %.

3.4 Vehicle Fleet

The vehicle fleet consists of two groups: Behr's test vehicles and vehicles provided by the OEMs. The first group consists primarily of vehicles from German automakers. While the test bench trials are coordinated and conducted in Stuttgart, the OEMs are responsible for the vehicle tests. Both groups together account for over 1.2 million kilometres driven, and probably even more, because not all of the test kilometres logged by the OEMs could be recorded.

4 Cooling Performance and Efficiency

The significant value COP (Coefficient of Performance [5]) of an R744 refrigerant circuit is comparable to that of an R134a circuit, and in some cases is even higher. The cool down dynamics and cooling performance are higher in each case, which can be utilized to reduce fuel consumption. However, the increase in efficiency diminishes as the ambient temperature increases. But the performance and dynamic advantages of the new refrigerant circuit can also be used to achieve a higher degree of climate comfort; a vehicle cabin heated by the sun, for example, can be cooled down much more rapidly. **Figure 3** shows the A/C temperature pull down curves for a compact-class vehicle equipped with an R134a and an R744 refrigerant circuit. The comfort temperature of 25 °C was reached 14 min faster with the R744 refrigerant circuit than with the R134a circuit, starting from an initial temperature of 70 °C in the heated interior.

On average, that means when all vehicle classes are included in the comparison, the comfort range with R744 refrigerant circuits is reached 8 min earlier than with R134a circuits, **Figure 4**. Here is also shown that the use of R744 refrigerant circuits makes a key contribution to reducing CO_2 emissions attributable to air conditioning. The 1000-times-lower greenhouse potential of R744 compared with R134a leads to the elimination of the proportion of total CO_2 emissions caused by leakage. In this way, the overall emissions from an R744 air conditioning system are reduced by about 30 %.

5 Safety

Regarding the safety of the refrigerant circuit, that means pressure safety and leak safety, the evaporator located in the vehicle interior is the most critical component. The safety status of the R744 refrigerant circuit is therefore demonstrated for this component.

5.1 Pressure Safety

Today, auto A/C systems around the world still mainly use brazed plate-type evaporators. At Behr, this technology was replaced in 2002 with evaporators manufactured from extruded flat tubes. These evaporators have a higher power density than all other types of evaporator known today. The flat tube, corrugated-fin technology can also be used for R744 evaporators, although in a modified and more robust form. In contrast to present-day evaporators, which are designed for a burst pressure of 30 bar (at room temperature), for R744 evaporators this must be 260 bar (at 90 °C). Owing to the higher specific cooling capacity of R744 compared with R134a, it was possible to reduce the cross-sections of the evaporator tubes. Relative to an R134a evaporator, the force exerted on the aluminum walls of R744 flat tubes is also decreased. **Figure 5** shows that the relative force, acting on the tubular header of an R744 evaporator, is approximately 15 % lower than that on an R134a header.

5.2 Leak Safety

It does not suffice to safeguard the evaporator against the high pressures of the refrigerant circuit; there must also be safeguards against leakage. Since the evaporator is installed in the interior beneath the cross member, it is probably located in the safest position in the vehicle. Special protective measures against a crash are therefore unnecessary, especially since, in the event of a crash, the refrigerant escapes into the atmosphere before it can penetrate into the cabin.

Any refrigerant escaping from the evaporator can therefore only be caused

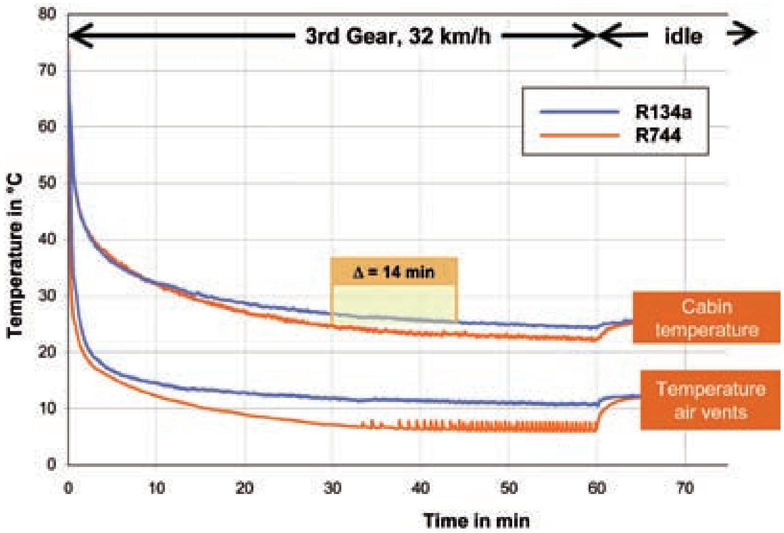

Figure 3: Comparison of cooldown measurements in a compact vehicle with an R134a and an R744 refrigerant circuit (43 °C ambient temperature, 15 % releative humidity)

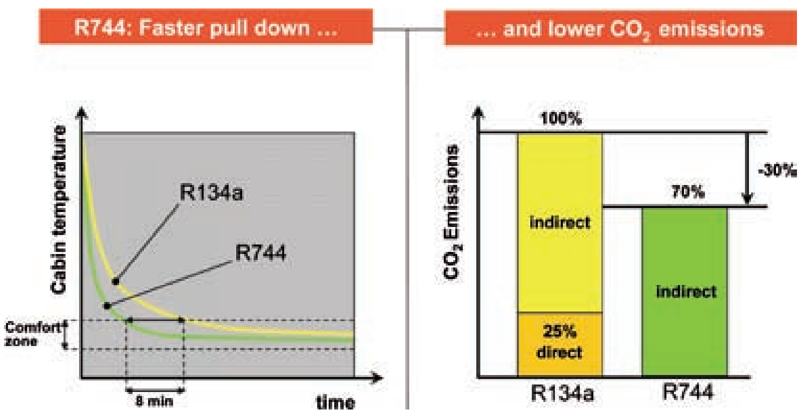

Figure 4: Comparison of R134a and R744 refrigerant circuits: left: rate of cooldown; right: lower CO_2 emissions; basis of comparison: Frankfort/Main, Germany climate profile, NEFZ (New European Driving Cycle), mid-range vehicle, 40 g/year leakage

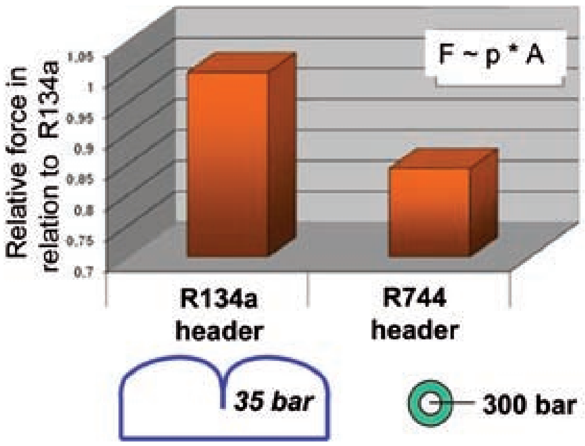

Figure 5: Comparison of the relative force (R134a set to 1) exerted on the walls of the header of an R134a and an R744 evaporator

by a corrosion hole. Assuming the correct material is used, such a leak begins insidiously, usually with a small quantity of about 1.5 cm³ of R744 per minute. However, it seldom remains a small hole; instead, several small holes will appear on a larger corroding surface after a short time. In this case, the leakage increases up to about 60 cm³/min. During the same one-minute interval, an adult human being exhales approximately 333 cm³ of CO_2, more than five times the maximum assumed corrosion leakage. Approximately 350 g of CO_2 are contained in an R744 refrigerant circuit at 65 bar. A human being takes approximately 10 h to generate this amount. It would take 84 days for this quantity to escape from a small corrosion hole; for several small holes as described above, it would take two days. In other words, the refrigerant circuit would be emptied in between 2 and 84 days.

In order to guarantee the evaporator's leak safety, it is subjected to an extensive, combined, long-duration test that consists of the following individual tests: connecting tube bending test, leak test, pressure cycling test, SWAAT (Sea Water Acetic Acid Test) corrosion test, vibration test (with shakers), and temperature cycling test. A second pressure cycling test is conducted upon completion of the prescribed test cycles, up to the destruction of the evaporator.

On the basis of these tests, a reliability of 99.4 % at a 97.5-% confidence level was demonstrated. "Reliability" is defined as the ability of a component to perform its required function under given conditions for a given time period. "Confidence level" indicates how trustworthy a statistical value is. There is, therefore, a probability of 97.5 % that the 99.4 % reliability stated above will be attained during each test.

6 Production Experience

Small-volume production of R744 components has shown which additional tests are necessary compared with those for the production of R134a components: a tube-bending test and a high-pressure leak test. The bending test should positively indicate that the tube connections are sufficiently protected from damage during the course of production. To this end, they must demonstrate a certain rigidity against bending, e.g. during shipment, which is checked in this test.

The additional leak test is necessary because of the high pressures in the refrigerant circuit; it is conducted at a test pressure of 150 bar. If a leak is detected during this preliminary leak test, the root cause can be determined. Manufacturing defects can be corrected in this way. Defective components are not repaired; the evaporator in question is removed from production.

7 Packaging and Vehicle Integration

The R744 refrigerant differs substantially from today's R134a refrigerant in terms of its thermodynamic and chemical properties. This has consequences for the functionality, size, and performance of the components installed in the R744 refrigerant circuit. Furthermore, in the R744 A/C circuit with the IHX, an additional component is used. The R744 components require less packaging space when substituted for R134a components, because, as a result of the higher density of R744 compared with R134a, the same cooling performance can be achieved at a lower volumetric flow rate than with present-day air conditioners. Consequently, R134a-based HVAC and cooling modules can easily be converted for R744 applications.

However, this cannot be accomplished by means of smaller size alone. The available space envelope in each vehicle model must preferably also be utilized as flexibly as possible. To this end, the same components were developed in different sizes, or integrated into modules; examples include:

- gas cooler: available as a separate component and as a gas cooler module with accumulator and IHX, **Figure 6**
- evaporator: similar to the R134a evaporator; integrated expansion valve, e.g. as an orifice tube with bypass
- IHX: separate, **Figure 7**, and in accumulator-integrated configuration or as part of the gas cooler module
- accumulator: stand-alone version and as combi unit consisting of accumulator and IHX, **Figure 8**.

These packaging space alternatives influence the thermodynamics (performance, refrigerant charge), the acoustics, and, of course, also the costs of the refrigerant circuit. These influences are determined during the development phase by means of simulation calculations, and the circuit is optimized accordingly. Aside from increasing packaging space flexibility, the integration of components into larger units also has the goal of reducing the number of assembly costs and connection points.

8 Service

Although the conventional refrigerant R134a may no longer be used in new vehicle models after 2011, no automobile manufacturer is obliged to wait that long before introducing R744 air conditioning systems. Behr Service will therefore offer auto workshops a complete R744 service system package correspond-

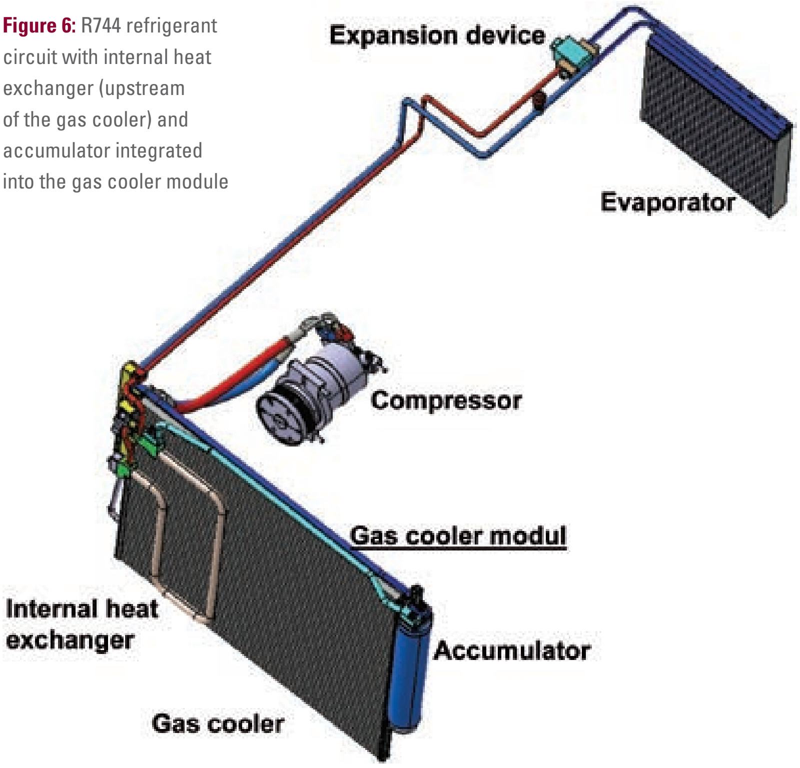

Figure 6: R744 refrigerant circuit with internal heat exchanger (upstream of the gas cooler) and accumulator integrated into the gas cooler module

ing to the start of large-scale production of R744 air conditioning systems, which provides not only for the delivery of spare parts and workshop equipment, but also for the training and certification of shop personnel, technical support, and technical information, e.g. service and repair manuals, as well as new tools and a fully automatic R744 servicing unit.

A preliminary manual R744 servicing unit was already developed in 1998 based on proven R134 service equipment. Today, a fully automatic unit is available, which is presently being evaluated on test vehicles. Its operability is comparable to that of the R134a service unit. Menu-driven functions facilitate both the implementation of individual work steps and integral, fully automatic A/C servicing. This virtually eliminates all operating errors, saving time and money. Individual functions such as the controlled draining of refrigerant, evacuation and dehumidification of the A/C circuit, recharging, replenishing of the refrigerant oil (as needed), and leak testing can be carried out by service personnel in the usual manner. For leak testing, a test gas is used which can be electronically detected.

The controlled removal of refrigerant by means of a discharge hose is necessary, so that it doesn't concentrate in the workshop. The refrigerant thus recovered is vented to the outside air. Workshops equipped with a vacuum system can use this facility to discharge the refrigerant. The R744 service station is equipped with digital pressure gauges and electronic pressure sensors, a pressure and temperature-controlled cylinder heater, and also overheating safeguards. With an evacuation time of 30 min, the complete servicing operation takes about an hour, as with the R134a equipment.

9 Summary

Given the fleet testing described by Behr, as well as the production experience obtained to date, a smooth transition from R134a refrigerant to R744 can be expected. The new refrigerant circuits surpass the present-day R134a systems in terms of eco-friendliness, cooling performance, and energy efficiency, and meet at least the same standards as current systems when it comes to operational safety, acoustics, packaging, vehicle integration, and service life. Easy servicing of the R744 A/C circuit in the workshop is likewise ensured. A fully automatic servicing unit was developed, and a training program to facilitate handling of the new

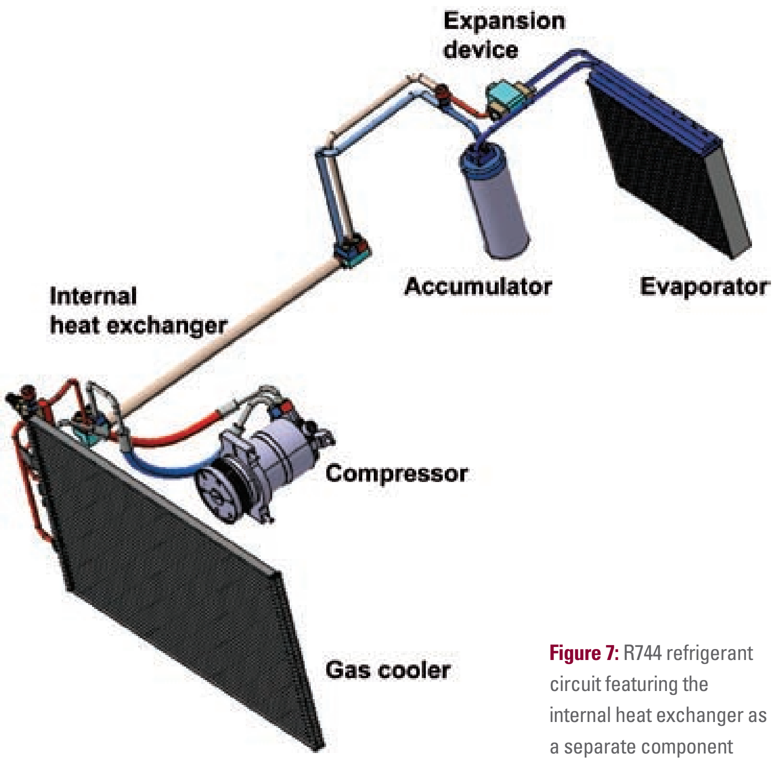

Figure 7: R744 refrigerant circuit featuring the internal heat exchanger as a separate component

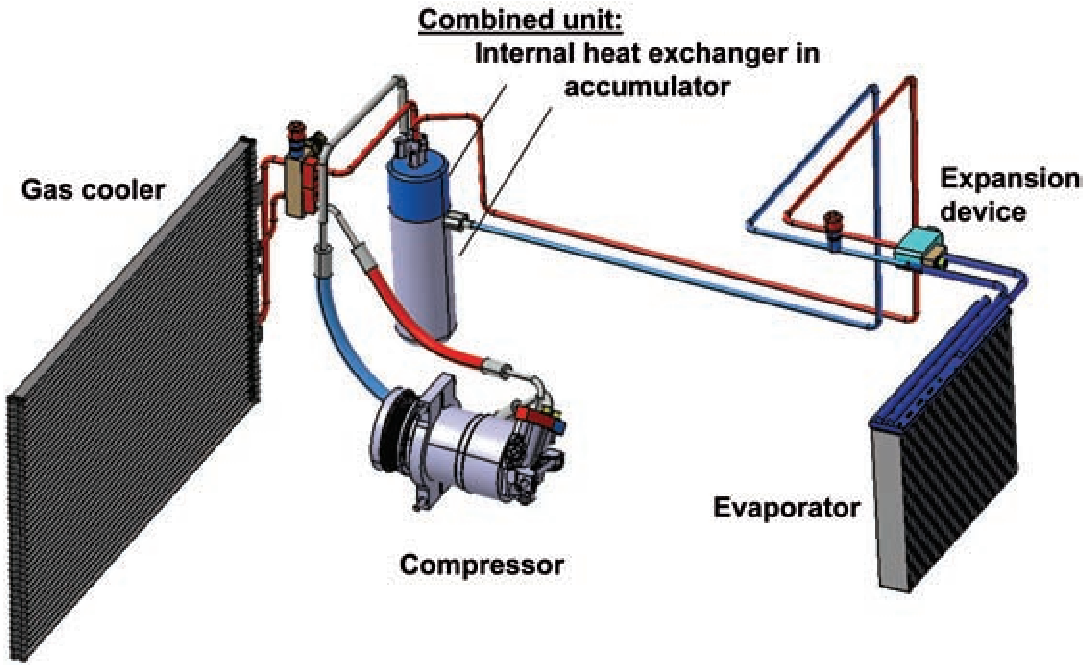

Figure 8: R744 refrigerant circuit with the internal heat exchanger integrated into the accumulator

A/C circuit is currently being prepared. An efficient national and international organization for marketing air conditioning components is also available.

Regular active participation at meetings and conventions (e.g. Society of Automotive Engineers (SAE) and German Association of the Automotive Industry (VDA) conventions) facilitates the broader dissemination of know-how and professional exchanges with customers and suppliers. One such meeting was, for example, this year's (February 2008) VDA Winter Meeting in Saalfelden, Germany, on advances in the introduction of alternative refrigerants for automotive air conditioning systems.

Behr stands ready as a competent partner for the automobile industry – a partner in simulation, concept development, advanced engineering, industrialization, and validation on a number of test stands, in the acoustics lab and the climatic wind tunnel, and with road trials. Together with joint-venture company BHTC (Behr-Hella Thermocontrol), a complete control system is also being developed and validated.

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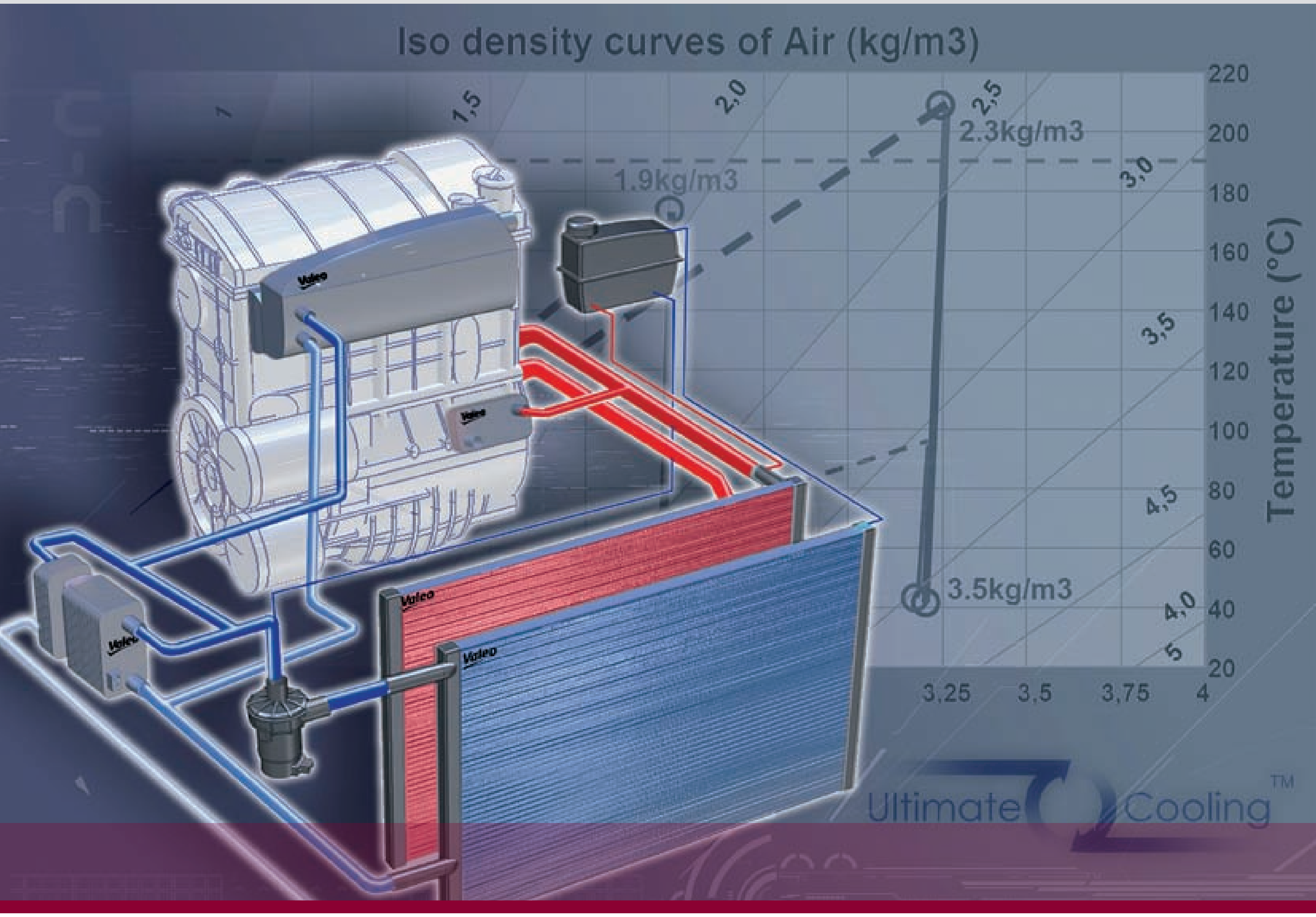

Modular Front-end Cooling Module Architecture for Future Powertrains

Cooling system development is driven by upcoming CO_2 reduction legislation. Valeo highlights an innovative cooling system architecture, which uses two modular main coolant radiators in the vehicle front-end. This newly developed "Ultimate Cooling" system has both low temperature and high temperature coolant loops, which are connected with each other. It allows together with an adapted control strategy to optimize the available heat dissipation capacity installed by the radiators in the vehicle front end. Results of measurements and simulation show the advantages of this new system in a demo-car with a Euro-4 diesel engine (50 kW/l) and a highly charged (80 kW/l) Euro-6 diesel engine.

1 Introduction

The factors that determine the dimensioning of heat exchangers in engine cooling modules, conventionally installed in the front end of vehicles are constantly evolving. They are directly linked to the functional need to cool the numerous fluids necessary for the operation of the powertrain, not to speak of the refrigerant fluid used in the air conditioning (A/C) loop. This means vehicle or chassis engineers have to reserve a packaging volume in the vehicle front end to install the different heat exchangers, the function of which is to dissipate heat generated by the powertrain to the external air.

This dedicated packaging volume is in conflict with other functions of the vehicle. In particular, it affects the dimension of the front overhang (x-axis), the minimum height of the bonnet and therefore its curve towards the front (z-axis) and the frontal width between the head lamps (y-axis). These parameters reduce the margin of manoeuvre left to chassis engineers in the styling choice at the front end. In addition, new regulatory constraints will further limit the possibilities of increasing this volume. These constraints are of two types: the pedestrian impact requirement [1] and the cost of repairing the front end after an impact at a speed of 15 km/h [2]. The pedestrian impact requirement is that the distance between the upper part of the cooling module and the vehicle hood is sufficient to make it possible to absorb the energy of pedestrian impact without any hard points; the 15 km/h impact required for the insurance class rating requires that the heat exchangers in the lower part of the module are not damaged by contact with the forward parts deformed by the impact. For that reason the heat exchangers in the lower part of the cooling module have to remain set back.

It should be possible through optimisation of the design of the heat exchangers to comply with these constraints. However, the difficulty arises from the fact that the powertrain cooling requirements increase, leading to an increase in the packaging volume required by the cooling module. One is then faced with a contradiction which, in order to be resolved, means that the general design of the cooling system and the associated module in the front end has to be reviewed in depth.

In order to meet this requirement and to open up new possibilities both to chassis engineers and to those responsible for the design of the cooling system that Valeo has developed an innovative cooling architecture [3, 4, 5]. As turbo charged diesel engines are the most restrictive with regards to the dimensioning of the cooling module in the vehicle front end, therefore this article focuses on cooling system architecture for Diesel engines. However, the results and recommendations formulated at the end of this article also apply to petrol engine versions.

2 Key Parameters Determining the Evolution of the Cooling Module

To do an evolution of the front-end cooling module, three points can be mentioned as key parameters. Firstly the engine downsizing influences the energy balance of the engines, secondly the strongly increased heat load on the charge air cooler need to be mentioned and the third point is the arrangement of the front end installed heat exchangers, which determines the future front-end cooling module development.

2.1 Change of the Energy Balance Due to Engine's Downsizing

Compliance with the future emission standard for example of 120 g of CO_2/km on average as of 2012 in Europe imposes a radical review of the design of combustion engines. As a consequence in most regions of the world an 'engine downsizing' trend is engaged since several years

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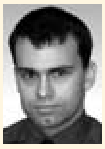

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Table 1: Energy balance at an actual diesel engine and one for the future – the sum of losses decreases for 7 % from 293 to 278 kW

Energy balance	Actual engine	Future engine
Specific power output in kW per l	50	80
Mechanical power	100 kW (34 %)	100 kW (36 %)
Exhaust gas heat rejection	132 kW (45 %)	122 kW (44%)
Engine cooling heat rejection	61 kW (21 %)	56 kW (20 %)
Sum power consumption	**293 kW (100 %)**	**278 kW (100 %)**

[6, 7]. The 'engine downsizing' principle consists in increasing the specific engine performance rating (kW/l) by means of intensive use of turbo charging and other evolutions of engine design. The fuel consumption savings are obtained by combining the advantages of a reduction in friction (less cubic capacity of the engine or even a reduction in the number of cylinders to achieve a similar performance level) with an operation of the engine in map areas with higher engine overall efficiency for the most frequent operating conditions. This principle applies to all type of combustion engines. In all cases, these engines make use of sophisticated turbo charging techniques that can combine a volumetric compressor and turbo compressor, bi-turbos and/or two step turbochargers operating in a parallel and/or sequential manner. The aim of these solutions is to obtain higher air densities to compensate the reduction in the engine displacement. These are essential conditions that must be met to deliver high torque even from the lowest engine rpm. In order to ensure engine acceleration performance equivalent or better to conventional naturally aspirated engines, particular attention is paid to eliminating the phenomenon of 'turbo lag' inherent in this type of solution. A reduced volume of air in the engine intake air path and a minimum charge air pressure drop loss between the outlet of the turbo compressor and the air intake at the cylinder head are determining factors in the compromise between high specific engine performance and 'driveability' meaning the spontaneous engine behaviour perceived by the vehicle driver.

The specific power of Euro 4 diesel engines is around 50 kW/l. For the forthcoming Euro 5 and Euro 6 standards, the values retained attain already and may exceed 80 kW/l. For the same mechanical power available at the crankshaft, the fuel consumption is lower. The values for heat rejection through the exhaust gases and the cooling system are also reduced as a consequence, **Table 1**.

2.2 Increase of Charge Air Heat Load

By comparing the energy balance of an engine rated 100 kW mechanical power output with two specific power levels of 50 and 80 kW/l, the impact on the volume of the heat exchangers placed in the front end should be favourable. Less heat need to be dissipated from the engine and therefore consequently smaller radiators could be used. In reality, the high turbo charging linked to the engine downsizing creates an increase of the charge air heat load which needs to be dissipated in the charge air cooler (CAC). For an engine with a specific power of 50 kW/l, the density of the air at the engine air intake is 2.5 kg/m³. In the 80 kW/l 'downsized' engine version, the density of the air at the engine air intake has to attain a value of 3.5 kg/m³ to compensate the reduction in volume of the engine's cubic capacity and to maintain the absolute mass of charge air equivalent to a conventional engine.

The increase in the density of the air by mechanical compression is achieved in two separate steps. A first step by an isentropic compression in the turbo compressor has the effect of increasing the temperature and consequently the pressure of the charged air. A second step by cooling the compressed hot air to the requested temperature level for the engine's intake manifold. The charge air cooling should be realized ideally without pressure drop (isobaric) in order not to loose the air density increase of the turbocharger's compression. In a conventional engine, the air density increases from 1.2 kg/m³ to 1.9 kg/m³ through the turbo compressor, then rises to its engine intake value of 2.5 kg/m³ through the impact of the charge air cooling.

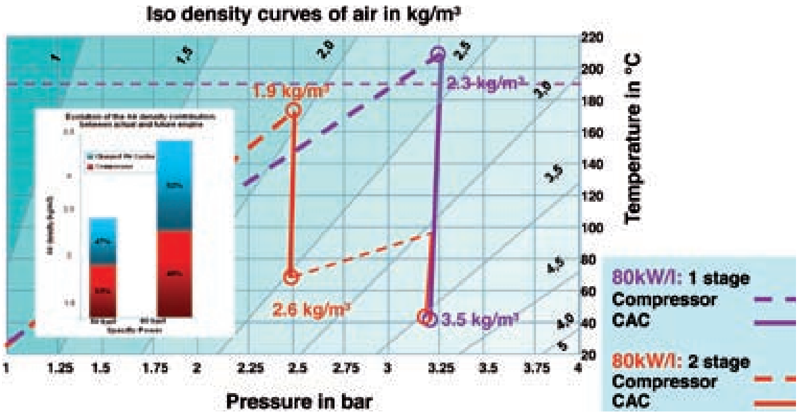

Figure 1: Evolution of air density for one and double-step turbocharging

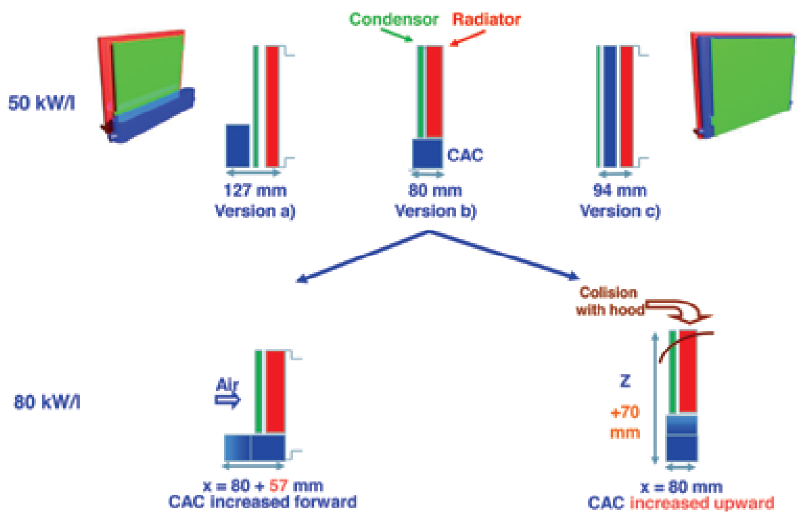

Figure 2: Configuration of a conventional front-end cooling module; evolution from 50 to 80 kW/l

In the 'downsized' engine version, the respective air density values are 2.3 kg/m³ after the first compression stage and 3.5 kg/m³ after the second compression stage. For both cases realistic charge air side pressure drop values were assumed, **Figure 1**.

It should be noted that the limit in the increase in the air density is conditioned by the temperature reached at the outlet of the compressor wheel. In order to avoid the use of more expensive materials, the compressed air temperature is restricted to 190–200 °C.

For an engine at 50 kW/l, the CAC contributes to 46 % of the total air density increase. This value rises to 52 % for an 80 kW/l engine, which shows the need to pay particular attention to the design of the CAC.

Figure 3: Front-end cooling module of the demo car

The work necessary to compress the intake air in a turbo-compressed version comes from the enthalpy available in the exhaust gases. For an engine running at 80 kW/l, the enthalpy is 30 % higher, attaining a density of 3.5 kg/m³. In a 50 kW/l engine the charge air heat load represents around 5.5 % of the total enthalpy, in an 80 kW/l engine the charge air heat load represents 7.2 % of the total enthalpy. This 30 % increase corresponds thus to the difference between the power dissipated in the CAC of the conventional version and the downsized version. The direct consequence is that the CAC has to increase its packaging volume.

In conclusion, with the prospect of the Euro 6, the downsizing of engines using high turbocharger compression ratios requires an increased heat capacity for the CAC of nearly 30 % and requires also limiting the increase of the charge air side pressure drop. Both functional requirements require more packaging space for an air cooled CAC and need to be achieved in an ever more confined front-end cooling packaging environment.

2.3 Architecture of Cooling Modules

Conventional cooling modules corresponding to 50 kW/l engines are principally constituted of three main heat exchangers: the cooling radiator dedicated to the engine coolant loop, the condenser of the A/C loop and a CAC for the turbo charging function. For diesel engine applications from the B segment, the equipment levels for air conditioning and engines with turbochargers exceed 80 %, attaining 100 % for the D segments and above. Under these conditions, the cooling module with three heat exchangers is the reference for dimensioning the packaging volume which needs to be reserved in the front end.

There are several possible arrangements for these three heat exchangers inside the module. The criteria that determine the choice are multiple. Nevertheless, the choice is guided by a search for the best possible compromise between the thermal efficiency of the heat exchangers and the ease of interfacing with pipes or hoses conveying fluids from the powertrain towards the front end, **Figure 2**.

Version a) is favourable for the function of the CAC but with higher overall (x-) dimensions in the lower part. Version b) improves the external cooling air flow through the CAC, nevertheless this version requires higher cooling air flow through the condenser and radiator as their frontal height are smaller than in versions a) and c). The version c) finally requires sufficiently dimensioned cooling fan power to overcome the external pressure drop losses of the three heat exchangers in serial configuration on the air side.

Complementary cooling requirements exist, such as for the oil used for the power steering system and for the oil for the automatic transmission. The thermal power of these heat exchangers is not needed simultaneously during the dimensioning operating points of the principal three main heat exchangers; for that reason these auxiliary heat exchangers generally do not impact the needed frontal surface of the vehicle cooling module.

In the future, with engines 'downsized' to 80 kW/l, the CAC has to be dimensioned to absorb a 30 % increase in thermal performance and a significant decrease in charge air side pressure drop. Heat exchangers such as the cooling radiator and the condenser for the A/C loop are not be subjected to the same heat load increase. With increasing engine efficiency, the radiator heat load may decrease by around 8 %; A/C comfort needs should not lead to an increase of the condenser sizing; nevertheless the introduction of alternative refrigerants fluids with lower Global Warming Potential (GWP) could impact the condensers' thermal efficiency and thus lead to increased condenser sizing.

In order to attain the required air density value of 3.5 kg/m³, it is necessary to increase the intrinsic performance of the CAC by acting simultaneously on the reduction in the internal air pressure drop losses from 100 to 50 mbar and improving the thermal efficiency from 82 to 89 %. In order to achieve this specific target, the intersection for the charge air path in the CAC must increase. The new dimensions of the CAC (for example solution b)), the most compact of the three) becomes incompatible with the available packaging volume unless the front overhang is increased or the line of the bonnet is raised.

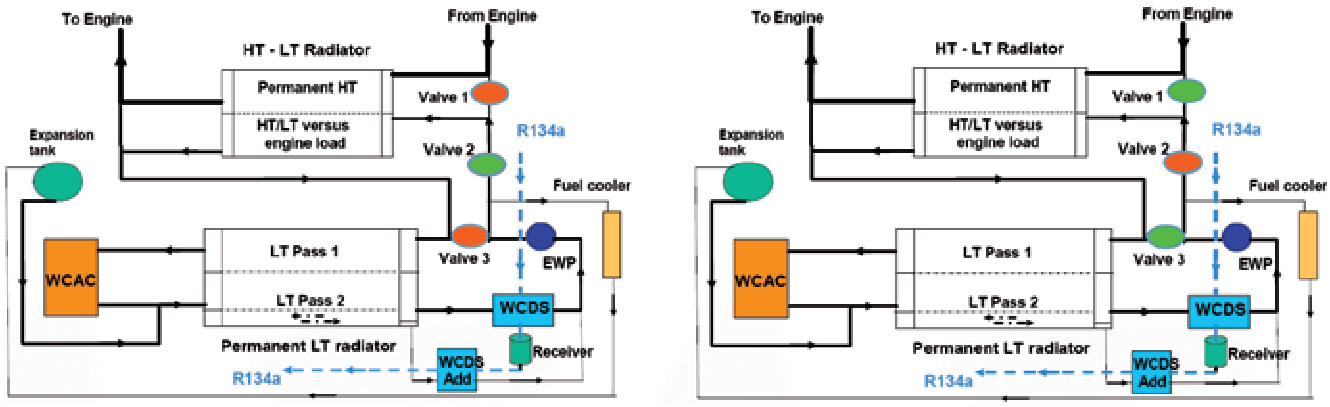

Figure 4: Ultimate Cooling system scheme in the demo car (left: for low and medium speeds; right: for high speeds and hill climbing)

In most cases all of these architecture proposals with increased CAC dimension face difficulties to be packaged into the vehicle's front end. The solution therefore requires a complete redesign of the of the lay out of the heat exchangers around the powertrain.

3 Description of the Ultimate Cooling Architecture

In a conventional cooling system, a high temperature (HT) circuit, principally dedicated to engine cooling, co-exists with specific circuits such as for the turbo charging of the engine, the air conditioning or the transmission oil. The principle of the new Ultimate Cooling system is to create, in parallel with the HT circuit, a low temperature (LT) coolant loop intended to cool these specific fluids. At the vehicle front end, the cooling module is constituted of two heat exchangers: a HT radiator and a LT radiator. These two heat exchangers can be interconnected, the total thermal dissipation capacity installed in the front end will be configured according to the cooling needs of the functions to be cooled connected to the LT circuit or to the HT circuit. As an example, the respective operating temperatures of the LT and HT circuits are at 55 to 60 °C and 100 °C for ambient temperatures of 38 °C. Functions connected to the different circuits are:

- LT: turbo charging air, A/C condenser, automatic transmission, power steering, fuel supply, exhaust gas recirculation (upon needs)
- HT: engine cooling system, engine oil, exhaust gas recirculation.

4 Vehicle Tests

The purpose of the vehicle tests funded by Valeo was to demonstrate the packaging volume savings made at the vehicle front end as well as the impact on fuel consumption. Measurements were carried out on a test vehicle equipped with the innovative cooling module. As a test vehicle a mid-class car of the type Mercedes-Benz C 220 CDI was used, **Figure 3**:

- 2.2 l displacement, common-rail turbo diesel engine, emission standard Euro 4
- 108 kW (147 bhp) power at 4000 rpm engine speed (50 kW/l)
- manual transmission, externally controlled A/C compressor.

The vehicle cooling module of the standard version is composed of a cooling radiator, an A/C condenser, a CAC, a fuel cooler and a power steering cooler, **Figure 4**. In the innovative cooling architecture, only a LT radiator and a HT radiator interconnected by solenoid valves remain to adjust the heat exchange capacity to the requirements for cooling the different functions depending on the operating conditions of the vehicle. A water cooled CAC and a water cooled condenser have been installed into the engine bay. For the LT circuit, a 50 W electric water pump assures a flow rate

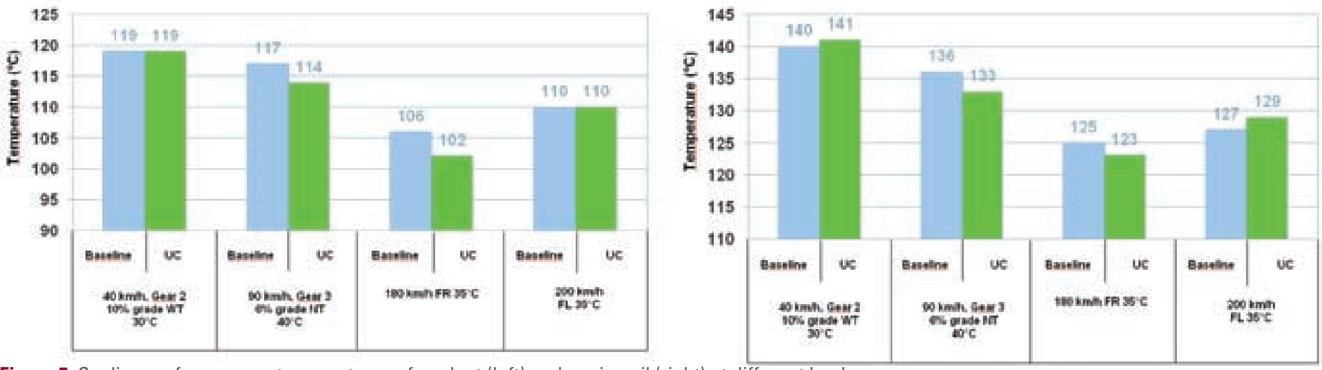

Figure 5: Cooling performance – temperatures of coolant (left) and engine oil (right) at different loads

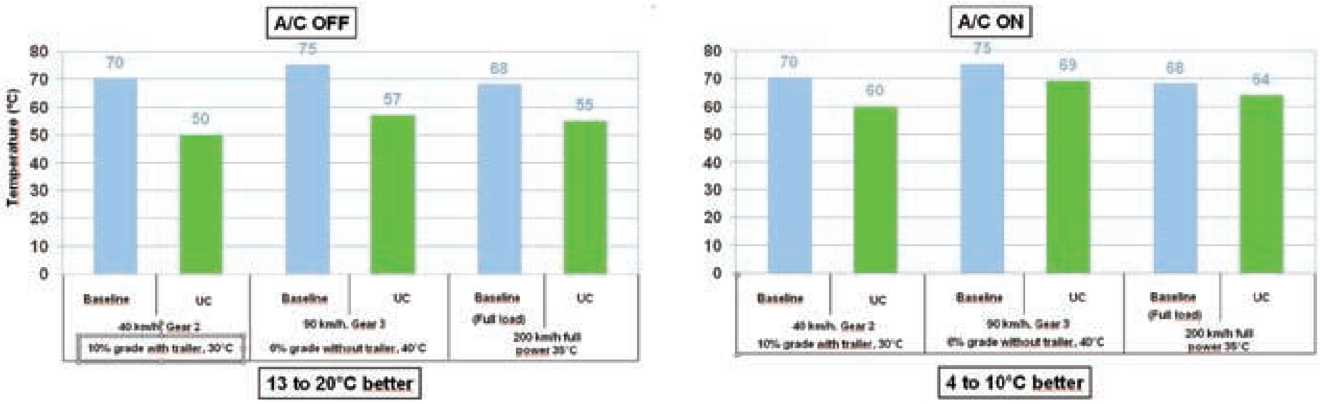

Figure 6: Air temperatures in the engine intake manifold

of around 1000 l/h, sufficient for the correct operation of the heat exchangers.

The vehicle in its standard configuration and in the Ultimate Cooling configuration was tested in a wind tunnel. To measure the fuel consumption it was proofed on a special test bed.

4.1 Tests Carried Out

The tests carried out were grouped in three parties. First, the verification of the cooling functions according to four tests:

- 40 km/h, 10 % slope with trailer, external temperature 30 °C
- 90 km/h, 6 % slope, external temperature 40 °C
- 180 km/h external temperature 35 °C
- 200 km/h, external temperature 35 °C.

Second, the verification of the performance of the A/C with an external temperature of 45 °C according to three tests:

- 40 km/h after adjusting to room temperature for 30 min
- idling for 30 min
- 90 km/h flat road for 30 min.

Third, the verification of the fuel consumption: driving profile of the European MVEG cycle according to two tests:

- urban test
- extra-urban test.

4.2 Test Results for Engine Cooling and A/C

From the test results of engine cooling, it may be concluded that the Ultimate Cooling system has the same performance as the standard configuration for the engine temperatures, **Figure 5**. With the A/C in the 'on' position, the innovative technology has intake air temperatures lower by 4 to 10 °C. With the A/C switched off, these differences increase favourably from 13 to 20 °C, **Figure 6**.

The amount of sunshine conditions was 1000 W/m² energy density with 40 % humidity. The results show that the average head temperatures in the passenger compartment are identical with the baseline. The comfort performance levels with Ultimate Cooling comply with the car manufacturer's specifications, **Figure 7**.

4.3 Test Results of Fuel Consumption Measurements

Measurements were carried out according to the driving profile of the European MVEG cycle with A/C 'on' and with an exterior temperature of 28 °C to have representative condition to measure impact of A/C on fuel consumption. On average, the fuel consumption reduction averages out at 6 % compared to the conventional architecture with air charge air cooler and air

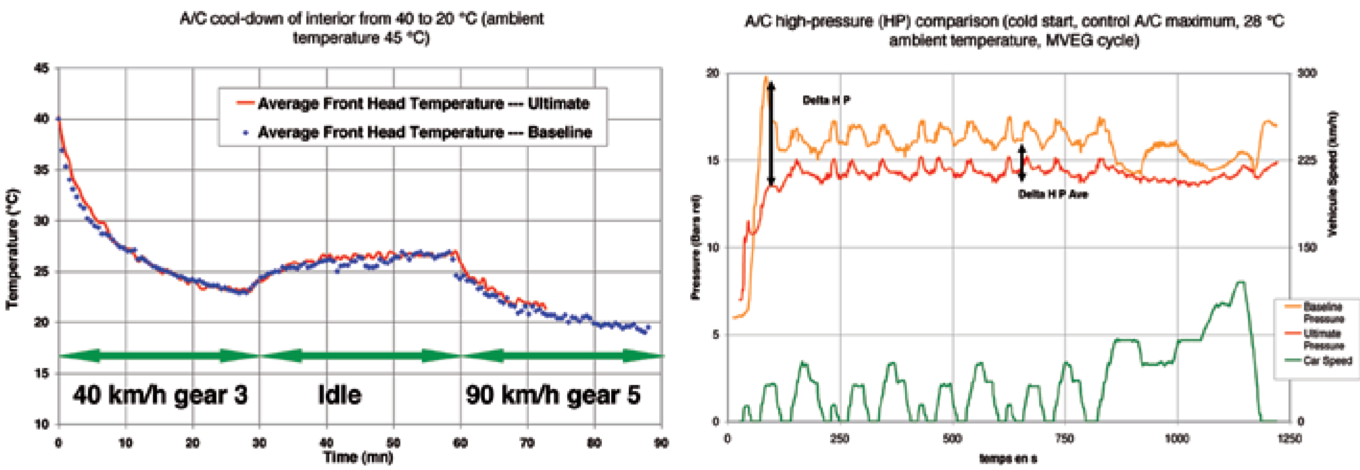

Figure 7: Climatic wind tunnel test – A/C performance results

Table 2: Measurement of fuel consumption – CO_2 comparison of baseline with Ultimate Cooling module architecture (conditions: driving profile according to MVEG cycle, cold start, A/C maximum, blower maximum (No 1), 28 °C temperature)

CO_2 emission urban traffic in g/km		CO_2 emission ex-urban traffic in g/km		CO_2 emission average in g/km		Δ CO_2 emission in %		
Baseline	Ultimate Cooling	Baseline	Ultimate Cooling	Baseline	Ultimate Cooling	Urban traffic	Ex-urban traffic	Average
346	319	181	179	243	229	–8	–1	–6

cooled condenser, with a more important effect on the urban phase of the cycle, **Table 2**.

The values of condensation pressure measurements of the refrigerant fluid are lower on average by 2 to 3 bars on all of the tests with Ultimate Cooling as with the baseline, Figure 7. This pressure level decrease reduces the work of the A/C compressor and therefore its resisting torque on the crankshaft of the engine. Unlike the conventional air condenser restricted in its dimensions, which has to be housed in the cooling module, the water condenser enables, through its installation outside of the front end, a dimensional design more favourable to the reduction of the internal pressure drop losses of the refrigerant fluid.

5 Conclusions of the Demo-car Wind Tunnel Tests

The application of the Ultimate Cooling architecture to the OEM vehicle tested enabled the following observations to be made:

- The working conditions of the engine, the A/C and the air intake are assured at least as well as with the conventional system.
- The fuel consumption in MVEG cycle type operation with the A/C operating has a significant reduction potential. The electrical power consumption of the additional electrical water pump is integrated in the fuel consumption measurements of Ultimate Cooling equipped vehicle.
- The volume taken up by the cooling module in the front end is reduced by 40 % and only requires two radiators, a LT radiator of 18 mm depth and a HT radiator of 27mm depth, **Figure 8**, left side. Here valuable package space is created for pedestrian and insurance rating crash norms.
- Since the HT radiator has two sections that can operate independently of each other, it is possible in partial load and low vehicle speed to operate the lower part of the HT radiator in LT mode, the upper part operating in HT mode. This added thermal heat dissipation capacity to the LT circuit allows improving the A/C system; in particular the condensation pressures of the refrigerant fluid can be maintained at a very low level.
- At high engine load and non-urban type vehicle speeds, the two sections of the HT radiator are entirely dedicated to the engine cooling function (and work as a conventional radiator).
- The absence of an A/C condenser at the front end limits the quantities of discharge of refrigerant fluid into the atmosphere in the event of a frontal accident.

6 Outlook

The tested vehicle has a specific power rating of around 49 kW/l and around 108 kW rated mechanical power. If it had to be equipped with a 'downsized' engine with a specific power of 80 kW/l, the engine displacement would be decreased from 2.2 l to 1.4 l but with both a reduction in the engine cooling requirement of 7 % and an increase of the charge air heat load of 30 % to be cooled by the LT radiator.

Under these conditions, both LT and HT radiators of the Ultimate Cooling system will maintain a global depth (x-direction) of 60 mm, nevertheless the LT radiator will increase from 18 to 27 mm depth and the HT radiator would decrease from 27 to 18 mm, Figure 8, right side.

With the prospect of the Euro 6 emission standards, engine manufacturers are obliged to drastically reduce the level of NO_x emission of the combustion engines [8]. One solution under development is the Low Pressure EGR architecture [9, 10]. For the latter the recirculated EGR gases are withdrawn downstream of the particulate filter.

In order to achieve lowest possible 'inner engine out' NO_x emission levels, the recirculated EGR level can attain 40 up to 70 %. This has as a consequence an increase in the CAC heat capacity and therefore an impact on its dimensioning.

If the EGR levels are mainly at partial load, there is no need to modify the dimensions of the heat exchangers. If the EGR levels are high including at high engine load [11, 12], both the LT (cooling function of the intake air) and HT (cooling function of the EGR) radiators must be re-dimensioned upwards through a slight depth increase of LT and HT radiator's cores.

Hybrid versions of vehicle keeping classic powertrain require also an installation of a dedicated LT radiator; this thermal need could be taken in charge by the LT radiator of the Ultimate Cooling system without necessarily a resizing. The packaging volume saving of the cooling module in the vehicle front end will be significantly improved if this LT radiator is shared with other functions such as charge air cooling and AC condenser.

The optimization of both LT radiator and HT radiator packaging needs in the vehicle front end requires the understanding of the control strategy of both HT and LT coolant loops. Through an adapted control strategy the Ultimate Cooling System can optimize the installed cooling capacity in the front end for all operating conditions.

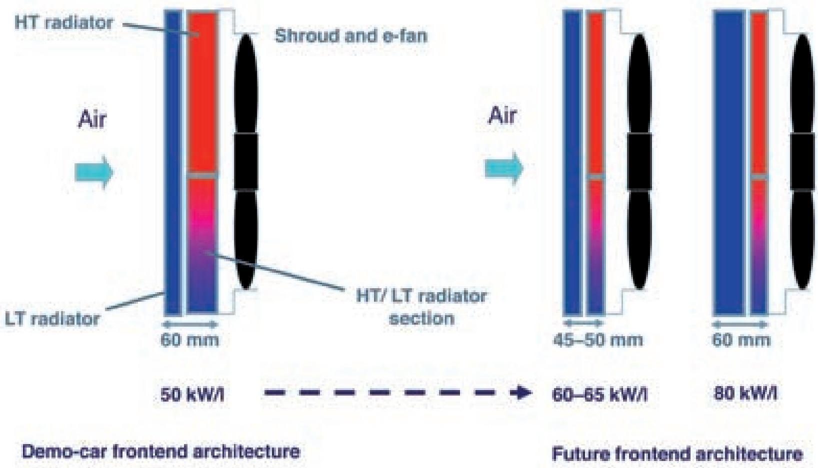

Figure 8: Ultimate Cooling application on a 100-kW downsized diesel engine – packaging of the front-end cooling (module depth can be maintained)

7 Summary

Cooling system development is driven by upcoming CO_2 climate gas reduction legislation resulting in engine down sizing, by ever more stringent emission legislation and by packaging volume limitation in the vehicle front end due to constraints of vehicle styling, of pedestrian and insurance choc legislation and vehicle aerodynamics.

This article from Valeo highlights a cooling system architecture which uses two modular main coolant radiators in the vehicle front end, this architecture being named Ultimate Cooling System. Both low temperature and high temperature coolant loops are connected with each other and allow together with an adapted control strategy to optimize the available heat dissipation capacity installed by the radiators in the vehicle front end.

The application of the innovative Ultimate Cooling architecture opens up new possibilities for the architecture of the cooling system, for the dimensioning of the module at the front end to meet the requirements of frontal crash impact energy absorption regulations and the technical evolution of powertrains that are more economical in terms of fuel consumption.

Reducing the technological diversity in the front end to two LT and HT radiators (with the same working fluid) simplifies the treatment of the diversity of diesel, gasoline and/or hybrid powertrains. It will be possible to standardise the vehicle cooling modules and to have only to adapt the relative size of the LT and HT radiators as a function of the requirements of the installed powertrain.

Future cooling systems need not only to fulfil the basic cooling functions, but need also to cool the powertrain with the lowest accessory power consumption (electrical fan, main coolant pump, additional electrical water pump, A/C compressor, TC compressor etc.) in order to reduce the vehicle's CO_2 emission. Both the water cooled charge air cooler and the water cooled condenser being part of the Ultimate Cooling architecture contribute to these requirements.

Additional complexity and costs in the cooling architecture (valve(s), electrical water pump) will be compensated by economies in hoses and piping (especially for charged air), by functional integration of for example water charge air cooler into the intake manifold, by reduced vehicle material content through a shorter vehicle front end and also by the reduced fuel consumption in real world driving conditions. Actually the fuel consumption of the A/C compressor is already part of the relevant fuel consumption driving cycles in Japan and in the USA. Valeo has the confidence in the possibilities offered by this new Ultimate Cooling architecture in order to actively participate in the development of innovative cooling system solutions.

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Management of Connections for Passenger Car Air-conditioning Using CO_2

An EU regulation prescribes that from 2011, with a transition period up to 2017, all new passenger cars and light commercial vehicles must contain an environmentally-friendly refrigerant. The German car manufacturers have decided in favor of carbon dioxide “CO_2” (R744) as the new natural refrigerant for vehicle air-conditioning systems. In addition to environmental friendliness, CO_2 air-conditioning systems also offer higher efficiency than current R134a systems. For a better management of connections Voss Automotive developed new connection systems and sealing design, which allow the pressures four times higher and operating temperatures twice as high in a CO_2 air-conditioning system.

1 System Structure of the CO_2 Air-conditioning System

Carbon dioxide or CO_2 is seen as environmentally neutral, because it can be extracted from air and as a waste product from industrial processes. Thus it has a 1300-times smaller potential to act as a greenhouse gas (Global warming potential, GWP [1, 2]) than today's refrigerant R134a.

In the refrigeration cycle the refrigerant has the job of extracting the heat from the vehicle interior and rejecting it to the surroundings. The heat extraction takes place at low pressure and temperature in the evaporator. The internal heat exchanger (IHX) is located behind the evaporator which cools the CO_2 refrigerant on the high pressure side to improve the efficiency at high external temperatures. On the low pressure side the refrigerant is heated in the IHX and this completes the phase transition from a fluid to a gas.

To ensure that only gaseous refrigerant is supplied to the compressor, an accumulator is integrated, which captures any remaining fluid refrigerant and any water that may be retained. At the same time it serves as a reservoir to compensate for any leakage of the refrigerant over time. Since the gaseous refrigerant is elevated to both a high pressure and temperature in the compressor, the downstream gas cooler is required, which transposes heat to the surroundings. In the expansion valve located behind the IHX the refrigerant is expanded and at the same time sharply cooled. From there it arrives back at the evaporator, thus completing the refrigeration circuit, **Figure 1**.

2 Requirements for Connections in a CO_2 Air-conditioning System

With CO_2 (R744) the air-conditioning cycle runs at pressures four times higher and operating temperatures twice as high compared to R134a. This means that significantly higher requirements are placed on the components of a CO_2 air-conditioning system. On the high-pressure side, the designs for the lines and connections must withstand operating pressures of 140 bar and a burst pressure of 340 bar. The operating temperature ranges from −30 °C on the low pressure side to +165 °C on the hot gas side.

In addition to the high mechanical requirements, the gaseous CO_2 displays a pronounced ability to dissolve at high pressure that means to permeate through elastomeric materials. As a result of a sudden pressure drop in the air-conditioning systems, elastomers into which CO_2 has charged tend to move towards „explosive decompression“. Mechanical damages could occur, such as the formation of bubbles and cracks in the seals. The connection techniques must permanently withstand all loadings that occur, such as temperature changes, vehicle vibrations and pressure pulsations.

A further requirement is the safe removal of a refrigerant line even in the event of misuse, if the pressure in the refrigeration circuit has not previously been vented as specified. The connection technology has to be designed that five removals and reinstallations are possible without replacing the seals.

3 Elastomeric Sealing System for the CO_2 Connection Techniques

The development of a suitable sealing system forms the basis of any efficient connection technique. At the present

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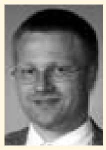

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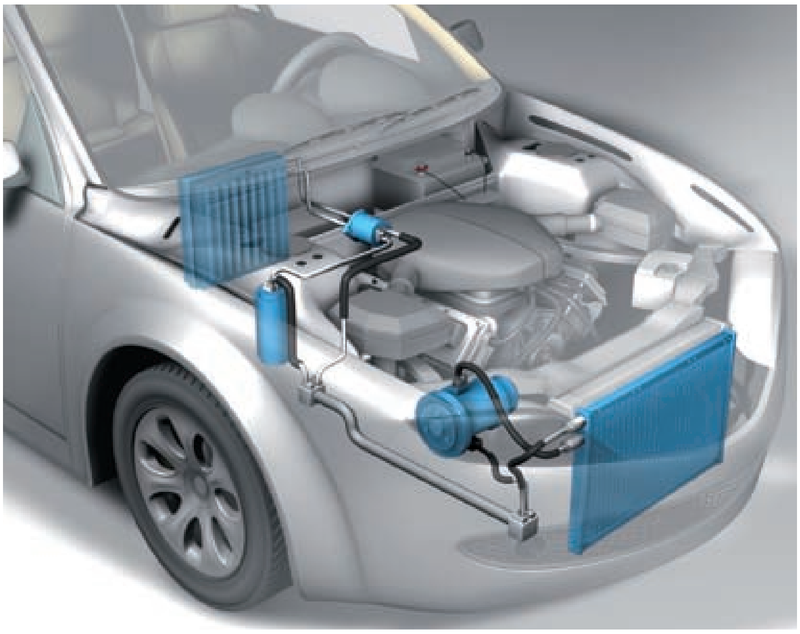

Figure 1: Schematic presentation of a CO_2 air-condition system

time two types of seals may be used, the metallic seal and the elastomeric soft seal. The metallic seal offers the fundamental advantage of being impervious to CO_2, thus it is permeation proof, and explosive decompression is eliminated. To achieve a seal quality with a metallic seal, any inaccuracies in manufacture, such as surface defects, must be compensated for by means of plastic deformation of the sealing element.

As a result of this plastic deformation of the seal, the number of removals and reinstallations is significantly restricted. The connection technique must be such that a constant axial preload is applied onto the metallic seal under all conditions of use, including the presence of vibrations, temperature and pressure fluctuations. A high level of leakage and the failure of the whole air-conditioning system is the result of a loss of the axial preload effects.

The sealing quality of elastomeric soft seals is achieved by means of the elastic deformation (compression) of the seal. The advantage of a radial seal configuration is that the compression of the seal is independent of any axial preload. Elastomeric seals must exhibit a high reliability with respect to the explosive decompression referred to above, and good resistance to the refrigerant oils used to lubricate the compressor. Especially resistant elastomeric materials have been developed for this purpose, with Shore hardness values above 85. By combining suitable elastomeric materials, optimized seal geometries and sealing grooves, very low permeation rates of less than < 0.5 g/a can be achieved. Compared with a standard O-ring, a shaped seal has the advantage that it features a compressed length that means a section for permeation, which is as large as possible. By means of a specially stepped groove the sealing ring is pressed against the ambient pressure wall face and thereby minimizes the free seal ring surface, **Figure 2**.

4 CO_2 Permeation Measurements

Permeation measurements serve to determine the leakage of elastomeric components that are used in filling valves, sensors, or connection techniques and flexible lines. A permeation measurement rig consists of a pressure generator, a measurement chamber located in a temperature-controlled cabinet, and a gas analyzer, **Figure 3**. The test pieces are located in a special permeation measurement chamber. The respective pressure and temperature levels are set according to prescribed loading spectra that correspond to the operating points of an air-conditioning system. In order to guarantee that CO_2 from the ambient air does not permeate into the analysis circuit, the system is flushed with an inert gas according to the measurement method, a vacuum is applied, or the measurement chamber is sealed against permeation of CO_2 from the environment.

Various methods are used for CO_2 analysis: mass spectroscopy, infrared gas analysis, the pressure rise method and photoacoustics. Here the photoacoustics measurement method is particularly advantageous since the direct and integral measurements can be performed very easily and without any conversion errors. The measurement chamber needs only to be sealed from the environment. Photoacoustics is a proven leakage measurement method for R134a.

5 Connection Systems for the CO_2 Air-conditioning System

The most widely used connection system in R134a car air-conditioning systems is the block connection, consisting of two connecting blocks that are connected together by means of a screw. While the coupling side is usually integrated in the unit, the connector side is joined to the refrigerant line by means of brazing or tube end machining, **Figure 4**.

In combination with a radial elastomeric seal system, the block connection is a cost-effective connection technique

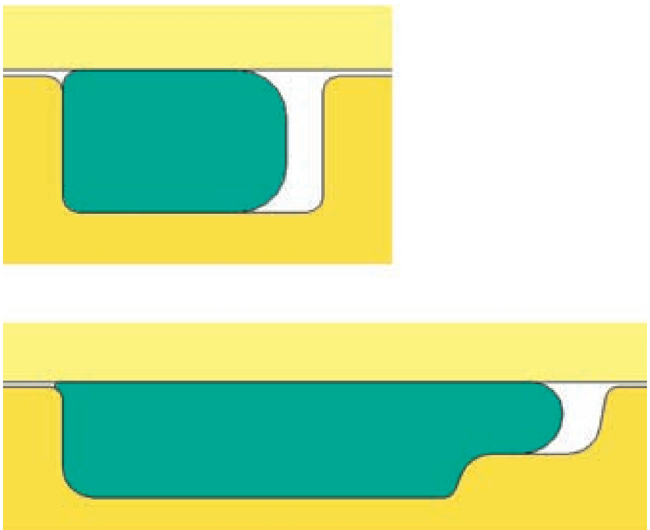

Figure 2: As large as possible compressed length that means section for permeation – O-ring (top) and better shaped seal (bottom) with the same line diameter in compressed status

Figure 3: Permeation measurement chamber for CO_2

that is not susceptible to vibration. Here it should be noted that for safe opening of a CO_2 air conditioning connection at high pressure the geometric design of the screw fitting (leakage path) must be adapted. An automatic opening function for the connection can be integrated as an option, in which unscrewing of the screw fitting automatically separates the connecting blocks. The axially sealing block connections open automatically, but have the disadvantages referred to above with regard to the axial preload.

An alternative to the block connection is the plug-in connection. This has the advantage of rapid assembly of refrigerant lines and units without tools and offers a high level of assembly security. The coupling side is directly connected with the aggregate, or with the line, if there is a line disconnection point. The connection of a rigid tube or an elastomeric hose with the plug-in connector side is made by brazing, welding, or tube end forming and/or by means of optimized connection of the hose. In order to ensure that the connection is not separated before the pressure has been completely relieved the plug-in connection is designed so that during unscrewing the refrigerant can escape via the integrated leakage path.

6 Line Management for the CO_2 Air-conditioning System

The various pressure and temperature levels in a CO_2 air-conditioning system require different systems of lines. On the compressor side flexible lines are required to compensate the engine movement relative to the components that are fixed to the chassis. On the high pressure side of the compressor (hot gas side) refrigerant temperatures of up to 180 °C can occur. Since the permeability of elastomeric hoses increases significantly with rising temperatures, in today's CO_2 systems stainless steel corrugated tubes are preferably used for the hot gas side and do not allow any permeation. The resistance to pressure of these corrugated tubes is achieved by means of a reinforced elastomeric top layer.

For the suction side of the compressor (low pressure side) flexible elastomeric hoses are used with a plastic barrier layer to improve the permeation properties. This combination of materials is also possible for the line on the high pressure side, to improve the ability to lay the tubes and also their acoustic properties compared with a rigid, purely metallic line. To connect the flexible elastomeric hoses to the aluminum tubes, specially sealed reinforcements must be developed, which, in addition to their ability to withstand pressure pulses and bursting pressures, also exhibit low permeation. All components, in particular the line systems, must in addition to static tests also pass dynamic tests that reflect the service life in a vehicle. Connections for sensors and filling valves, which are usually brazed onto metallic tube sections as well as the attachment elements, complete the design of the lines.

7 Summary

Today block connections with radially compressed elastomeric seals are defined as the standard for R134a air-conditioning systems. The significantly higher requirements of future CO_2 air-conditioning systems can be achieved by Voss Automotive with special soft sealing block connections. Moreover, plug-in connections offer significant simplifications in vehicle assembly and thereby a clear reduction of the assembly time. Both connection designs offer a high level of functional security and durability.

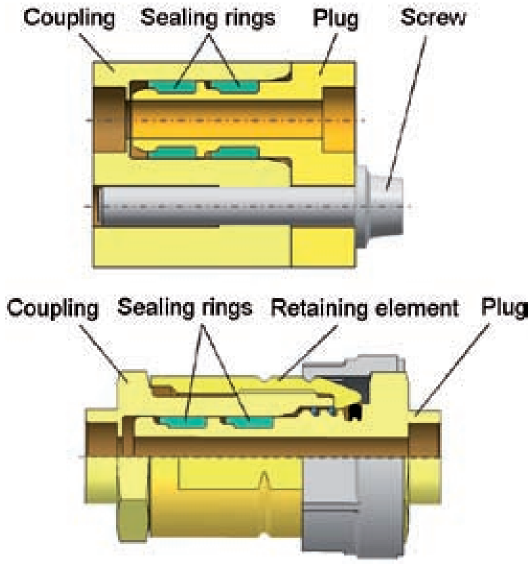

Figure 4: 2D presentation of a block screw and plug connection with elastomeric sealing

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CO_2 Optimized All-wheel-driven Vehicle

The necessity to reduce CO_2 has an overproportional effect on all-wheel-driven vehicles because due to their purpose oriented design they have a higher fuel consumption and CO_2 emission. The essential savings potential in the area of the drive train is optimizing the mechanical efficiency, reducing the weight and applying a vehicle specific control strategy. As one leader with all-wheel-driven vehicles, with innovative developments Magna Powertrain strives to provide aggregates that are as efficient and as light as possible with the appropriate intelligent logics.

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1 Introduction

The influences of human civilization on nature are diverse and through climate change the current CO_2 problems are only the tip of the iceberg. In the long run, only systems will prevail which have a sustainable improvement of the environmental burden and do not just shift the burden to other areas. Serious changes, like for example bio fuels or electrical vehicles need a long term strategy, because they can cause very complex changes which are not always positive for humans and the environment. Direct savings through improvements of efficiency or weight reduction have a direct positive effect on the environment and are therefore to be given a priority as short and middle term measures.

2 Purpose

The manufacturers of motor vehicles not only expect the supply of drive-train components for all-wheel-drives, but much more complete systems including application in the vehicle. Magna Powertrain strives to offer a wide product range with concepts and technologies as innovative as possible and the corresponding functional and economic advantages. Thus the customer can compile the system which is ideal for himself according to his specific demands, local conditions and legal regulations. Electrical all-wheel-drives have functional advantages with the short term power peaks, contribute to the increase of the system efficiency and in addition allow a freer interior design without the tunnel.

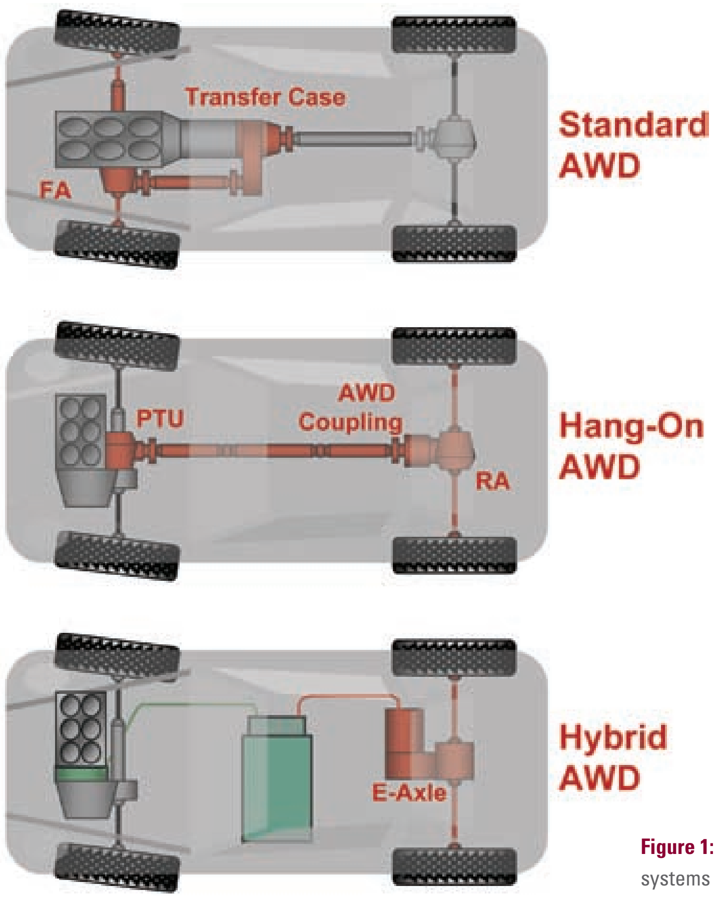

Figure 1: Overview AWD systems

3 Overview All-wheel-drive Systems

Figure 1 shows the most common conventional all-wheel-drive architectures and a representative hybrid system, the all-wheel-drive specific components are shown in red. With a standard-drive based vehicle, these are a transfer case, a propeller shaft, the front axle gears and the two halfshafts. The transversal engine based vehicles need a power take-off unit (called PTU or PTO), a propshaft, an all-wheel-drive- coupling, a rear axle drive and the two halfshafts.

The hybrid vehicle shown is based again on a front drive, has an electric motor, for example a starter generator, control electronics for the energy management and an accumulator. The all-wheel-drive specific unit on the rear axle consists of an electrical machine, a gearbox and the halfshafts. In addition to these "mainstream" architectures, there are of course still many further variations which however are not significant for the market.

4 An Overview of the Optimizing Potentials

First vehicles which are available both as one axle driven and as all-wheel driven are compared in equipment versions that are as identical as possible. The additional consumption determined from the published values of common all-wheel-driven vehicles (1, 2) can be seen in **Figure 2**. From the diagram, in addition a so-called specific additional consumption for 100 kg all-wheel-drive can be seen which, with this vehicle sample, adds up to some 0.9 l with the gas vehicles and to 0.45 l with diesel vehicles. The additional consumption of the all-wheel drive is mainly caused by the additional driving resistance:

- the additional masses cause increased acceleration, climbing and rolling resistances.
- drag losses which are independent from load decrease the overall efficiency in the secondary drive train
- losses which are independent from the load are in particular significant with hang-on drive trains with the two additional angular gears (PTU and rear axle drive)
- additional air resistance can result through increasing the height and the change of the underbody.
- hybrid concepts, as shown in figure 1, tend to cause higher weights and must take into account losses in the power electronics and electrical machines.
- through the use of smaller combustion engines, shifting of their operating points in the direction of optimum consumption and recuperation, an improvement of the CO_2 balance can be reached in particular with dynamic operating cycles
- decreasing wheel slip leads to slight consumption savings with all-wheel-driven vehicles.

The values for the diverse vehicles have an extensive range of variation. The individual causes for an increase in consumption are examined in detail in the following; **Figure 3** gives you an overview.

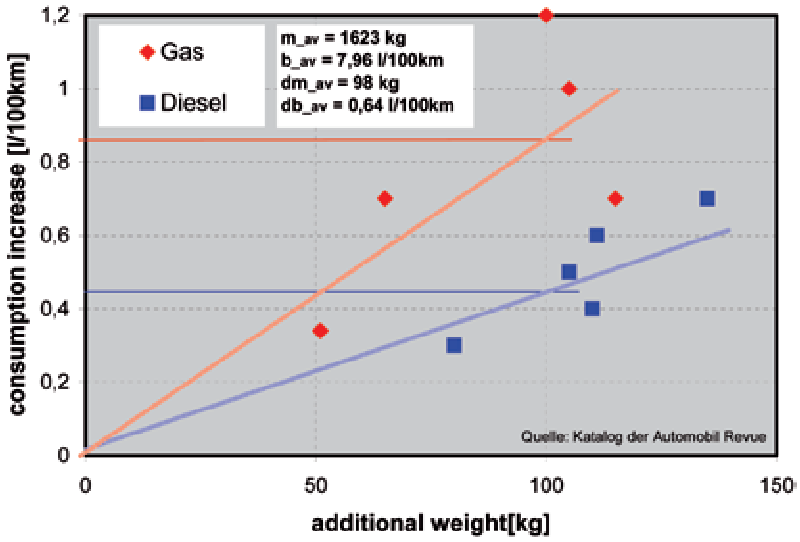

Figure 2: Additional fuel consumption and weight of all-wheel-driven vehicles

5 Weight

The additional weight of the all-wheel drive depends in general linearly on the drive torque to be transmitted. Typical examples [3] for the European market are shown in **Figure 4**, in this you can see that for each 1000Nm axle torque some 45 kg are necessary.

The simulation based on a typical SUV with 2000 kg shows that 100 kg additional weight causes an additional consumption of 0.21 l/100 km gas or 0.16 l/100 km diesel in the NEDC. The comparison with the additional consumption through all-wheel drive in Figure 2 shows that the weight is directly responsible for this by some 20 to 30 % without taking into consideration the rotational inertia, this correlates very well with the results in [8]. Measures for the reduction of weight are therefore forced more and more. For example with a modern axle drive, as

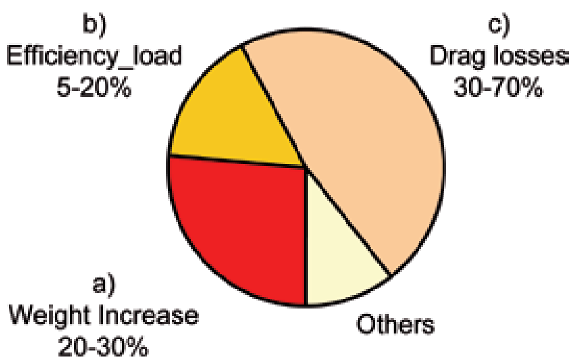

Figure 3: AWD related losses

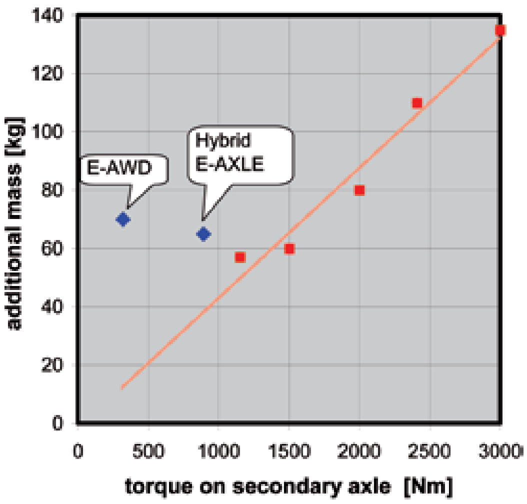

Figure 4: Additional weight of all-wheel-drive versus torque capacity

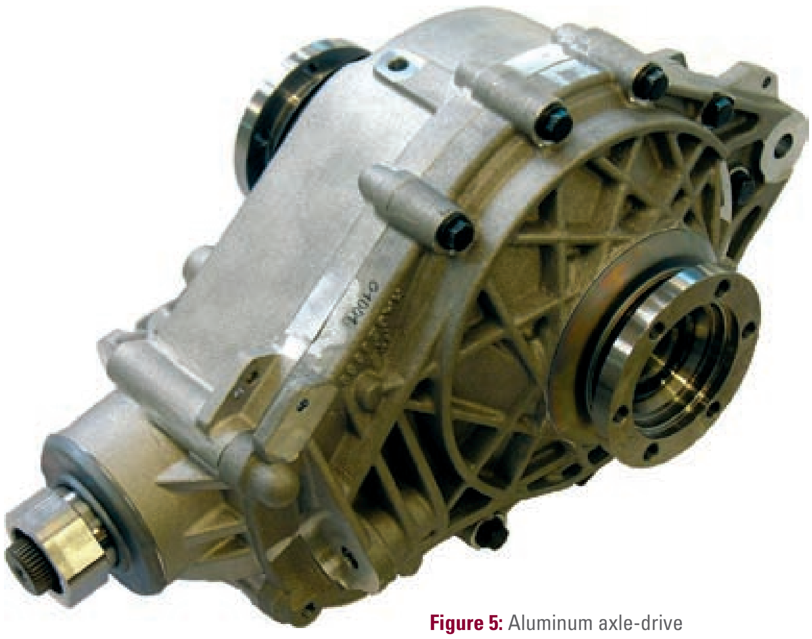

Figure 5: Aluminum axle-drive

shown in **Figure 5**, through the use of a light metal housing [4] some 7.5 kg could be saved as compared with the predecessor model. Further light construction measures, like the use of magnesium or composite materials are increasingly used in spite of more extensive development and higher costs.

6 Efficiency Optimization

If you analyze a common all-wheel-drive concept [5] – as shown in the center of Figure 1 – then in the secondary drive train to the rear axle there are losses, in particular in the two angular gears. As an example **Figure 6** shows the power flow for one particular driving condition. The angular drives in vehicles are besides a few exotic exceptions hypoid gear-sets which due to the relatively high gliding part in the gear motion have a load-dependent efficiency in the range of 97 % for each hypoid gear-set. This results in a loss of some 6 % of the transmitted power.

With the permanent four-wheel-drive with center differential, power is distributed approximately symmetrically to both axles and thus the overall loss is only 3 % relating to the overall power use. Therefore the consumption and the CO_2 emissions also increase about 3 %. With multi-staged PTUs, this value increases with the additional helical gear-sets. The example in Figure 6 has a center differential with a 60/40 distribution, through the right branch with a three staged power take-off unit (PTO) and rear axle drive (RA) the power is distributed to the rear axle. The load-dependent losses are accordingly some 800 W. The optimization of the load-dependent efficiency with hypoid drives target the reduction of the friction coefficient and the gliding share. The improvement of the gliding characteristics can only be reached through the further development of the tribologic systems, for example through coating and additives.

With the reduction of the gliding motion, the package, weight and in particular the noise generation are the limiting factors. The reduction of the load-inde-

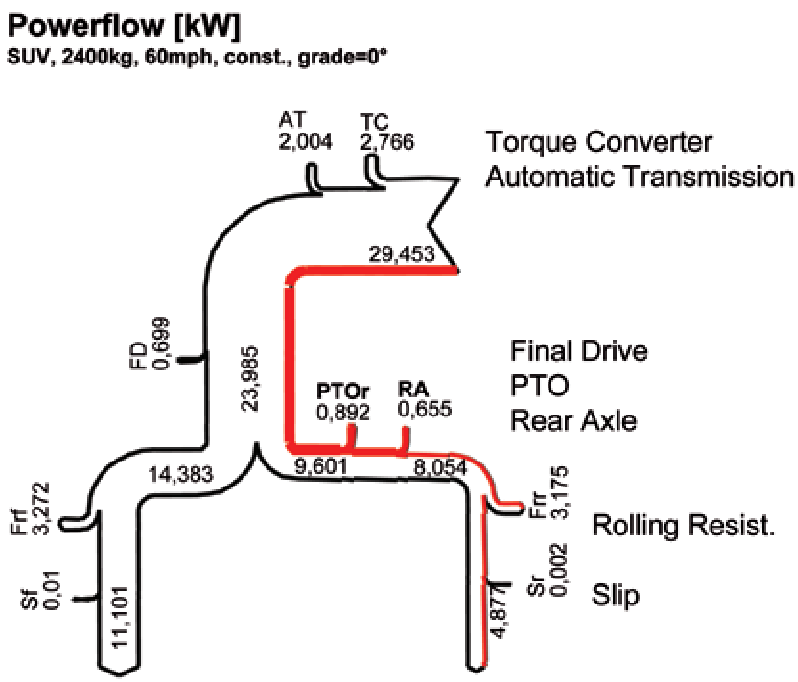

Figure 6: Powerflow in AWD vehicle at 100 kph constant

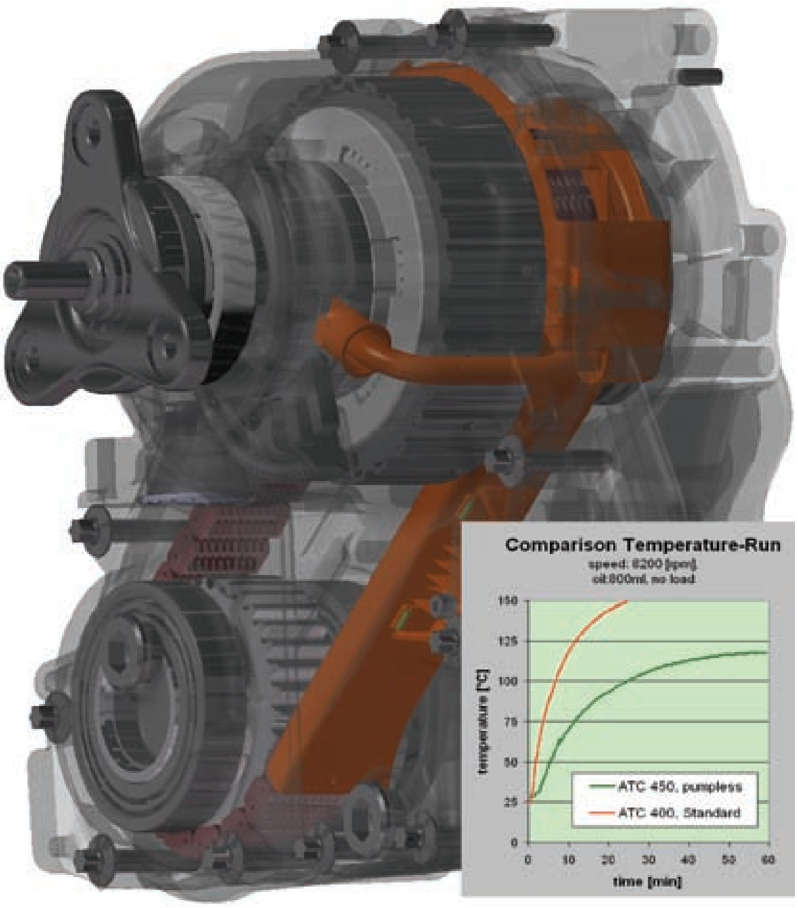

Figure 7: Pumpless transfercase

pendent losses (drag losses) has the highest priority because they don't contribute anything to driving but are dominant in the NEDC as well as in all low load driving cycles. The main causes of losses are the preloaded tapered roller bearings of the hypoid drives, shear losses in the oil by the turbulence in the gear and chain drives as well as the losses of mechanically driven lubrication pumps in the transfer-cases.

In the modern axle drives, like for example in Figure 5, the bearings are optimized in terms of drag torque by use of the angular contact ball bearings or by geometry optimized tapered roller bearings. The pump losses of the transfer-cases are eliminated best by substitution of the pump using energy saving oil distribution devices.

The transfer-case shown in **Figure 7** which is one speed with an actively controlled clutch is equipped with oil distribution devices [6, 7] which on the one hand direct the oil to the components which are to be lubricated and cooled, that is the bearings and the coupling plates and on the other hand the rotating components are to be shielded in the sump to prevent unnecessary turbulence of the oil. These measures contribute to a fuel savings of some 0.13 l in the NEDC for a sportive SUV with 200 kW gas engine and manual transmission. In addition the oil temperature can be lowered substantially, which has a positive effect on the durability and the required oil capacity.

Alternatively the requirement-controlled electrical oil pumps can minimize these losses. The drag losses due to oil turbulence often called splash losses, are significant in the lower temperature range, based on the large increase of the viscosity with falling temperatures, which can lead to noticeable losses in short distance operating conditions and also in the standard NEDC. Newer transmission oil developments show a lower temperature dependence, which mainly is reached through the admixture of viscosity index modifiers and thus minimize the losses in the lower temperature range.

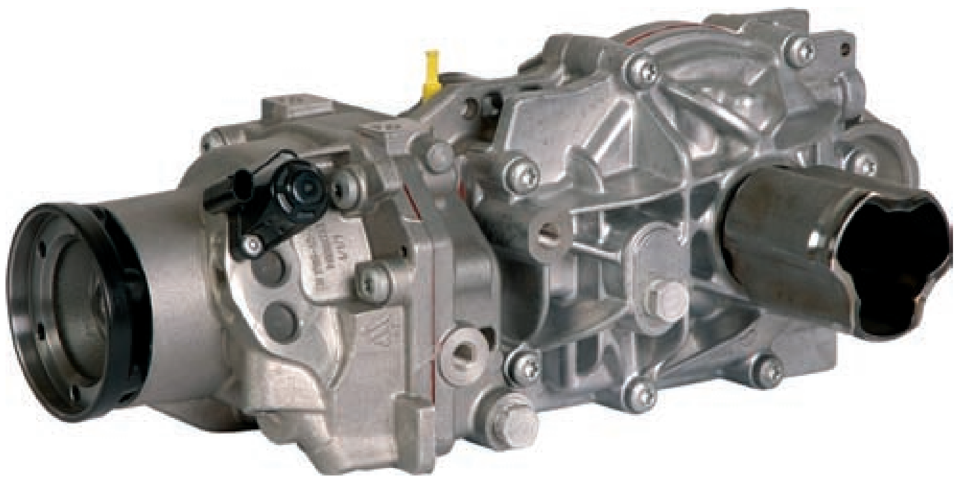

Figure 8: AWD coupling, self-actuating, hydraulic, active control

7 System Optimizing, Drive-train

The use of intelligent control strategies [3] leads in particular with hang-on drive-trains to the rear axle to significant savings. The “on-demand” drive torque distribution to the rear axle lowers the load-dependent losses directly because driving power is transferred via the branch with the better efficiency. The highest potentials can be utilized at driving conditions with moderate longitudinal and lateral accelerations and on high friction coefficients, thus the consumption cycles defined by the legislators fall into this category. For an SUV with 2000 kg, in the NEDC savings of up to 0.2 l/100 km can be reached [3], depending on driving power distribution. In the past with visco-couplings and differential-speed dependent hydraulic actuated couplings, systems were offered which could very well use these advantages, but however due to their restricted compliance with ABS and ESP they were rejected again. A new generation of couplings with hydro-mechanical actuation is shown in **Figure 8**. The reactive basic characteristic is overlaid by an active modulation of the pressure and is thus fully ESP compatible. The design of the all-wheel drive train according to the real user demands leads to noticeable redimensioning especially with the modern “onroad” SUVs. By making the aggregate smaller, there are not only weight advantages, but also correspondingly reduced drag losses.

A further possibility for consumption savings is axle-disconnect, which is popular on “part time” all-wheel-drives in American vehicles. Here the drag losses of the bearings, **Figure 9**, and the acceleration of the rotating masses are avoided. These systems need a timely activation by the driver because the synchronizing and switching of the drive train from standstill needs some time. Recently work has been done on systems which execute a quick automatic synchronization as soon as the probability threshold for four-wheel-drive demand is reached, which is determined by an intelligent analysis of sensor data like outdoor temperature, rain sensor, speed, friction coefficient recognition etc. Thus for example with homogenous dry roadway which prevails most of the time, the fuel consumption and the CO_2 emissions can be reduced.

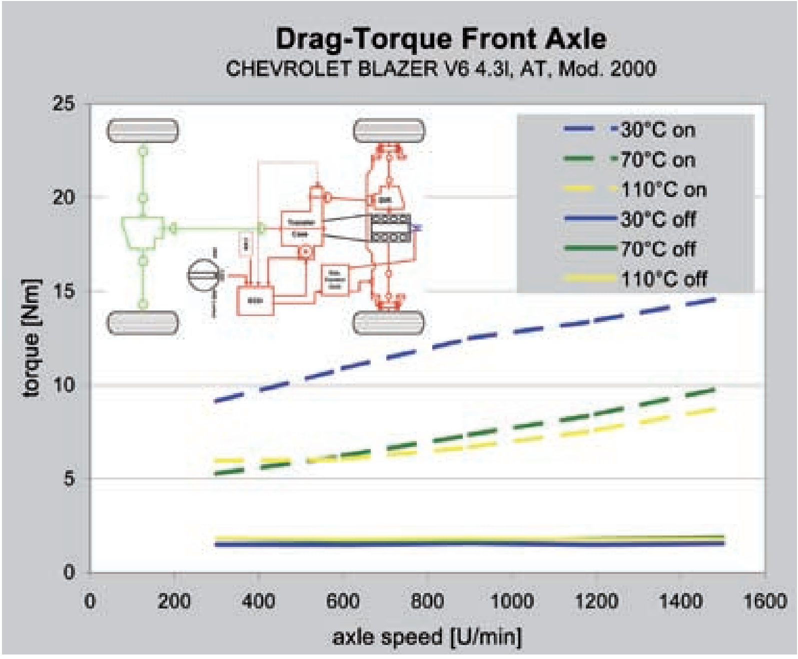

Figure 9: Drag torque reduction with axle disconnect

8 Electrical All-wheel-drive and Hybrid

Of course a conventional mechanical four-wheel drive-train can be combined with a hybrid drive or electric drive, however the availability of an electrical energy source or a battery for the introduction of an electric-motor driven axis is obvious, **Figure 10**. Further advantages of an electrical all-wheel drive according to Figure 1 are the elimination of the propshaft tunnel and the PTU at the crowded front end and the transmission doesn’t need all-wheel-drive adaptations.

The electrical drive machine can additionally be used for the recuperation of brake energy, which in particular with a dynamic operation cycle like city traffic leads to a substantial increase in overall efficiency and corresponding CO_2 savings. The flow of brake energy to a storage device allows for a reduction of the brake size, because the necessary thermal capacity is decreased.

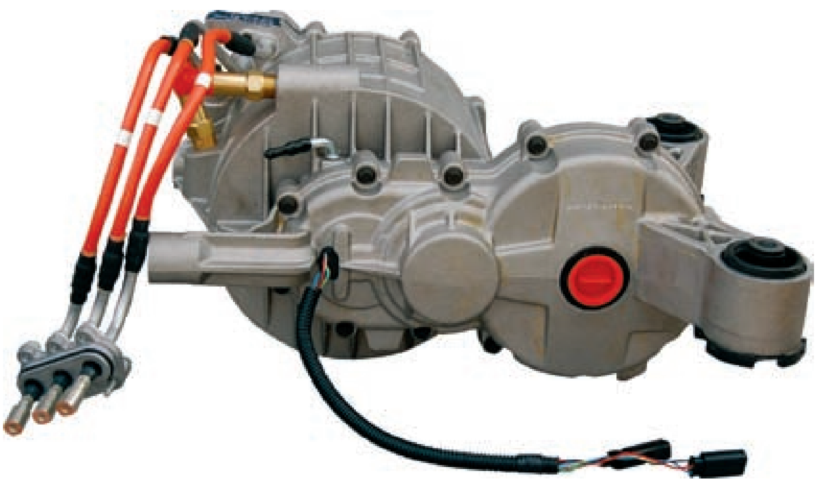

Figure 10: Electric rear-drive-module

On the other hand an additional weight of the electrical drive and the necessary storage capacity are to be taken into consideration, thus a part of the savings will again be reduced through increased masses.

Essential for a successful concept is the energy management of the overall vehicle in which the various influences are to be taken into consideration. This includes the defined driving characteristics like the acceleration capacity or the gradeability, driver specific parameters like sportiveness or an orientation on comfort, depending on the tracks like commuter traffic, mountain roads or freeways and in particular the state of charge of the storage device.

These requirements are only to be defined from the view of the overall vehicle, essentially from the OEM. Magna Powertrain concentrates in providing drive units for the differing concepts and requirements. In doing so there is a wide field between traction assist as a replacement for snow chains and sportive high performance drive as well as between axle drive and wheel drive. After an initial phase of diversity, depending on the customer acceptance and the social framework conditions in the long run only a few concepts will be implemented.

9 Summary and Outlook

If you observe today's drive train architectures, then in the short and middle terms there are savings with all-wheel driven cars and SUVs of 5 to 15 %. In addition to the optimizing of the weight and efficiency, a redimensioning of the requirements must be made. Naturally the older and heavier vehicles have a larger potential for savings. For further savings, more radical changes in the drive architecture and the overall vehicle are necessary. Essentially we are dealing with the better use of the primary energy and with recuperation of brake energy. The use of these long term potentials through hybrid vehicles and other alternative drives will primarily be determined by future vehicle concepts and only secondarily by the all-wheel drive.

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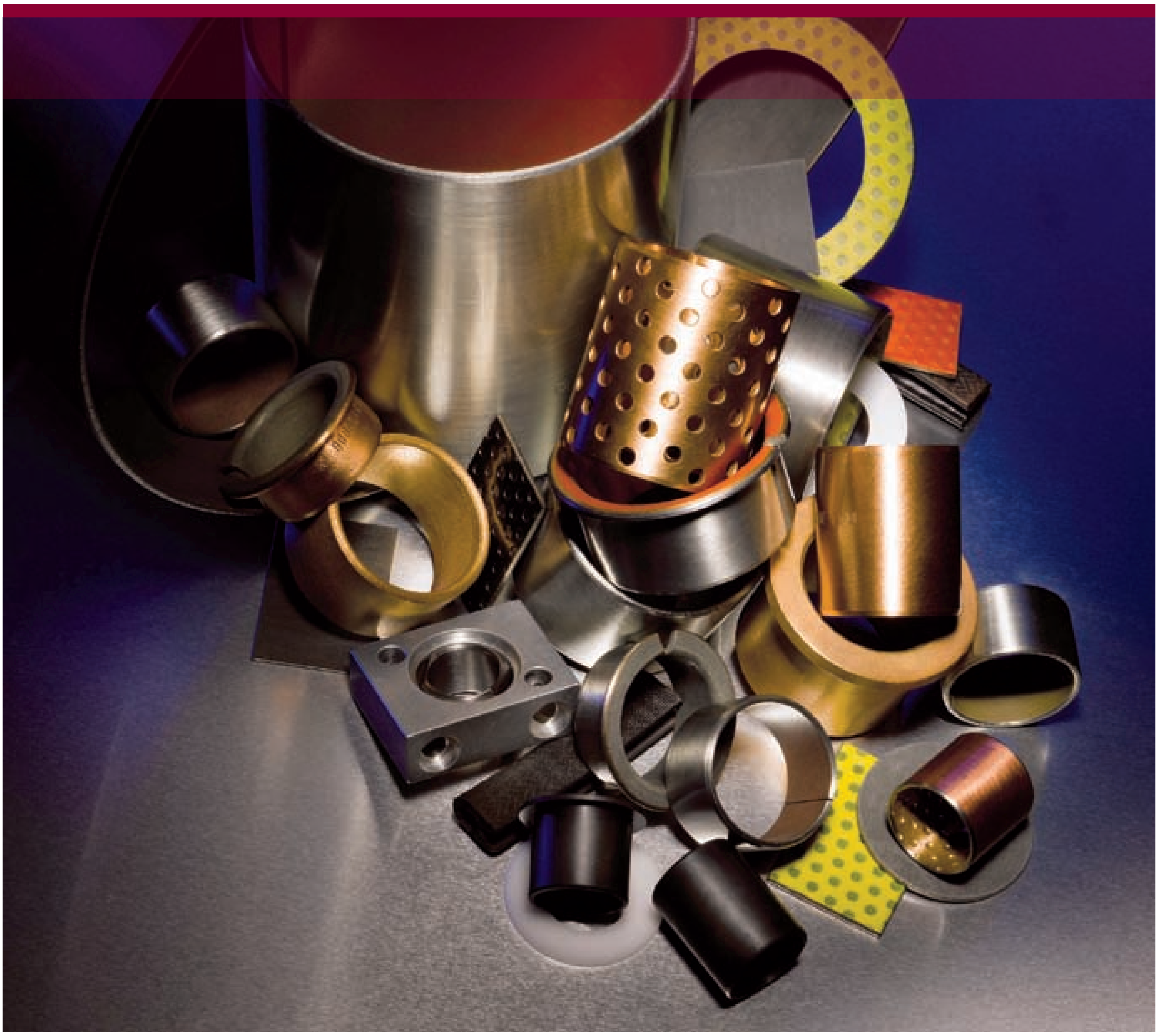
Solid Polymer Bearings in Tribological Applications

This article deals with the performance potentials that can be used in the application of modern plain bearing materials under fully lubricated operating conditions. It shows how these can be used, for example in coolant pumps, compressors or other ancillary aggregates, in order to obtain innovative solutions. Here, a conventional plain bearing solution made of bronze is compared to a composite material (steel/bronze modified PTFE) and a plastic compound (PEEK with aramid fibers and PTFE). In particular, GGB deals with the possible options in the use of modern high-performance solid polymers.



1 Introduction

Plain bearings offer designers and engineers as many possibilities to design a bearing location, as there are different types of bearings that make up this category. Originally plain bearings were made of bronze or white metal alloys, and thus were limited by the characteristics of these metals. Today high-performance plastics and composites open many interesting, new possibilities not readily available with metal bearings. Understanding the strengths and weaknesses of these types of bearings is the key to their successful application. Their basic characteristics allow users to preselect a bearing for a particular application and make adjustments at the early stages of project planning. The individual details are then left to bearing experts.

2 Application Example Radial Plain Bearing

The following scenarios are based on a fully lubricated radial plain bearing as the point of reference. The diagrams and trends apply only to the specified variants and are not transferable to other materials and/or operating conditions. The comparisons are drawn using dimensionless numbers in accordance with [1], including:

– relative bearing clearance

$$\psi = \frac{C}{D} \qquad \text{Eq. (1)}$$

– relative minimum film thickness number

$$h^*_{min} = \frac{h_{min} \cdot 2}{C} \qquad \text{Eq. (2)}$$

– dimensionless load capacity number

$$F^* = \frac{F \cdot \psi \cdot h_{min}}{B \cdot D \cdot \eta \cdot U} \qquad \text{Eq. (3)}$$

– dimensionless maximum pressure number

$$p^*_{max} = \frac{p_{max} \cdot \psi^2 \cdot D}{\eta \cdot U \cdot 2} \qquad \text{Eq. (4)}$$

– coefficient of friction

$$f = \frac{M_f \cdot 2}{F \cdot D} \qquad \text{Eq. (5)}$$

Explanation of symbols can be found in **Table 1**. As material variants the following materials were chosen:
– bronze (copper/tin alloy CuSn12)
– metal-polymer composite (steel/bronze modified PTFE)
– plastic compound (PEEK with aramid fibers and PTFE).

All three variants are subject to the same operational conditions that mean load, revolutions, axle/arbor coarseness, lubricants and/or viscosity and thermal output. The relative bearing clearance, Eq. (1), is likewise selected and can be produced in all variants by mechanical remachining. The wall thickness thereafter is 1.5 mm.

Table 2 contains material parameters of the bearing materials. These characteristics and their structure of solid or composite materials result in a specific

Table 1: Explanation of formulae abbreviations

Sign	Meaning	Unit
B	Bearing width	mm
C	Diameter clearance	mm
D	Bearing diameter	mm
h_{min}	Minimum film thickness	mm
F	Loading force	N
M_f	Friction torque	Nm
η	Dynamic viscosity	
U	Hydrodynamic effective speed	m/s

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Table 2: Bearing variants materials (at 90 °C)

Material variant	E-Module in N/mm²	Pressure yield point in N/mm²	Tmax in °C	Density in kg/m³
Bronze	110,000	120	350	8800
Composite material	10,000	150	280	7800
Plastic compound	2500	55	290	1390

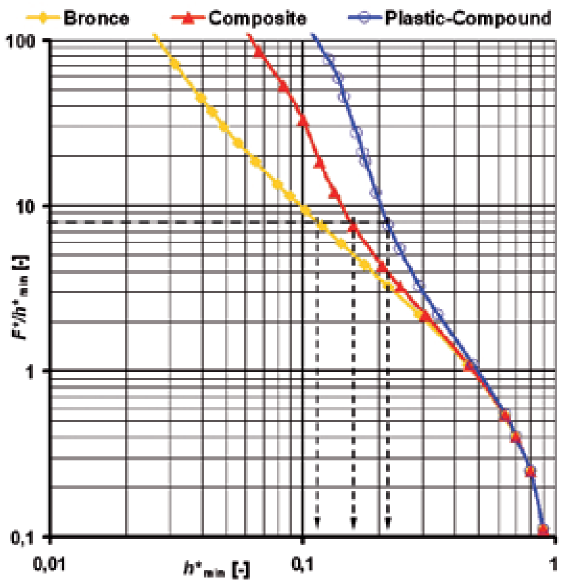

Figure 1: Load capacity characteristic number as function of relative minimum film thickness number

bearing dynamic, which is subsequently compared.

An important characteristic in the evaluation of a lubricated bearing is the minimum film thickness h_{min}. This indicates whether there is a sufficient lubricating layer between the counter body and the bearing material to avoid wear. Usually h_{min} is compared with the permissible film thickness $h_{min,lim}$. The permissible film thickness takes into consideration the roughness of the sliding surfaces, as well as any misalignment or deformities. To allow effective comparison of oil film characteristics between the materials, the relative minimum film thickness number h^*_{min} is used, Eq. (2).

Knowing the load capacity of the bearing is decisive in the construction of the system or assembly in which it is to be used. Calculating the load capacity of the bearing uses the dimensionless number F^* according to Eq. (3). This number includes the flexible deformation of the material and takes into account the elasto-hydrodynamic effect (EHD), which tends to increase the load capacity.

Figure 1 addresses the load capacity, illustrated by the characteristic number F^*/h^*_{min}, for all three material variants. Up to a relative minimum film thickness of $h^*_{min} \approx 0.5$, there are no significant variations in the attainable load capacities. At $h^*_{min} > 0.5$, all bearing variants have the same load capacity. The bearing configuration can follow commonly used methods without regard to EHD effects.

With smaller film thickness, the elasticity of the material does have a significant effect on operational dynamics. To compare the achievable film thicknesses for equal load capacity, that means the value of $F^*/h^*_{min} = 8$ is stated. Figure 1 shows the relative film thickness of the three types of bearings with the same load capacity and compares the resulting h^*_{min} values. The visible effects of the selected material variants are compared in **Table 3**.

It becomes clear that the relative minimum film thickness number depends on the selected material and can vary considerably. This can be attributed to the elastic characteristics of the materials alone.

To establish a reference for an application such as a coolant pump, a bearing measuring D = 20 mm and B = 20 mm is used to ascertain the minimum film thickness h_{min} in µm. The permissible film thickness $h_{min.lim}$ is determined pursuant to [1]. The roughness for the journal is $R_{z,J}$ = 1 µm and for the bearing is set at $R_{z,B}$ = 2.5 µm. Form deviations are not considered.

The use of plastics, which do not contain abrasive components such as glass or carbon fibers, yields still another useful effect. In comparison to the journal, usually made of steel, these are relatively soft and flexible. The elasticity of the plastic is sufficient to accommodate the roughness of the counter surface, so the roughness of the bearing material can be disregarded. Using this method, good results were achieved. The attained permissible minimum lubrication gap heights are listed in Table 3, too.

At h_{min} = 1.8 µm, the minimum film thickness of the bronze bearing is too small. This bearing causes wear, overheat and fail.

The minimum film thickness of composite bearing is h_{min} = 2.55 µm. This is

Table 3: Comparison of lubrication gap height h, dimensionless maximum pressure p and friction f (example)

Material Variant	h^*_{min} [-]	h_{min} [µm]	$h_{min,lim}$ [µm]	p^*_{max} [-]	f_{stat} [-]	f_{dyn} [-]
Bronze	0.12	1.80	2.75	30	0.30 ± 0.12	0.1500
Composite material	0.17	2.55	1.50	16	0.15 ± 0.07	0.0011
Plastic compound	0.22	3.30	1.50	12	0.25 ± 0.10	0.0010

1.05 μm larger than required and well within an acceptable operating range.

At h_{min} = 3.3 μm, the plastic bearing offers the largest minimum film thickness and would have the largest safety regarding film thickness.

In mass production scenarios, such as the automobile industry, bearings should be able to accommodate misalignment and should react robustly. Manufacturing tolerances can be made better by mechanical after work. As mentioned in this project, bearings based on high-tech polymer have these features with each both can be fulfilled. Thus, they can be used intelligent and economically.

3 Stresses

As a further step the stress of the bearing material itself should be investigated. The highest stress for the bearing material within the lubrication film is caused by the maximum hydrodynamic pressure. For the comparison of the bearing variants, the characteristic number p^*_{max}, Eq. (4), will be used. Based on the load capacity and the relative film thickness, the maximum pressure is ascertained in **Figure 2**.

When using composite and plastic variants, the maximum lubrication pressures are significantly lower than when using bronze. Here, too, the elasticity of the plastics causes the bearing material to draw back, thereby reducing the maximum pressure. The hydrodynamic distribution of pressure is thus expanded, resulting in reduced demand on the bearing material, **Figure 3** and **Figure 4**. This translates into less demand on the material as well as the lubricants.

4 Friction Behavior

Finally, the possible friction characteristics based on the friction coefficient *f* will be compared. First the static friction of the three variants is compared. This has an influence on the start-up behavior of a lubricated application. To minimize the effect of static friction, the lowest possible friction coefficient should be selected to optimize bearing performance and reduce temperatures within the contact zone.

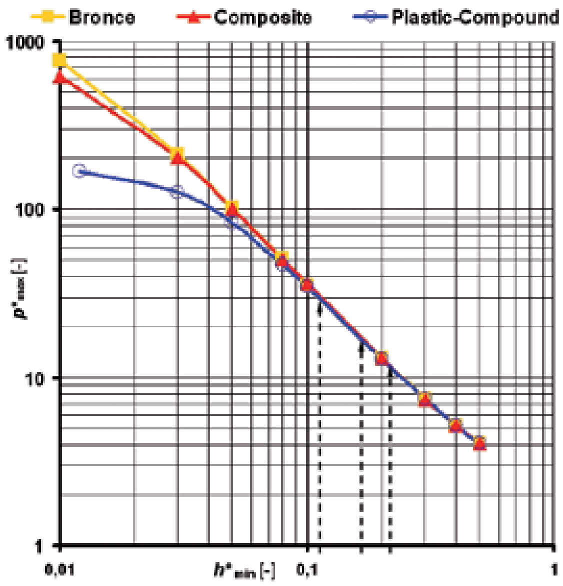

Figure 2: Comparison of the dimensionless maximum pressure number

Table 3 shows the advantages of the composite materials, which are characterized by a combination of metal components and plastics. They take advantage of the load bearing capacity of the metals and the favorable friction dynamics of the modified polymers. In lubricated applications, the friction characteristic is mainly related to the interaction between the bearing material and the lubricant, especially when operating with small film thicknesses. The coefficient of friction *f* versus minimum film thickness number h^*_{min} is illustrated in **Figure 5**.

What can be seen clearly are the friction minimums of the material variants. If the relative film thicknesses becomes to small the bearing is considered to be in mixed lubrication. This can be seen in Figure 5 by the strong increase of the coefficient of friction. For the example, mixed lubrication results from contact between the shaft and bearing material

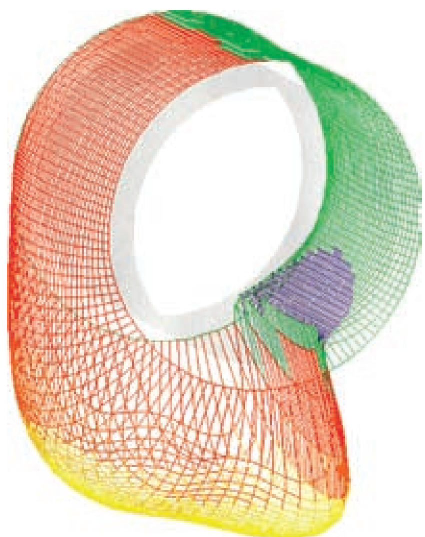

Figure 3: Hydrodynamic pressure distribution of a radial friction type bearing made of a plastic compound (standardized using p^*_{max})

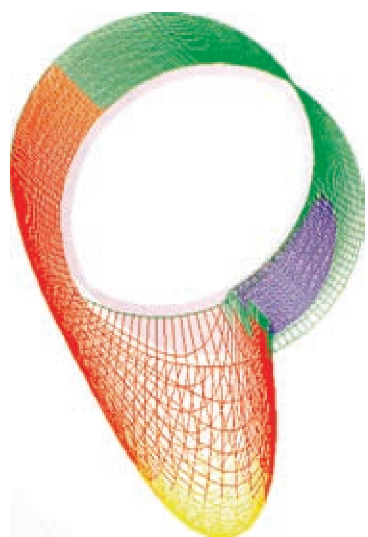

Figure 4: Hydrodynamic pressure distribution of a radial friction type bearing made of bronze (standardized using p^*_{max})

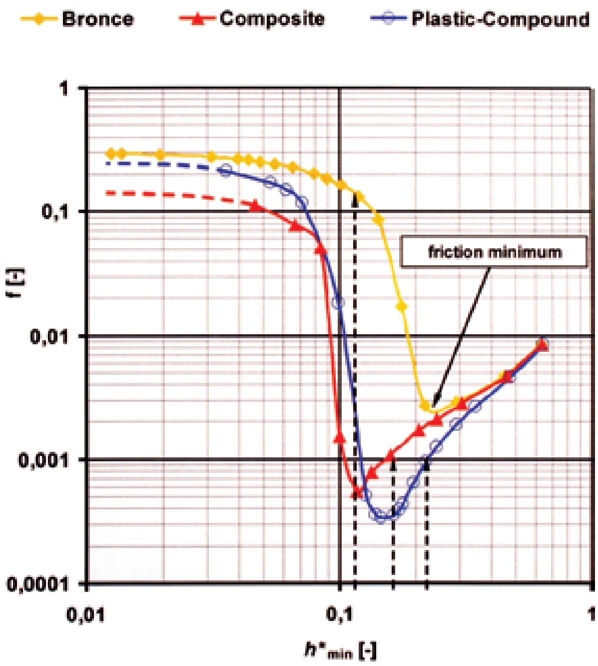

Figure 5: Dynamic coefficient of friction is presented as a function of the relative minimum film thickness number

Table 4 serves as a general guideline for the pre-selection of bearing materials, indicating the suitability of the material variants for each specific implementation. The classifications are as follows: 1 = advantage; 2 = compromise, 3 = disadvantage.

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Table 4: Matrix for the pre-selection of materials (1) For example water, water glycol mixture, biodegradable lubricants, low viscosity oils; 2) For example low-speed aggregates, numerous startups and shut downs)

Operational Criteria	Bronze	Composite material	Plastic compound
$h^*_{min} < 0.5$	3	2	1
Low viscosities[1)]	3	2	1
Low speeds[2)]	3	2	1
Misalignment and edge loading	3	2	1
Contaminated lubricants	1	3	2
Dynamic forces	1	1	2
Low startup friction	3	1	2
Reduced in weight	3	2	1
Material creeping	2	1	3
Tight fit within housing	2	1	3

and fluid friction. When a bearing material is stressed by the solid-body friction, it begins to wear. Such working condition should be avoided.

In comparing the material variants, the advantages offered by the soft polymer layers and their friction characteristics become clear. Having the same load capacity as the others, they produce larger film thicknesses. They can minimize friction and function reliably with thinner film thicknesses as well, both under startup and operating conditions. The results can be taken from Table 3.

5 Summary

As can be seen in this comparison of the three plain bearings materials bronze, metal-polymer composite (steel/bronze modified PTFE) and plastic compound (PEEK with aramid fibers and PTFE) by GGB, exact knowledge of the material dynamics is absolutely necessary. Due to its mechanical properties, the bearing material reacts differently to different operating conditions. The dimensioning of the bearing should always be performed by an expert.

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Success Factors of Globally Applicable Side Door Latches

One of the most essential requirements of a globally operating automotive manufacturer is to be able to use standard components across various models, platforms and vehicles. The challenge for a product design to span across regions and brands is to master the number and complexity of variants. Therefore a development method is required which helps to generate a cost efficient end product with as few variants as possible. Kiekert, a leading supplier of automotive latch systems, presents in this article their standardized solution for side door latches, the “alpha modular latch system”.

1 Introduction

The engineering of a side door latch, applicable worldwide and across brands, requires special variants and complexity management of the globally operating OEM for multiple brands and there suppliers. Such a demanding engineering project often fails due to regional requirements: different user interfaces, market specific applications in relation to functionality, legal requirements or diverging market philosophies. Volumes are lost due to the number of variants. In addition base variants are often burdened by protecting the design for additional features and therefore adding cost so that the end product is no longer competitive. During the engineering phase additional functions are being included to the once fully optimized basic design. Consequently the planned cost optimization is no longer achievable. In order to minimize any later adjustments or to exclude right from the start, Kiekert has created a modular scheme, which is applied for the first time in the "alpha modular latch system" (alpha – advanced latch philosophy with high applicability).

2 Benchmark and Product Specification Definition

The alpha modular latch system was created and validated independent from the customer. It contains 100 % of globally required latch functions and meets the various market specifications. Therefore the modular latch system is broadly applicable. In order to guarantee the advantages mentioned, the following critical features were taken into consideration:

- Meeting 100 % of globally required functions and interfaces
- Meeting of special market requirements and specifications
- Basic design provides possibilities to realize OEM specific identification features
- Use of globally available low-invest technologies, materials and finishes
- 100 % design validation of the modular latch system with samples made from prototype tool set

A comprehensive benchmarking preceded the engineering process. As a latch system specialist with years of worldwide engineering competence Kiekert could draw from substantial data about globally applicable side door latches. For the market screening which was carried out at the beginning of the project Kiekert relied mainly on proprietary information which was complemented by a competitor benchmark. In total more than 40 latches with 200 various features were compared which fell into the categories functions, specifications, interfaces and packaging.

Functions and interfaces from the benchmark were fully (100 %) transferred into the product specification. The assessment of the required market specification showed that the specific requirements of individual automotive manufacturers were well above the market average. Consideration of such higher specifications in the creation of a universal modular latch system led to a non-competitive product.

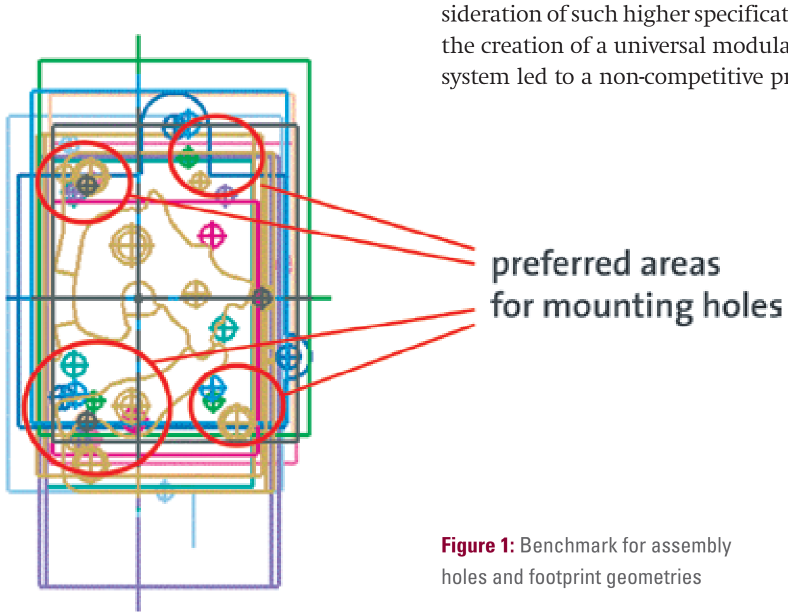

Figure 1: Benchmark for assembly holes and footprint geometries

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The Kiekert product specification focuses on the common market requirements with the exception of applications such as corrosion or EMC (electromagnetic compatibility). Two classes were defined for these exceptions, which can be used for all specification levels.

An important step was to filter from 200 requirements those which were specific to an OEM. Kiekert also used its knowledge about customers and markets as well as years of engineering experience as the basis for selecting the criteria. Examples for OEM specific identification features are connector systems, footprint and interface connections. The correct and complete documentation of the identification features in the product specification is crucial for the marketability of the modular latch system and important for the ultimate design solution. The product design must assure to meet the OEM specific identification features without leaving the validated basic concept. This is the only way to integrate the advantages of the optimized and validated modular latch system into the individual OEM projects.

The example of the footprint shows which idea was pursued. **Figure 1** displays the result of the benchmark in relation to the footprint. The product design was carried out in such a way that without changes to the inner lever chain the majority of footprint shown in Figure 1 can be realized. For marketing, it is essential to be able to use existing footprints of existing products with the modular latch system. This enables a "running change" for the OEM without any problems. In order to maximize the applicability of the modular system, it is also important to define critical and non-critical package properties. The motto, "the smaller

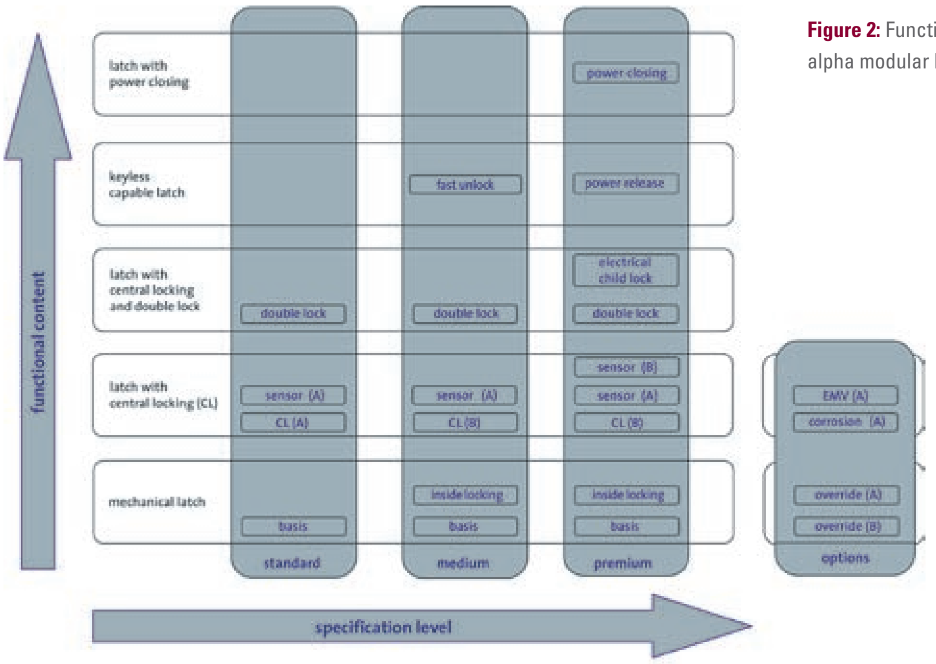

Figure 2: Functional expansion levels in the alpha modular latch system

the better", may not be used in this context. Otherwise complicated design solutions become necessary, which influence costs and robustness in a negative sense.

3 Modular Latch System Definition

The completed product specification is the basis for the definition of the modular system. This is the only way to overcome the engineering paradoxes of a product design which is cost-optimized for all variants, ensuring at the same time universal applicability and providing customer specific identification features. Establishing potential parameter combinations of the various functions and required features reduces the number of product variants to a reasonable market-conform level. This step requires comprehensive market knowledge and a good assessment of future market trends. The result is the modular system matrix as shown in **Figure 2**. The matrix displays the function expansion levels realized in the alpha modular latch system from the simple mechanical latch, a latch with central locking, double locking, power open to a latch with integrated power closure. The three classes, standard, medium and premium represent different customer requirements – for example the number of sensors or variants with and without inside locking. The requirement classes arise from the different combination of the parameters defined in the product specification. Parameters such as higher corrosion or EMC requirements can be applied as options in all expansion stages.

4 Target Costs

Definition of the target sales price for all variants is the basis of the retrograde product cost calculation. The target costs are calculated from the sales price per function and required parameter. The benchmark data supplies the "best in class" function costs which are undercut by the alpha modular latch system.

5 Product Design

The actual product design is carried out in an iterative algorithm, **Figure 3**, where the level of meeting the requirements and target costs is continuously improved until

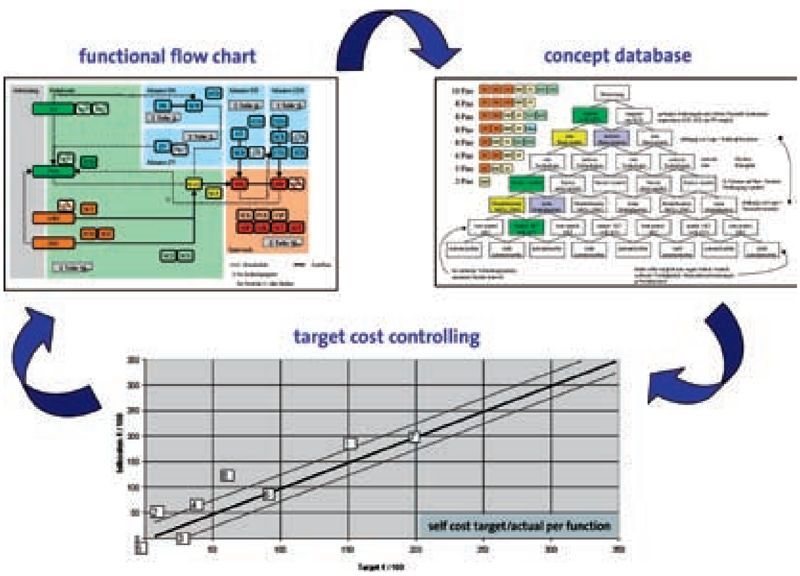

Figure 3: Iterative algorithms for product design

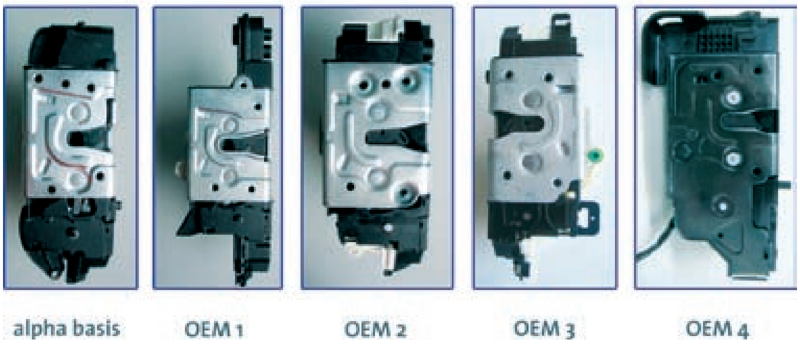

Figure 4: Typical examples for footprint geometries

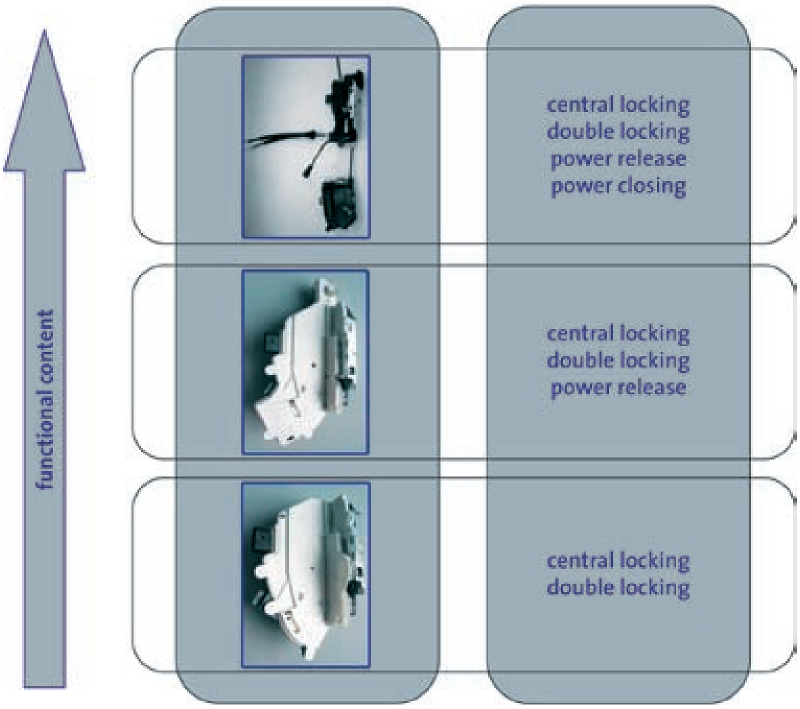

Figure 5: Examples of OEM specific variants of function

the optimized design has been achieved. This is done by abstract function flow charts, a concept database with functional solutions and target cost control. The use of known and proven, serial production functional solutions minimize engineering and cost risks. At the end of this iterative process the complete modular system is defined on the basis of the functional flow charts with related function designs and costs. It is only now that the actual design process begins with layout of the selected function design and the design of the interfaces. In order to achieve a working unit, compromises regarding additional components or the deviation from the optimized package may be necessary. Comprehensive theoretical validations secure the design and minimize component validation. In this context the alpha modular system benefits from the pioneer work Kiekert has done, especially in the theoretical optimization of the acoustic features when closing or opening the door – and Kiekert went a step further. The latch system specialist has invested in a complete prototype tool set in order to be able to carry out a complete design validation. This minimizes engineering risks in the customer specific application and guarantees shorter realization periods. The specific test equipment and the know-how of Kiekert guarantee real life test conditions in our laboratories. An example, is the special vibration test bench, which simulates movements between body and door in all three directions with various amplitudes and frequencies avoiding time and cost intensive test drives. This minimizes engineering risks in the customer specific application and guarantees shorter realization periods.

Figure 4 shows the alpha latch with typical footprints of various OEMs. All solutions can be produced without changes of the inner layout. Every operating interface can be connected via Bowden cables or rods. **Figure 5** displays various function applications in various OEM specific variants – from a latch with central locking, with double locking to a latch with modular power closure. The used modular closure forms a separate modular system which is used for various side and tailgate latch applications. Especially the possibility to combine the modular closure with a Kiekert engineered and produced ECU allows the use of this function as a stand-alone solution in existing vehicle electronic architectures.

Today the alpha latch is already being used by five globally operating OEMs as a corporate latch. To meet these orders Kiekert's production line output exceeds 15 million alpha latches for the European, NAFTA, Korean and Chinese markets. Due to the high level of maturity and the immediate availability of tool-based prototypes, the shortest development period until the launch amounted to 20 months. With regard to costs, performance and applicability the alpha modular latch system is the benchmark amongst side door latches.

6 Prospects

Parallel to the market development Kiekert works on the expansion of the alpha modular latch system. A new requirement class called "Emerging Market", which will meet the requirements of vehicle segments in emerging and growing markets, will be added to the modular latch system matrix displayed in Figure 2. Experiences from realized developments of emerging market applications in India and China will be included in this class. Furthermore, Kiekert is working on an innovation for the function "power closing" called i-close, which will also be integrated into the alpha modular latch system and reduce considerably the complexity of this function. ■

With CNT coatings fogged glass could shortly belong to the past

Carbon Nano Tubes for Heated Windows and Body

Carbon Nano Tubes (CNT) offer as actuators of automobile control systems many solutions. The developers of the Fraunhofer Technology Development Group (Fraunhofer TEG) have made another breakthrough: CNT coatings as heated panes for car windows and car mirrors are about to achieve series-production readiness. The application of the CNT technology might also be important in the future for composite materials for manufacture of extremely stable and light car body parts.

1 Introduction

The nanotechnology holds a very high innovation potential and is considered to be a key technology in the 21st century. However, the term "nano" is more and more used inflationary, despite the fact that the technology is limited to a very small but precise measure: Nanotechnology is the research, manufacture or application of molecular materials and their boundaries and surfaces with manufacturing tolerances below the range of 100 nanometres [1].

2 CNT Architecture and CNT Characteristics

The Fraunhofer TEG has specialized in the versatile world of the molecules on Carbon Nano Tubes, in brief CNT, **Figure 1**. CNT are hexagonal networked carbon atoms, which form tubular molecules (tubes). Peculiarities: The carbon tubes have a diameter of merely approximately a few nanometers, but length dimensions of up to one millimetre. And herein lays the closeness to the biological „archetype". Similar to natural muscles CNT consists of billions of individual nanoscopical thin fibres, **Figure 2**, which can perform, for example, mechanical work. Opposed to the relative weak fibre of a naturally muscle the new artificial muscles are made of tiny carbon tubes and therefore very strong and tough. CNT do have a good "kinsmanlike background": Carbon in form of a diamond is the hardest material and does have the greatest thermal conductivity. Graphite as the other form of carbon in turn is a good conductor of electricity. These characteristics are also applied for CNT.

Their good conductivity and special electro-magnetic characteristics, like the so-called electro-strictive effect is predestined for miniature fibres for use as actuators, that means for the application as actuating elements as they are often used in minimal invasive medicine or in the automotive sector. The principal works as follows: If electrical voltage is placed on carbon tubes one gets a motion similar to a natural muscle.

Advantageous in that regard is the high cohesiveness of the fibres by which they perform with each movement more work but they can also produce higher mechanical tensions than all other available technologies for actuators. The material expands over the lengths more than with other systems and the direct comparison with piezoelectric actuators does show it. If one places an electrical voltage on a piezoelectric crystal a geometrical change does occur in regards to the length. However, the disadvantage is the lower expansion for each field stress. For comparison: If one layers piezoelec-

Figure 1: Model of Carbon Nano Tubes (CNT), only a few nanometers large, in the laboratory of the Fraunhofer TEG

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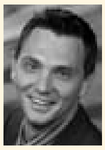

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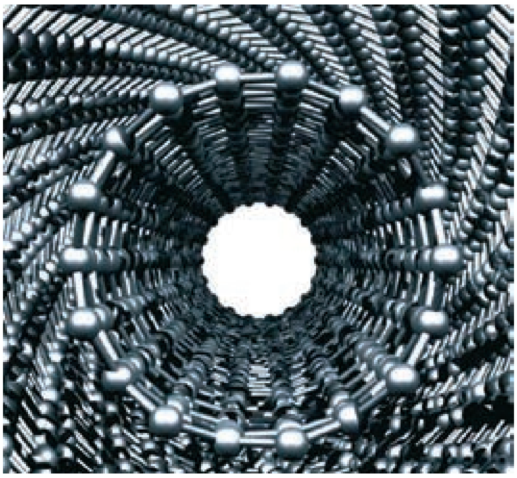

Figure 2: Similar to muscles, CNT consist of billions of individual nanoscopical thin fibres

tric ceramic to a stack of 8 cm and if voltage is placed onto it one gets a change of length of 0.04 mm. However, it requires a voltage in the range of kilo volts. The carbon tubes have expansion rates, which are larger than approximately by the factor 30. And all under a supply voltage, which is in the range of a single digit [2].

With these characteristics one can use the smallest actuators elements in locations where actions and reactions are required within the smallest space, that means the entire micro system technology of modern automobiles. Mechanical and hydraulic applications such as seat adjustments, power window lifts, power steering or brake systems are supplemented or replaced for cost reasons with electro-mechanical actuators. Additionally, the proportion of vehicle electronic grows exponentially due to higher comfort, infotainment and safety requirements – a broad field for powerful, light and low-consumption actuators made of CNT.

CNT surpasses the capacity limits of all current micro actuators in terms of heat-resistance of the carbon. Therefore, CNT at temperatures of up to 2800 °C in vacuum and 800 °C in the air are thinkable. This opens up "hot" areas of application in the automobile sector, for example in motor control, in the field of exhaust-gas cleaning, for turbo chargers, etc.

Although there has been for some time a general great interest in micro actuators on the part of industry, the market penetration extent was not significant. High manufacturing costs of the actuators mostly produced in laboratory scale and use of uncommon and expensive materials prevent their economic use. The CNT, which become more and more popular, currently change this picture due to their outstanding exceptional position: low-cost raw material and low power input promise many possibilities of application for the new actuators.

3 Handling and Processing of CNT

One of the greatest challenges in this promising area of nanotechnology was and is the handling of the CNT, **Figure 3**. After all, for technical application as actuators the nanoscopical small carbon tubes must first of all be put in a useable and manageable size. As only in macroscopic form can CNT be conditioned to units such as control point, displacement, actuation speed, power consumption and force for the respective application. The starting point for the research of actuator characteristics of CNT was the so-called Bucky Paper [3], named by Richard Buckminster Fuller. Bucky Paper is the name for a fleece consisting of CNT, which is produced with a sedimentation process similar to paper manufacturing. This system requires for conversion of electrical energy into mechanical energy an electrolytic solution [4]. For many applications a system operated in a liquid might be disadvantageous, additionally the stability of the Bucky Papers was not sufficient for many applications. A "dry" system working in the air does have – with simple handling – a low design demand and low material costs.

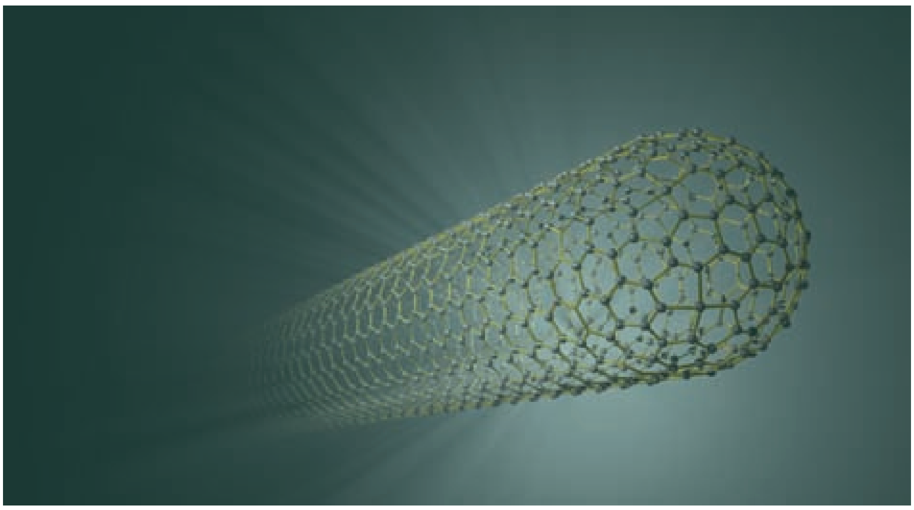

Figure 3: For technical application as actuators the nanoscopical small carbon tubes must be put in a useable and manageable size

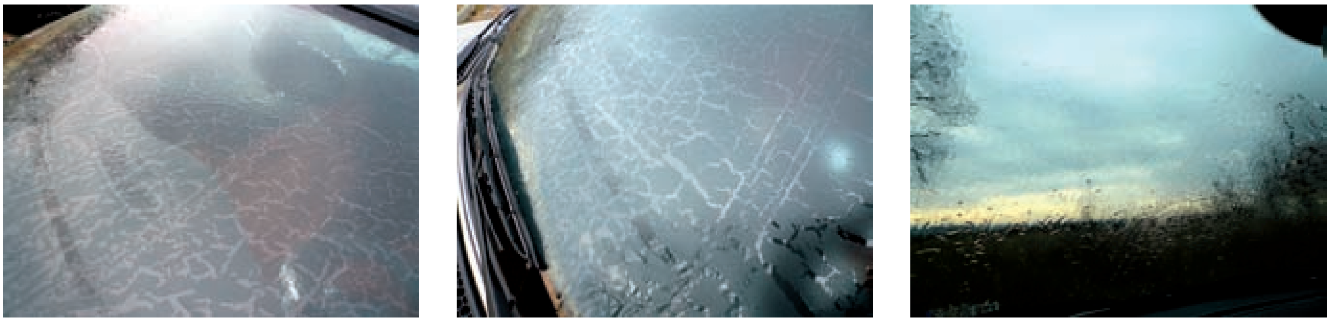

Figure 4: Entirely transparent and surface-covering resistance heaters with CNT coating for a windshield (defrosting from left to right)

In order to overcome this technological barrier and to realize innovative products the Fraunhofer TEG has established – as one of the leading research societies in this area – a CNT application laboratory. In an efficient collaboration of subject-involved and application-oriented Fraunhofer Branch Institutes and a Max-Planck Institute as scientific partner expert knowledge is bundled to forward the CNT progress. Thus, important milestones could be already achieved in research of the elementary basics and also in industrial implementation. The findings of the CNT application laboratory put the Fraunhofer TEG into a position to transfer the potentials of the CNT technology to other new applications.

4 CNT Composite Solutions

The most important research object was at first to develop actuators, which can work without electrolytic solution [5]. This was achieved by the CNT application laboratory with the development of a new CNT composite. The composite consists essentially of two polymer layers. One layer consists of the carbon tubes as electrolytic active component; the other layer serves as support matrix for the – dry – electrolytic component. If a low voltage is used the desired expansion of the composite in all three dimensions takes place. This bi-layer system can also be arranged in three layers: Based on configuration of these actuating elements linear, stack and bend actuators can be realized. The market-oriented preparatory research of the CNT application laboratory is currently heavily working on the evaluation of the best suitable composites with the object to make available CNT for various adaptronic applications. Aside of increase of the actuator force to more than 2000 % the actuation time could be markedly improved.

During research for suitable matrix materials for CNT amazing research results were gained in regards to material characteristics. Already with a low CNT proportion important basic characteristics of materials can be positively influenced and they can be optimized in the desired direction. The object is to adjust purposely the electrical conductivity of basic materials via the filler material content in CNT. In doing so it is important that the characteristics of the matrix are not negatively influenced. A homogeneous distribution in the matrix support material is a prerequisite to achieve this object.

4.1 New Products with Thermal Advantages

Materials such as cellulose, polyurethane or silicone were modified in various procedures with adding of CNT. The carbon tubes are delivered in powder form, which looks similar to graphite powder. The CNT are adhesive within the powder and form larger agglutinations. These microscopic agglutinations of carbon tubes do no have any potential in this form, which would improve significantly thermal, mechanical and electrical characteristics of composite materials. Therefore, CNT must first be individualized and then distributed equally over the support substance to use their excellent characteristics. This adding is a highly complex process (which can not be simply considered as a stirring of a substance into another substance) and it does pose a great challenge. Therefore, it is called dispersion process of the CNTs, which mostly takes place in a liquid medium. The complete dispersion is later applied to the matrix material.

Another possibility is to apply the dispersion as a kind of varnish onto different surfaces. If voltage is applied on such prepared composite materials an electrical current will flow. The CNT composite material represents an ohmic resistance, which results in conversion of electrical energy into heat. This can then be used to heat-up various surfaces. As the composite material itself does have only a low heat capacity the resulting heat is passed into the environment. Another highly relevant advantage compared to common resistance elements is: The heat is equally distributed over the entire surface.

The described characteristics work also in case of extremely thin layers with low CNT content. The advantage for the automotive sector is that the coatings are not only extremely conductive but also transparent. Applied onto windscreens and back panes of automobiles or exterior mirrors these CNT composite materials can be used as entirely transparent, **Figure 4**, and surface-covering resistance heaters – without expensive copper wires, annoying line-of-sight obstructions and elaborate manufacturing processes.

Another application for the carbon tubes in the automobile sector are seat heaters with prepared CNT fabric dye which can efficiently heat any car seat and which would require only a fraction of today‘s heating elements. With additional modifications transparent electrodes for displays can be realized in car interiors by CNT.

4.2 New Products due to Improved Material Characteristics

Aside of excellent electrical and thermal characteristics the CNT parts in polymer materials result also in significant improvements of mechanical characteristics in the support material. A product, developed by Fraunhofer TEG, which has already reached series-readiness and which is already produced, can show the immense potential of CNT for improvement of base materials.

It was found that the adding of so called Multi Walled Carbon Nano Tubes (MWNT) can improve the damping characteristics of polymers significantly. This approach, which is very interesting for the automobile industry, is used by the sport item manufacturer Völkl for the first time. A cost-effective composite material was successfully developed by the Fraunhofer TEG and was used for the first series of 300,000 tennis rackets. Additional 100,000 items are already in production. Thus, it is a first ever that CNT is used in industrial series production.

The advantages of the CNT in the handle and frame of the high-tech tennis racket can also be used in the future for other equipment for sports: Thinkable and already partially realized is CNT in skis, ski and walking sticks, surf boards, bicycle helmets or sports shoes to just name a few possibilities [5].

5 Summary and Outlook

The CNT composite technology can be used on green house components as heating and for vehicle body parts excellently. One advantage found out by the Fraunhofer Technology Development Group (Fraunhofer TEG) is that a CNT coating is not only extremely conductive but also transparent.

Besides, Carbon Nano Tubes do not only improve the damping characteristics of the materials but also optimize the resilience extremely: CNT are very light and due have only a quarter of the weight of steel but have 135 times better ratio of tensile strength to density than steel. In times where the lowering of energy consumption and CO_2 emissions is the prevalent subject in vehicle manufacture CNT will move more in focus in the automobile and supply industry. With their high electrical conductivity carbon tubes can also assist to make advancements in the area of storage capacity of accumulators.

The advantageous research results and application examples for CNT composites can be classified into the two groups form characteristics and temperature behaviour:

1. Form Characteristics
- The form of the CNT composite material can be freely selected so that an adjustment to various form surfaces is possible.
- CNT coatings can be applied with simple techniques onto three-dimensional surfaces.
- The CNT composite material constitutes a conductive path – it conducts also with locally limited damages.

2. Temperature Behaviour
- Due to the low heat capacity the developing heat in CNT composite materials is quickly forwarded.
- Equal heat distribution in the CNT composite material over the entire surface – not only punctual heat-up on contact surfaces with conductive paths.
- Short reaction time: Quick heat-up and short cool-down phases for the CNT composite material.

The CNT application laboratory of Fraunhofer TEG works already for eight years and currently on 30 industry projects with this high-tech material. There is no lack of product ideas, especially for the automobile industry. Slowly, but at this time only sparsely there are impulses from the companies themselves. Furthermore, the manufacturing of CNT is now taken on in big industrial style. Companies such as Bayer Material Science plan to expand their yearly capacities till 2012 to 3000 t of CNT – with a material pureness of up to 95 %. This and the accompanying positive price trend will result in further advancements for CNT applications in the automobile sector.

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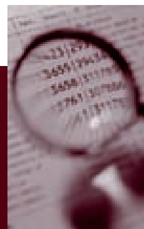

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Incorporating Customer's Driving Behaviour in Vehicle Development

The automobile industry has already made great progress in improving fuel efficiency. This progress is monitored by a for the manufactures prescribed unified test cycle. Since this customer behaviour is determining the real fuel consumption of the vehicles it is important to implement this individual behaviour in the vehicle development process. The article describes a methodology, developed in corporation with the TU Dresden, the Spiegel-Institut Mannheim and the BMW Group, to incorporate model-specific customer's driving behaviour into the development process and the there out resulting solution approach.

1 Introduction

The momentarily increasing price of crude oil and the continuing debates about Climate Change put fuel efficiency into the focus of final customer's attention. Successfully implementing fuel efficient technologies is not only dependent on CO_2-emissions established in the New European Driving Cycle (NEDC) but mainly dependent on the real customer fuel consumption. The prescribed standardised NEDC for fuel consumption determination can only represent to some extent the individual customer driving behaviour due to set requirements like reproducibility, comparability and drivability. The development focus of engineers on the NEDC and the there out forthcoming technologies do not necessarily lead to the desired reduction in fuel consumption under normal driving conditions.

To break the tension field between set requirements, budget pressure and customer satisfaction it is necessary to integrate the customer's driving behaviour in the development process. Instead of investing in expensive complete vehicle optimization, individual cost efficient measures are identified and implemented which are most beneficial to customers.

The customer's driving behaviour is the topic of intensive research since over ten years. There are different starting points to make the driving behaviour recordable and thus usable to optimize the development process of vehicles. One possibility exists in the traffic simulation, in which the driver behaviour results from interaction between vehicle and driving environment values [1, 2, 3, 4]. Besides these, there are existing methods to describe the driver behaviour by evaluation of measured driver and driving environment values statistically [5, 6, 7, 8]. By systematically determined measuring databases thereby the driver is depicted in the prognosis-like simulation during the early stage of the development process.

The goal of the work presented here is to develop a method with which it is possible to intend the representative driving behaviour of the vehicles for a broad class of model-specific customers. The methodology, presented here by TU Dresden, the Spiegel-Institut Mannheim and the BMW Group to identify real model-specific customer driving behaviour, can be incorporated into the vehicle development process. Therefore five specifically selected models, **Table**, of the car manufacturer BMW were analysed.

2 Selection Process of Participants

For a cost-effective data acquisition where both representativity and measurement accuracy are assured, the project team decided to combine a customer questionnaire with a measurement survey of customer vehicles. Using stratified random sampling first a representative customer questionnaire was conducted with the purpose of determining representative participants for each vehicle model.

For budgetary reasons a sample of ten to twenty participants per vehicle model has been selected. In total five models were fitted with measurement equipment to record the driving behaviour over a distance of about 5,000 km per vehicle. The emphasis of the research was the fuel consumption.

Table: Overview of tested models

Tested No.	Vehicle segment	Body shape	Engine
1	Compact Class (CC)	Saloon / Sedan (Hatchback)	SI 4 Cylinder
2	Medium Class (MC-G, gasoline)	Saloon / Sedan	SI 4 Cylinder
3	Medium Class (MC-D, diesel)	Saloon / Sedan	Diesel 4 Cylinder
4	Sports utility vehicle (SUV)	Sports utility vehicle (SUV)	Diesel 6 Cylinder
5	Upper Medium (UMC)	Saloon / Sedan	Diesel 6 Cylinder

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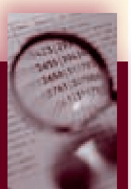

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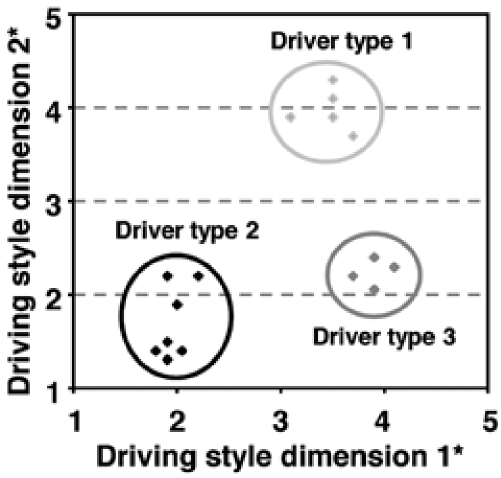

Figure 1: Example of a cluster analysis and derived driver types (* idealized example data for two driving style dimensions were used)

2.1 Used Sample Selection Process: Stratified Random Sampling

The selected participant sample should if possible cover the complete driver spectrum for each model. A complete random sampling process using a limited amount of participants can not guarantee this distribution. It can be expected that the distribution of relevant parameters in a small random sample will be different to the distribution of the same parameters in the basic population. To avoid a to strong deviation a stratified random sampling process is the established approach [9].

With stratified random sampling, the population is first divided into a number of parts or ‚strata' according to certain characteristics, chosen to be related to the major parameters being studied, beneath age, gender and fraction of company cars.

To incorporate driving style in the sampling process, it was chosen as one of the stratification variables. In the following the selection of acceleration and velocity level as well as the vehicle operations, gear-, throttle-, and brake paddle control are referred to as driving style. Its enormous influence on fuel consumption was analysed many times before. Through deliberate driving style training one can achieve fuel consumption reductions of 10 % or more [10].

2.2 Methodology for Determining the Type of Driving Style

Following a qualitative preliminary study the Spiegel-Institut Mannheim developed a questionnaire to detect driving style. These items were conducted in a twenty minute telephone interview (CATI) with 200 till 300 drivers of each vehicle model. The CATI participants where already grouped according to stratification variables like gender, age and whether the vehicle is privately owned or it is a company car to represent the customer distribution of the total population.

Using cluster analysis, the individual participants who demonstrate a comparable characteristic pattern in the driving style dimensions where grouped, **Figure 1**. These collections will be referred to as driver types in the following. The analogy between participants is largest within a collection and smallest between the collections.

From every group of driver types, Figure 1, representative members are chosen who have the smallest distance to the cluster middle point; also taking other stratification criteria like gender, age, etc into consideration. Due to the small sample size from every dimension an equal amount of members are chosen, as general rule five members per driver type group. The recorded vehicle data got evaluated by means of weighted analysis taking into account the group-type distribution ("disproportionate sample" [11]). On one hand, this approach ensures that the variation of the parameter driving style in the sample is the same or similar to its variation in the total population, on the other hand, disruptive factors due to deviation from the mean vehicle usage are kept to a minimum.

2.3 Comparison of Driver Types Based on the Questionnaire and Measurement Data

During the comparison of the model-specific driver types it became noticeable that these types diverge significantly from each other with respect to:

- time driven per day
- daily mileage
- yearly mileage
- fuel consumption (especially out of town)
- customer fuel consumption satisfaction.

From these results it can be concluded that "driver type" as stratification criteria is a legitimate parameter for sample building for vehicle data acquisition. A comparison of the customer data with the derived driver types shows that there is a significant difference in fuel consumption for the individual driver types of the middleclass vehicle segment, regardless of the diminutive sample size.

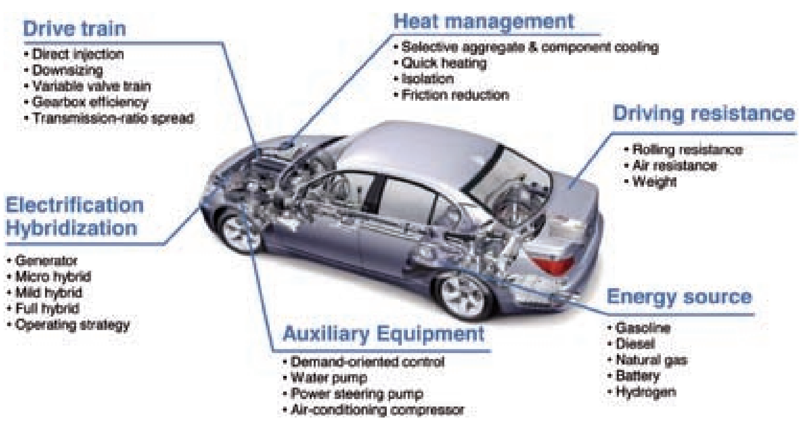

Figure 2: Areas and approaches of fuel consumption reduction

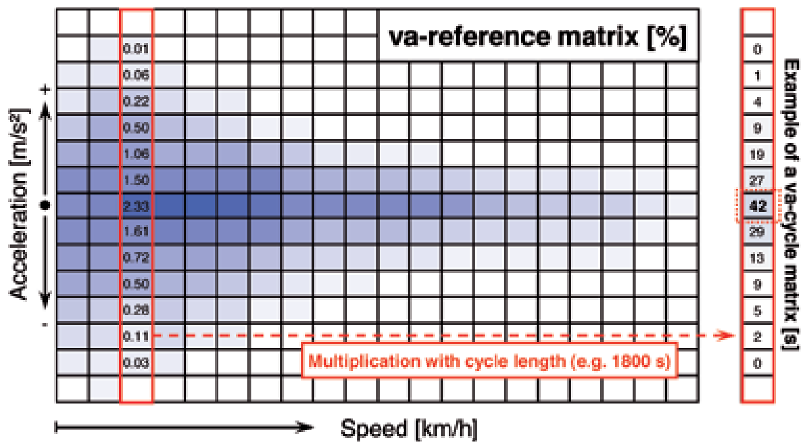

Figure 3: Time sections of the va-reference matrix in % (example compact vehicle class)

3 Measurement Equipment

CAN-bus systems in today's vehicles offer an easy access to the vehicle status variables relevant for the driving behaviour. With variables like speed, longitudinal- and transversal acceleration as well as several engine variables and comfort functions like air conditioning usage the driving behaviour of a driver can be documented. For the data acquisition M-LOG data loggers of Ipetronik have been used. These were typically mounted in the glove compartment box of the vehicles. The power supply for the equipment is provided by the vehicle's board net. A typical measurement would start by switching on the ignition and continue until the engine is switched off.

Afterwards the data would be transferred using GPRS via a GSM-network to an internet server. For this purpose a little antenna was stuck to the front screen of the vehicle. An FTP connection made it possible to transfer the data from the server and translate it into a format suitable for evaluation. All together, over 65,000 trips and 580,000 km were recorded.

4 Possible Application Fields of the Data

Using the acquired data multiple technical queries can be answered. Until now the effectiveness of certain fuel saving technologies depicted in **Figure 2** could only be determined in the NEDC by using recorded data. Now this can also be evaluated under real driving conditions. Performing statistical analysis alone will not be the winning solution. The combination of real life data with detailed vehicle simulation gives information over the fuel saving potential of the different technologies. Therefore customer driving cycles need to be generated, which represent the customer's driving behaviour in the simulations and on dynamometers.

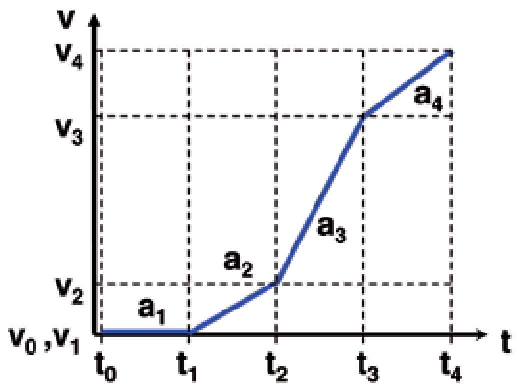

Figure 4: Piecewise calculation of velocities

5 Generating Customer Driving Cycles

Beside dynamometer measurements nowadays it is common practice as part of the development process to calculate fuel consumption and the effectiveness of new technologies using vehicle simulation tools. This enables engineers to evaluate certain development potentials for customer fuel efficiency as early as in the concept phase. Being able to feed this demand a methodology has been developed to generate representative model-specific customer driving cycles in a straightforward manner.

5.1 Theory Behind Cycle Generation

There are several approaches for the generation of driving cycles; some are more arbitrary, others require demanding statistical methods [12]. Using parameters like average speed and acceleration, stationary time etc. driving cycles can either be created synthetically or built from real life velocity progression plots which are fitted together in a way that they represent the desired driving behaviour.

5.2 Description Criteria for Driving Cycles

Our research has revealed that three-dimensional velocity-acceleration-matrices (va-matrix) are best used to describe a driving cycle, **Figure 3**, since from the va-matrix all other parameters (like average speed, average acceleration, etc.) can be derived [13]. These time partitions are then accredited to specific velocity and acceleration bins based on their affiliation with this bin. The transformation to relative fragments is made to clarify the visualisation in the graphs.

When a driving cycle is created that has the same distribution of time fractions in his va-matrix as the reference va-matrix (input data), then all important cycle parameters will be representative (average speed, average acceleration, velocity- and acceleration distribution, etc.). This aim can be reached using preset acceleration intervals, **Figure 4**, to calculate the resulting end speed at the end of such an interval – using the equation

$$v_{i+1} = v_i + a_{i+1} \cdot \Delta t \qquad \text{Eq.}$$

then concatenating these intervals will build the desired velocity-time curve. In

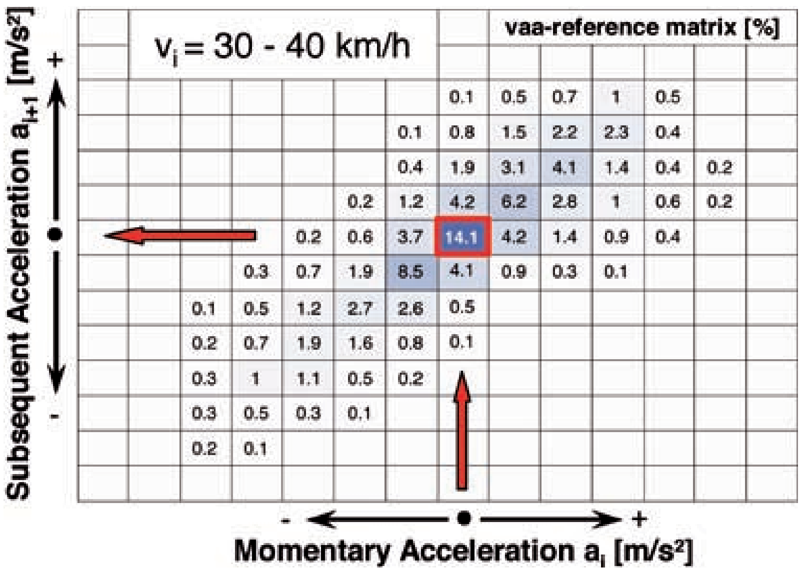

Figure 5: vaa-reference matrix (example compact vehicle class)

the infinite variation possibilities of the last approach lies the challenge to develop a certain systematic that generates physically sensible velocity-time curves and reflects the time fractions from the reference va-matrix.

5.3 Methodology for Generating Driving Cycles

When a vehicle is moving at a certain point in time t_i with a certain speed v_i undergoing a certain acceleration ai, then there is a certain probability that in point t_{i+1} it continues moving with acceleration a_{i+1}, where a_{i+1} can indicate an acceleration, a deceleration or maintaining constant velocity. Therefore new probability matrices (velocity-acceleration-acceleration-matrix, vaa-matrix) are constructed, **Figure 5**. As an example, Figure 5 shows a vaa-reference matrix. It is plotted for the velocity v_i = 30 to 40 km/h. It depicts for a certain time ti, at speed v_i belonging to a certain velocity class the probability that acceleration a_i is followed by a subsequent acceleration a_{i+1}.

In the reference matrix the summation over all entries will give 100 %. This means the probability that a vehicle at t_i driving with a constant velocity that falls in velocity bin v_i = 30 to 40 km/h continues to drive with a constant velocity is equal to 14.1 % (see mark-up in Figure 5).

For generating a cycle with this approach it is now necessary to allocate the vaa-reference matrices absolute time fractions according to the cycle length. This means the relative probability distributions get exchanged by absolute time fractions which represent an according distribution [14].

On the left side **Figure 6** shows an example of vaa-cycle matrices for the velocity class v_i = 30 to 40 km/h. On the right side of Figure 6, it gives the resulting distribution of subsequent accelerations of the class a_i = xx to yy. Each filled square corresponds to one second with a certain subsequent acceleration class a_{i+1}. The summation of all these squares over all vaa-cycle matrices gives the desired length of the cycle. The driving cycle gets generated by means of weighted drawing of the one second time fractions of each subsequent acceleration class a_{i+1}. The end speed of each fraction is calculated according to the noted Eq. This approach is shown here, where the piecewise generation process of the driving cycle is depicted.

Analogue to Figure 4, when the addition of a one second time fragment to the driving cycle is completed, this one second is eliminated out of the subsequent acceleration class (cross in Figure 6, right). This elimination process changes the distribution of the vaa-cycle matrices and therefore the probability of occurrence. When the velocity in the driving cycle is under- or overshooting the velocity class of the current vaa-matrix the next valid velocity class is used for drawing the subsequent acceleration.

An example for a model-specific customer-based city driving cycle is depicted

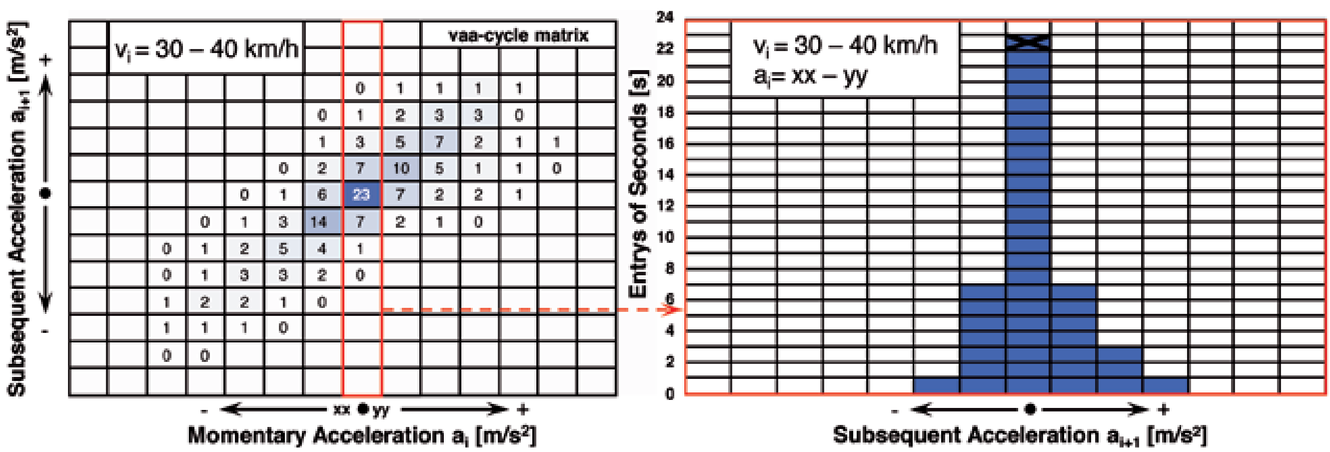

Figure 6: Possible subsequent accelerations for v_i = 30 to 40 km/h and a_i = xx to yy

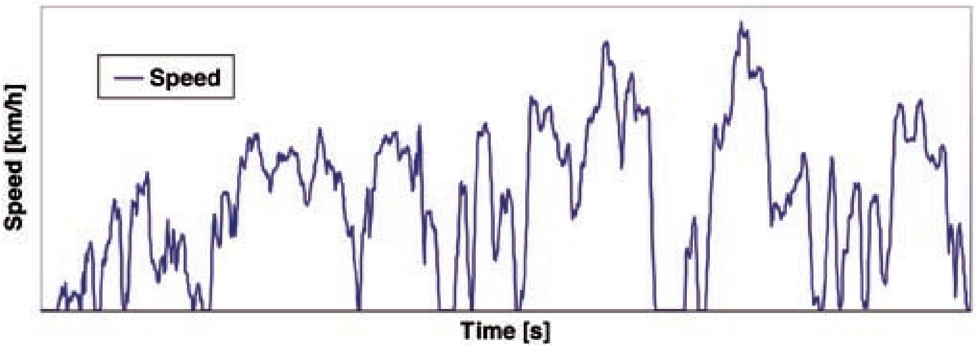

Figure 7: Example of a model-specific city driving cycle

in **Figure 7**. With the help of driving cycles like these it is now possible to integrate model specific driving behaviour in the vehicle development process.

6 Evaluation of Model-specific Measures

Combining the original measured data with the customer based driving cycles in vehicle simulations enables engineers to perform extensive technology evaluations. **Figure 8** illustrates the gap between the NEDC and a customer based driving cycle for a upper middleclass car in terms of energy flow distributions. Remarkable are the relative low driving resistance energy losses (sum of c_x*A, brake energy loss and rolling resistance) in the NEDC compared to the UMC-cycle. This can be explained by the increased demand in driving performance by the customers compared to the NEDC. Therefore in the NEDC the drive train energy losses are overestimated and the driving resistance energy losses underestimated. Figure 8 also illustrates the difference in fuel consumption between manufacturer specifications measured according to the NEDC and customer fuel consumption caused mainly by the increased demand of driving performance as well as usage of auxiliary equipment.

Optimizing the drive train will noticeably reduce the fuel consumption measured in the NEDC. However, the customer will not experience this effect in such great sense. Only if the driving resistance energy losses will be reduced too, this will lead to equal reduction in fuel consumption and only then meet the customer's expectation. Therefore it is necessary to not only define technology packages that meet legal requirements but also live up to the customer's expectation. When energy loss distributions are compared on a vehicle type specific basis peculiarities in driving behaviour for these different groups become visible, **Figure 9**.

Unsurprisingly the diesel vehicles illustrate a greater energy loss due to driving resistance than the gasoline vehicles. Diesel vehicles have a higher annual mileage than gasoline vehicles and drive more often at higher speeds on motorways. In comparison to the diesel limousines the diesel SUV drives less often at high speeds, but due to a poorer c_x*A ratio has the same driving resistance energy losses. Both natural aspirated (spark ignition, SI) engine powered vehicles demonstrate relatively high engine energy losses compared to the diesel-engine powered vehicles. The lower energy efficiency of the Otto cycle in comparison to the diesel cycle is a reason for this. In addition, SI-engine powered vehicles are mainly used on short distances, which will increase the relative energy losses due to engine heat-up.

Figure 9 demonstrates clearly the need for individual optimization of the different vehicle classes and the approach angle to be taken. For the compact class increasing engine efficiency will accomplish the highest fuel consumption reduction potential. For the diesel-engine powered vehicles of the middleclass and upper middleclass the emphasis should lie in reducing the driving resistance. For middleclass SI-engine powered vehicles and SUVs both reducing driving resistance and optimization of the drive train (engine heat-up, engine, gearbox, and differential) should be underlined.

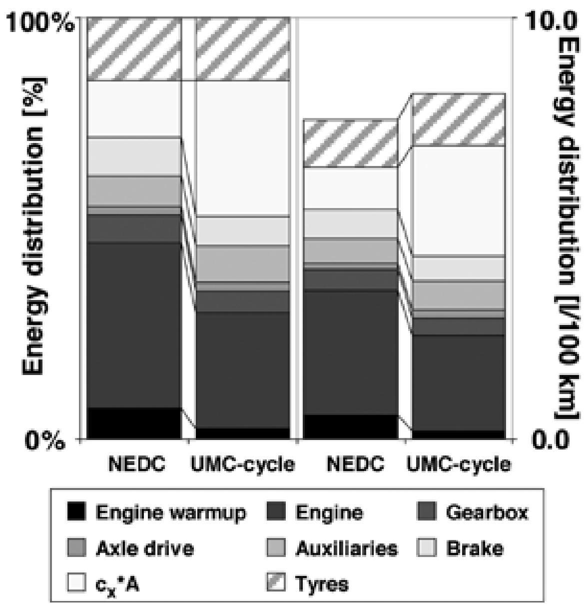

Figure 8: Energy distribution for NEDC and the customer-based UMC-cycle (the energy distribution is presented without thermal losses of the circle process)

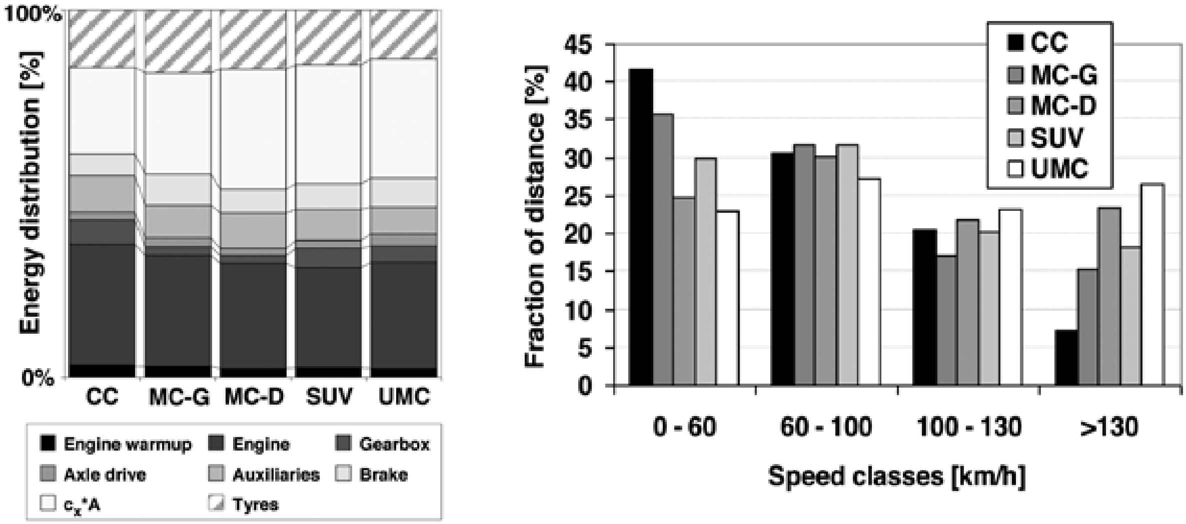

Figure 9: Energy and speed distributions for customer vehicles (the energy distribution is presented without thermal losses of the circle process)

Once more the individual effectiveness in driving cycles of the different fuel saving measures shows again **Figure 10**. This is done for mass variation and variation of air resistance reduction.

In both variance-analyses the reduction of the variable causes a reduction of fuel consumption in all driving cycles (NEDC and model-specific customer driving cycle). However the effectiveness of the variance in both cycles is notably diverse. Reducing the air resistance by ten percent results in a three times higher effectiveness by customers, depending on the model type. Reducing the vehicle weight is twice as effective for customers compared to the NEDC. Whereupon – absolutely speaking – model types with lower drive train losses will benefit most of it.

7 Summary

Car manufacturers have reached such a high optimization level that makes it necessary to implement more intensified customer demands on a model type specific level to further enhance their products. The introduced methodology, developed in corporation with the TU Dresden, the Spiegel-Institut Mannheim and the BMW Group, demonstrates the feasibility to record customer's driving behaviour in a cost and time efficient manner. For the first time model-specific unaffected customer driving behaviour can be measured, evaluated and digested based on substantial measurement data. The recorded data reveal and confirm the expected model-specific differences as well as the dissimilarities with the NEDC. Deriving model-specific customer-based driving cycles enable engineers to evaluate the efficiency of new technologies on a customer level, using modern simulation techniques. The here out forthcoming information delivers a great contribution to the internal decision-making process of car manufactures. They can now correctly define the equi-

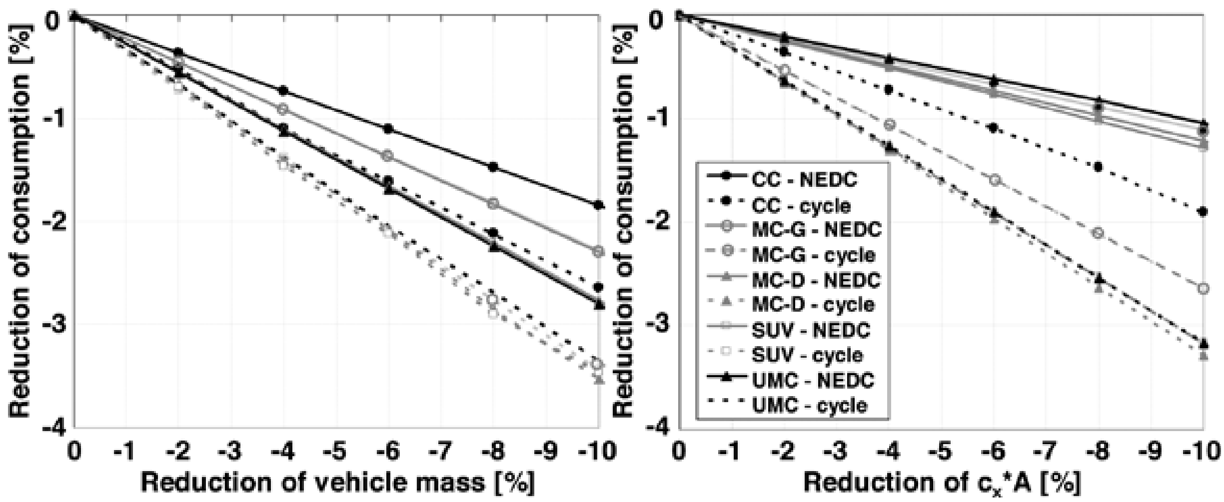

Figure 10: Model-specific mass variation of and variation of air resistance reduction

librium between customer demands and legal requirements.

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The automobile industry has already made great progress in improving fuel efficiency. This progress is monitored by a for the manufactures prescribed unified test cycle. Since this customer behaviour is determining the real fuel consumption of the vehicles it is important to implement this individual behaviour in the vehicle development process. The article describes a methodology, developed in corporation with the TU Dresden, the Spiegel-Institut Mannheim and the BMW Group, to incorporate model-specific customer's driving behaviour into the development process and the there out resulting solution approach.

1 Introduction

The momentarily increasing price of crude oil and the continuing debates about Climate Change put fuel efficiency into the focus of final customer's attention. Successfully implementing fuel efficient technologies is not only dependent on CO_2-emissions established in the New European Driving Cycle (NEDC) but mainly dependent on the real customer fuel consumption. The prescribed standardised NEDC for fuel consumption determination can only represent to some extent the individual customer driving behaviour due to set requirements like reproducibility, comparability and drivability. The development focus of engineers on the NEDC and the there out forthcoming technologies do not necessarily lead to the desired reduction in fuel consumption under normal driving conditions.

To break the tension field between set requirements, budget pressure and customer satisfaction it is necessary to integrate the customer's driving behaviour in the development process. Instead of investing in expensive complete vehicle optimization, individual cost efficient measures are identified and implemented which are most beneficial to customers.

The customer's driving behaviour is the topic of intensive research since over ten years. There are different starting points to make the driving behaviour recordable and thus usable to optimize the development process of vehicles. One possibility exists in the traffic simulation, in which the driver behaviour results from interaction between vehicle and driving environment values [1, 2, 3, 4]. Besides these, there are existing methods to describe the driver behaviour by evaluation of measured driver and driving environment values statistically [5, 6, 7, 8]. By systematically determined measuring databases thereby the driver is depicted in the prognosis-like simulation during the early stage of the development process.

The goal of the work presented here is to develop a method with which it is possible to intend the representative driving behaviour of the vehicles for a broad class of model-specific customers. The methodology, presented here by TU Dresden, the Spiegel-Institut Mannheim and the BMW Group to identify real model-specific customer driving behaviour, can be incorporated into the vehicle development process. Therefore five specifically selected models, **Table**, of the car manufacturer BMW were analysed.

2 Selection Process of Participants

For a cost-effective data acquisition where both representativity and measurement accuracy are assured, the project team decided to combine a customer questionnaire with a measurement survey of customer vehicles. Using stratified random sampling first a representative customer questionnaire was conducted with the purpose of determining representative participants for each vehicle model.

For budgetary reasons a sample of ten to twenty participants per vehicle model has been selected. In total five models were fitted with measurement equipment to record the driving behaviour over a distance of about 5,000 km per vehicle. The emphasis of the research was the fuel consumption.

Table: Overview of tested models

Tested No.	Vehicle segment	Body shape	Engine
1	Compact Class (CC)	Saloon / Sedan (Hatchback)	SI 4 Cylinder
2	Medium Class (MC-G, gasoline)	Saloon / Sedan	SI 4 Cylinder
3	Medium Class (MC-D, diesel)	Saloon / Sedan	Diesel 4 Cylinder
4	Sports utility vehicle (SUV)	Sports utility vehicle (SUV)	Diesel 6 Cylinder
5	Upper Medium (UMC)	Saloon / Sedan	Diesel 6 Cylinder

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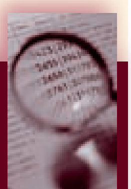

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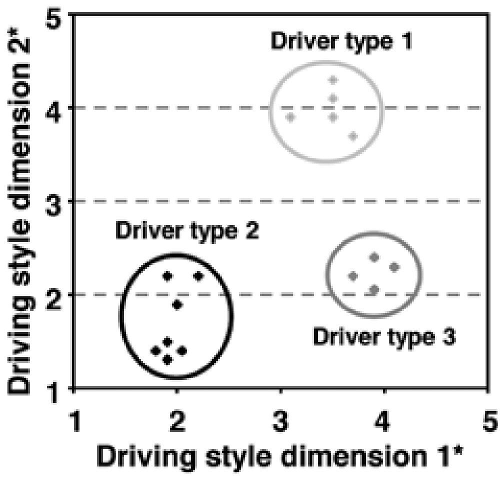

Figure 1: Example of a cluster analysis and derived driver types (* idealized example data for two driving style dimensions were used)

2.1 Used Sample Selection Process: Stratified Random Sampling

The selected participant sample should if possible cover the complete driver spectrum for each model. A complete random sampling process using a limited amount of participants can not guarantee this distribution. It can be expected that the distribution of relevant parameters in a small random sample will be different to the distribution of the same parameters in the basic population. To avoid a to strong deviation a stratified random sampling process is the established approach [9].

With stratified random sampling, the population is first divided into a number of parts or ‚strata' according to certain characteristics, chosen to be related to the major parameters being studied, beneath age, gender and fraction of company cars.

To incorporate driving style in the sampling process, it was chosen as one of the stratification variables. In the following the selection of acceleration and velocity level as well as the vehicle operations, gear-, throttle-, and brake paddle control are referred to as driving style. Its enormous influence on fuel consumption was analysed many times before. Through deliberate driving style training one can achieve fuel consumption reductions of 10 % or more [10].

2.2 Methodology for Determining the Type of Driving Style

Following a qualitative preliminary study the Spiegel-Institut Mannheim developed a questionnaire to detect driving style. These items were conducted in a twenty minute telephone interview (CATI) with 200 till 300 drivers of each vehicle model. The CATI participants where already grouped according to stratification variables like gender, age and whether the vehicle is privately owned or it is a company car to represent the customer distribution of the total population.

Using cluster analysis, the individual participants who demonstrate a comparable characteristic pattern in the driving style dimensions where grouped, **Figure 1**. These collections will be referred to as driver types in the following. The analogy between participants is largest within a collection and smallest between the collections.

From every group of driver types, Figure 1, representative members are chosen who have the smallest distance to the cluster middle point; also taking other stratification criteria like gender, age, etc into consideration. Due to the small sample size from every dimension an equal amount of members are chosen, as general rule five members per driver type group. The recorded vehicle data got evaluated by means of weighted analysis taking into account the group-type distribution ("disproportionate sample" [11]). On one hand, this approach ensures that the variation of the parameter driving style in the sample is the same or similar to its variation in the total population, on the other hand, disruptive factors due to deviation from the mean vehicle usage are kept to a minimum.

2.3 Comparison of Driver Types Based on the Questionnaire and Measurement Data

During the comparison of the model-specific driver types it became noticeable that these types diverge significantly from each other with respect to:

- time driven per day
- daily mileage
- yearly mileage
- fuel consumption (especially out of town)
- customer fuel consumption satisfaction.

From these results it can be concluded that "driver type" as stratification criteria is a legitimate parameter for sample building for vehicle data acquisition. A comparison of the customer data with the derived driver types shows that there is a significant difference in fuel consumption for the individual driver types of the middleclass vehicle segment, regardless of the diminutive sample size.

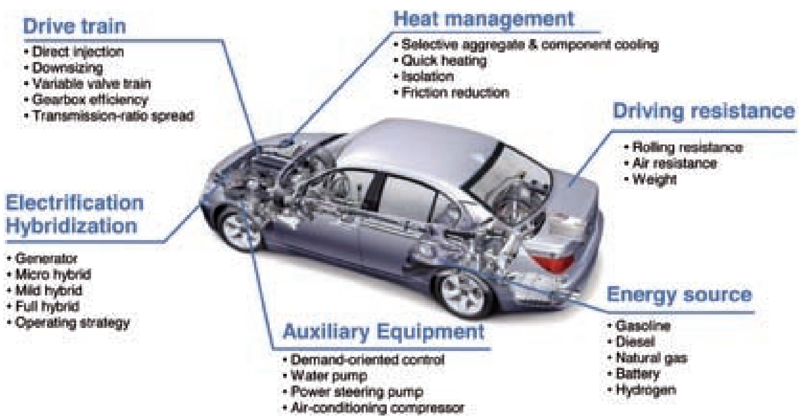

Figure 2: Areas and approaches of fuel consumption reduction

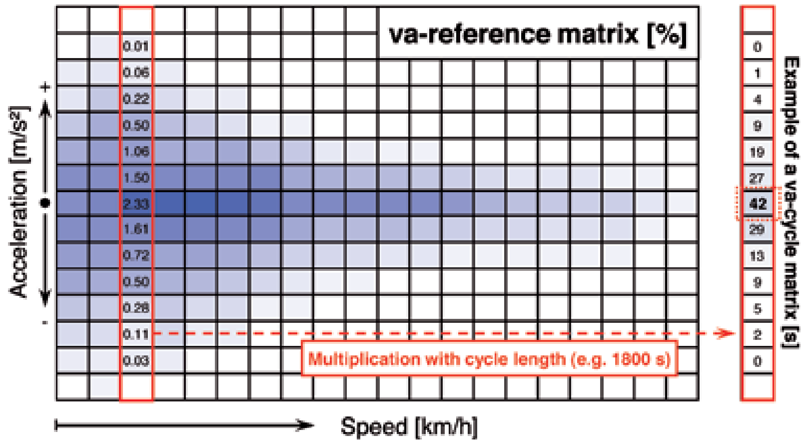

Figure 3: Time sections of the va-reference matrix in % (example compact vehicle class)

3 Measurement Equipment

CAN-bus systems in today's vehicles offer an easy access to the vehicle status variables relevant for the driving behaviour. With variables like speed, longitudinal- and transversal acceleration as well as several engine variables and comfort functions like air conditioning usage the driving behaviour of a driver can be documented. For the data acquisition M-LOG data loggers of Ipetronik have been used. These were typically mounted in the glove compartment box of the vehicles. The power supply for the equipment is provided by the vehicle's board net. A typical measurement would start by switching on the ignition and continue until the engine is switched off.

Afterwards the data would be transferred using GPRS via a GSM-network to an internet server. For this purpose a little antenna was stuck to the front screen of the vehicle. An FTP connection made it possible to transfer the data from the server and translate it into a format suitable for evaluation. All together, over 65,000 trips and 580,000 km were recorded.

4 Possible Application Fields of the Data

Using the acquired data multiple technical queries can be answered. Until now the effectiveness of certain fuel saving technologies depicted in **Figure 2** could only be determined in the NEDC by using recorded data. Now this can also be evaluated under real driving conditions. Performing statistical analysis alone will not be the winning solution. The combination of real life data with detailed vehicle simulation gives information over the fuel saving potential of the different technologies. Therefore customer driving cycles need to be generated, which represent the customer's driving behaviour in the simulations and on dynamometers.

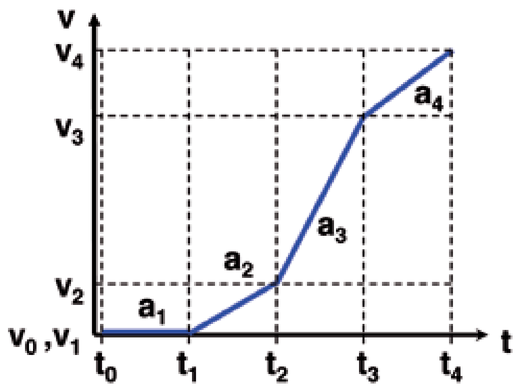

Figure 4: Piecewise calculation of velocities

5 Generating Customer Driving Cycles

Beside dynamometer measurements nowadays it is common practice as part of the development process to calculate fuel consumption and the effectiveness of new technologies using vehicle simulation tools. This enables engineers to evaluate certain development potentials for customer fuel efficiency as early as in the concept phase. Being able to feed this demand a methodology has been developed to generate representative model-specific customer driving cycles in a straightforward manner.

5.1 Theory Behind Cycle Generation

There are several approaches for the generation of driving cycles; some are more arbitrary, others require demanding statistical methods [12]. Using parameters like average speed and acceleration, stationary time etc. driving cycles can either be created synthetically or built from real life velocity progression plots which are fitted together in a way that they represent the desired driving behaviour.

5.2 Description Criteria for Driving Cycles

Our research has revealed that three-dimensional velocity-acceleration-matrices (va-matrix) are best used to describe a driving cycle, **Figure 3**, since from the va-matrix all other parameters (like average speed, average acceleration, etc.) can be derived [13]. These time partitions are then accredited to specific velocity and acceleration bins based on their affiliation with this bin. The transformation to relative fragments is made to clarify the visualisation in the graphs.

When a driving cycle is created that has the same distribution of time fractions in his va-matrix as the reference va-matrix (input data), then all important cycle parameters will be representative (average speed, average acceleration, velocity- and acceleration distribution, etc.). This aim can be reached using preset acceleration intervals, **Figure 4**, to calculate the resulting end speed at the end of such an interval – using the equation

$$v_{i+1} = v_i + a_{i+1} \cdot \Delta t \qquad \text{Eq.}$$

then concatenating these intervals will build the desired velocity-time curve. In

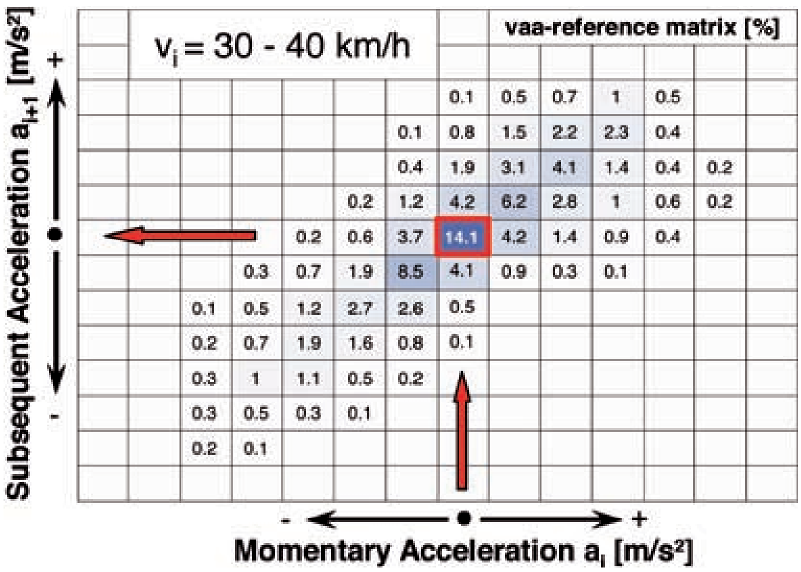

Figure 5: vaa-reference matrix (example compact vehicle class)

the infinite variation possibilities of the last approach lies the challenge to develop a certain systematic that generates physically sensible velocity-time curves and reflects the time fractions from the reference va-matrix.

5.3 Methodology for Generating Driving Cycles

When a vehicle is moving at a certain point in time t_i with a certain speed v_i undergoing a certain acceleration ai, then there is a certain probability that in point t_{i+1} it continues moving with acceleration a_{i+1}, where a_{i+1} can indicate an acceleration, a deceleration or maintaining constant velocity. Therefore new probability matrices (velocity-acceleration-acceleration-matrix, vaa-matrix) are constructed, **Figure 5**. As an example, Figure 5 shows a vaa-reference matrix. It is plotted for the velocity v_i = 30 to 40 km/h. It depicts for a certain time ti, at speed v_i belonging to a certain velocity class the probability that acceleration a_i is followed by a subsequent acceleration a_{i+1}.

In the reference matrix the summation over all entries will give 100 %. This means the probability that a vehicle at t_i driving with a constant velocity that falls in velocity bin v_i = 30 to 40 km/h continues to drive with a constant velocity is equal to 14.1 % (see mark-up in Figure 5).

For generating a cycle with this approach it is now necessary to allocate the vaa-reference matrices absolute time fractions according to the cycle length. This means the relative probability distributions get exchanged by absolute time fractions which represent an according distribution [14].

On the left side **Figure 6** shows an example of vaa-cycle matrices for the velocity class v_i = 30 to 40 km/h. On the right side of Figure 6, it gives the resulting distribution of subsequent accelerations of the class a_i = xx to yy. Each filled square corresponds to one second with a certain subsequent acceleration class a_{i+1}. The summation of all these squares over all vaa-cycle matrices gives the desired length of the cycle. The driving cycle gets generated by means of weighted drawing of the one second time fractions of each subsequent acceleration class a_{i+1}. The end speed of each fraction is calculated according to the noted Eq. This approach is shown here, where the piecewise generation process of the driving cycle is depicted.

Analogue to Figure 4, when the addition of a one second time fragment to the driving cycle is completed, this one second is eliminated out of the subsequent acceleration class (cross in Figure 6, right). This elimination process changes the distribution of the vaa-cycle matrices and therefore the probability of occurrence. When the velocity in the driving cycle is under- or overshooting the velocity class of the current vaa-matrix the next valid velocity class is used for drawing the subsequent acceleration.

An example for a model-specific customer-based city driving cycle is depicted

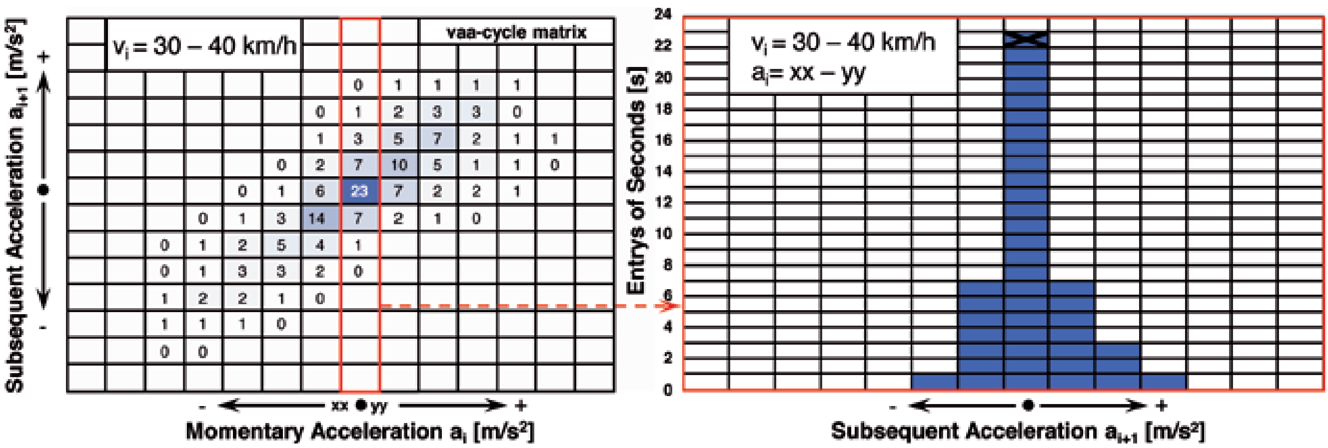

Figure 6: Possible subsequent accelerations for v_i = 30 to 40 km/h and a_i = xx to yy

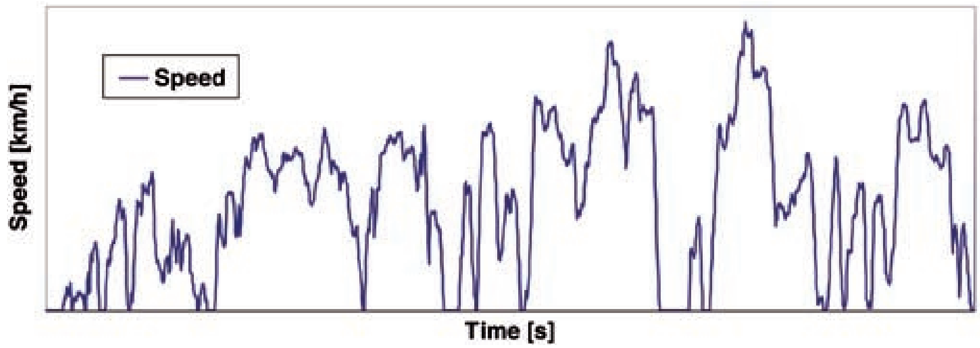

Figure 7: Example of a model-specific city driving cycle

in **Figure 7**. With the help of driving cycles like these it is now possible to integrate model specific driving behaviour in the vehicle development process.

6 Evaluation of Model-specific Measures

Combining the original measured data with the customer based driving cycles in vehicle simulations enables engineers to perform extensive technology evaluations. **Figure 8** illustrates the gap between the NEDC and a customer based driving cycle for a upper middleclass car in terms of energy flow distributions. Remarkable are the relative low driving resistance energy losses (sum of c_x*A, brake energy loss and rolling resistance) in the NEDC compared to the UMC-cycle. This can be explained by the increased demand in driving performance by the customers compared to the NEDC. Therefore in the NEDC the drive train energy losses are overestimated and the driving resistance energy losses underestimated. Figure 8 also illustrates the difference in fuel consumption between manufacturer specifications measured according to the NEDC and customer fuel consumption caused mainly by the increased demand of driving performance as well as usage of auxiliary equipment.

Optimizing the drive train will noticeably reduce the fuel consumption measured in the NEDC. However, the customer will not experience this effect in such great sense. Only if the driving resistance energy losses will be reduced too, this will lead to equal reduction in fuel consumption and only then meet the customer's expectation. Therefore it is necessary to not only define technology packages that meet legal requirements but also live up to the customer's expectation. When energy loss distributions are compared on a vehicle type specific basis peculiarities in driving behaviour for these different groups become visible, **Figure 9**.

Unsurprisingly the diesel vehicles illustrate a greater energy loss due to driving resistance than the gasoline vehicles. Diesel vehicles have a higher annual mileage than gasoline vehicles and drive more often at higher speeds on motorways. In comparison to the diesel limousines the diesel SUV drives less often at high speeds, but due to a poorer c_x*A ratio has the same driving resistance energy losses. Both natural aspirated (spark ignition, SI) engine powered vehicles demonstrate relatively high engine energy losses compared to the diesel-engine powered vehicles. The lower energy efficiency of the Otto cycle in comparison to the diesel cycle is a reason for this. In addition, SI-engine powered vehicles are mainly used on short distances, which will increase the relative energy losses due to engine heat-up.

Figure 9 demonstrates clearly the need for individual optimization of the different vehicle classes and the approach angle to be taken. For the compact class increasing engine efficiency will accomplish the highest fuel consumption reduction potential. For the diesel-engine powered vehicles of the middleclass and upper middleclass the emphasis should lie in reducing the driving resistance. For middleclass SI-engine powered vehicles and SUVs both reducing driving resistance and optimization of the drive train (engine heat-up, engine, gearbox, and differential) should be underlined.

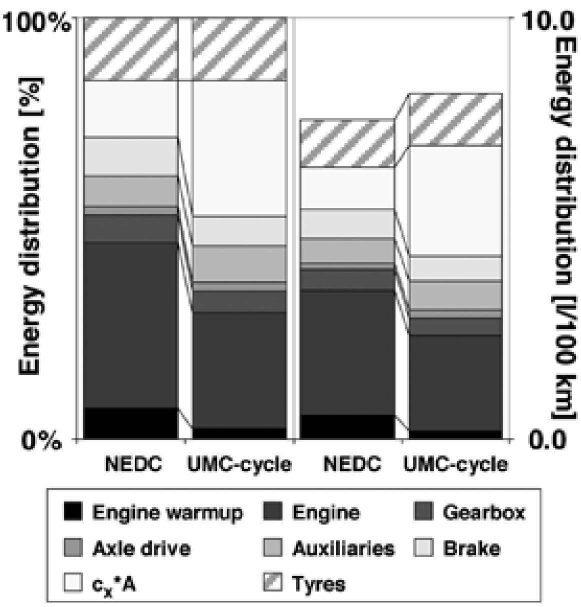

Figure 8: Energy distribution for NEDC and the customer-based UMC-cycle (the energy distribution is presented without thermal losses of the circle process)

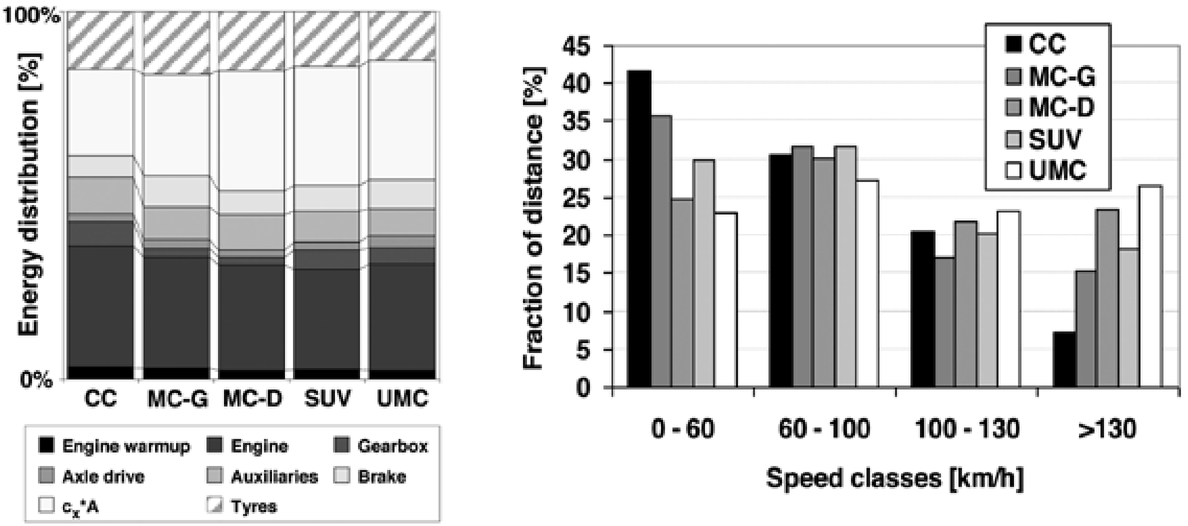

Figure 9: Energy and speed distributions for customer vehicles (the energy distribution is presented without thermal losses of the circle process)

Once more the individual effectiveness in driving cycles of the different fuel saving measures shows again **Figure 10**. This is done for mass variation and variation of air resistance reduction.

In both variance-analyses the reduction of the variable causes a reduction of fuel consumption in all driving cycles (NEDC and model-specific customer driving cycle). However the effectiveness of the variance in both cycles is notably diverse. Reducing the air resistance by ten percent results in a three times higher effectiveness by customers, depending on the model type. Reducing the vehicle weight is twice as effective for customers compared to the NEDC. Whereupon – absolutely speaking – model types with lower drive train losses will benefit most of it.

7 Summary

Car manufactures have reached such a high optimization level that makes it necessary to implement more intensified customer demands on a model type specific level to further enhance their products. The introduced methodology, developed in corporation with the TU Dresden, the Spiegel-Institut Mannheim and the BMW Group, demonstrates the feasibility to record customer's driving behaviour in a cost and time efficient manner. For the first time model-specific unaffected customer driving behaviour can be measured, evaluated and digested based on substantial measurement data. The recorded data reveal and confirm the expected model-specific differences as well as the dissimilarities with the NEDC. Deriving model-specific customer-based driving cycles enable engineers to evaluate the efficiency of new technologies on a customer level, using modern simulation techniques. The here out forthcoming information delivers a great contribution to the internal decision-making process of car manufactures. They can now correctly define the equi-

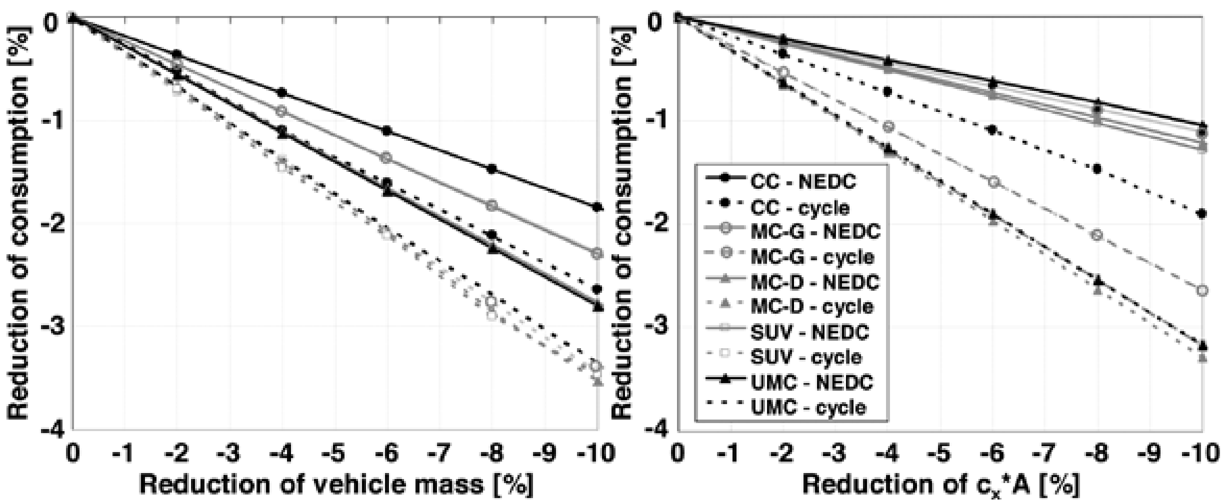

Figure 10: Model-specific mass variation of and variation of air resistance reduction

librium between customer demands and legal requirements.

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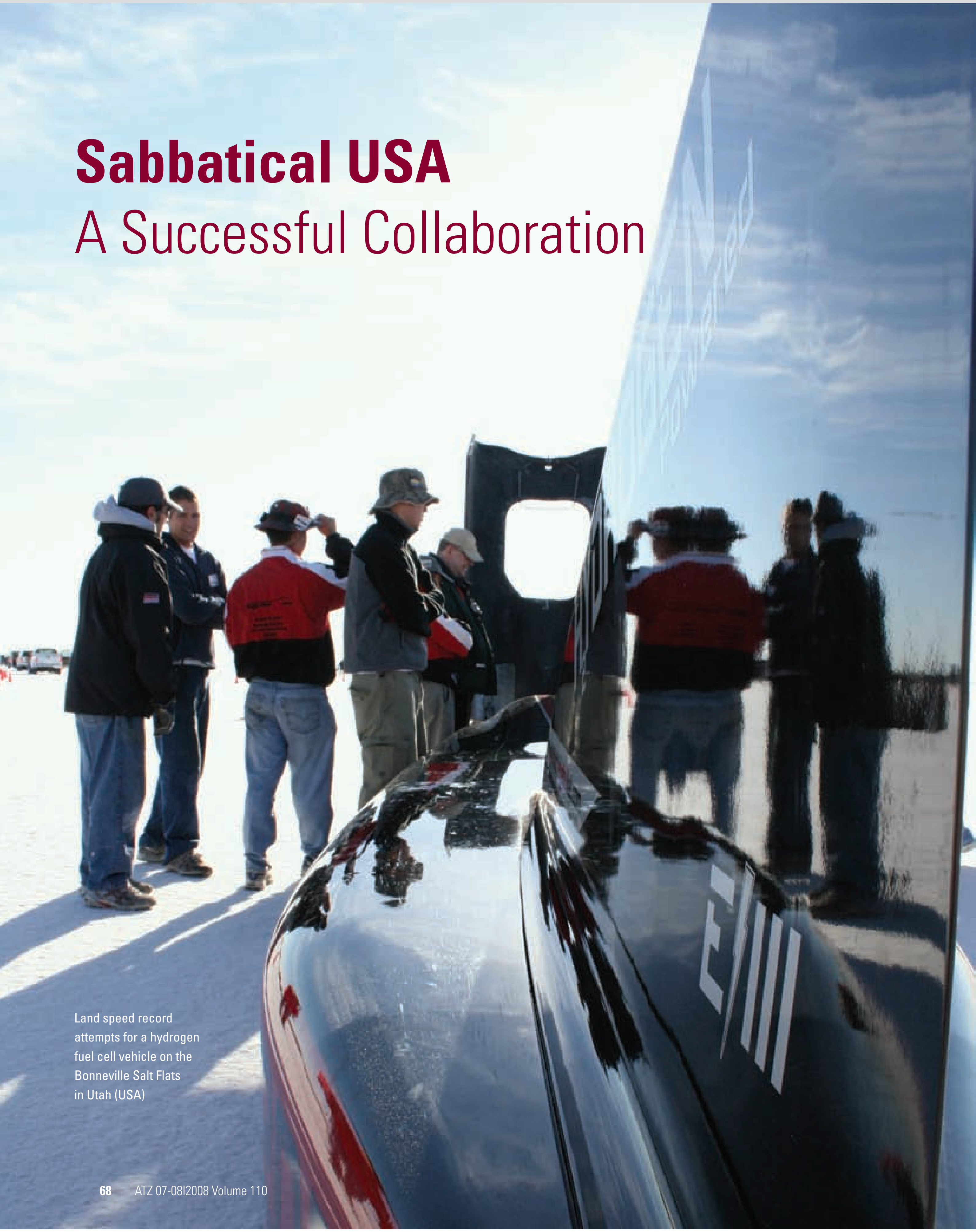

Land speed record attempts for a hydrogen fuel cell vehicle on the Bonneville Salt Flats in Utah (USA)

This report documents the six-month visit of Prof. Dr.-Ing. Michael Bargende in the USA to the Ohio State University (OSU) at the Center for Automotive Research (CAR) as part of his sabbatical leave from Universität Stuttgart. Normally he teaches and conduct research projects at the German Institut für Verbrennungsmotoren und Kraftfahrwesen (IVK/FKFS) at the University Stuttgart. For half a year Bargende learned much from the CAR director Prof. Giorgio Rizzoni about the structure and organization of US universities, and experienced the „American way of life".

Introduction

The first contact between Prof. Bargende and CAR dates ten years back, when he became acquainted with colleagues at OSU in 1999 through the General Motors Technical Education Program – an organization that promotes the continuing education of GM employees. This initial encounter led to collaborations in education, with the joint development of educational material for courses in automotive powertrain systems. In 2003, FKFS and CAR signed a Memorandum of Understanding detailing a research collaboration concerning fuel atomization technology for Diesel HCCI applications. Between 2003 and 2007, FKFS and CAR exchanged visits on a regular basis; in particular, Prof. Bargende and Mr. Hannes Berner of FKFS as well as Profs. Guezennec and Rizzoni and Dr. Shawn Midlam-Mohler of CAR each spent time at the partner institution. In 2007 Prof. Rizzoni spent a six-month sabbatical at Politecnico di Milano and Politecnico di Torino, and during this time visited FKFS and suggested a sabbatical leave for Prof. Bargende as a possible means of strengthening the relationships between these two institutes.

Background

The worldwide automotive industry is facing unprecedented challenges due to globalization, projected energy shortages, climate change, the environmental impact of vehicles, and traffic congestion. These challenges, coupled with an increasingly competitive business environment, are forcing reductions in work force and production costs while complexity and demand for quality increase steadily.

In this context, a need has arisen for collaborative initiatives in support of the automotive industry among research institutes located in different markets and experienced in their specific needs.

CAR has reached a position of leadership in North America in developing relations with the key industry players. FKFS holds the same position in Germany and Western Europe. Therefore, collaboration between these organizations is only logical.

CAR and FKFS work in similar areas of automotive research and engineering services. The two institutes have a comparable size vis-à-vis personnel, equipment and resources and – most important – an identical vision of future challenges in automotive research and development. This vision includes delivering high quality engineering services to the automotive industry.

A focused collaboration between these two institutes is logical, as together they can better assist and serve automotive companies with a presence in both markets in facing the tremendous technical changes and challenges. Among future challenges to the industry we note hybrid drivetrains and electric vehicles, HCCI diesel and HCCI gasoline IC engines, intense usage of gaseous fuels like compressed natural gas (CNG) and later hydrogen, high fidelity solutions for driving resistance reduction, and new materials. On the other hand, simple and intelligent technical solutions are mandatory to serve the needs for affordable transportation in emerging markets, such as India and China. The new Indian low-cost Nano car by Tata Motors is only the beginning of this trend.

These developments will inevitably influence future engineering curricula in the United States and in Germany. CAR and FKFS will insure that OSU and Universität Stuttgart continue to extend their leadership in the education of a

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Prof. Dr.-Ing. Giorgio Rizzoni is director of the Center for Automotive Research (CAR) at the Ohio State University (OSU) in Columbus, Ohio (USA).

Figure: Signing Ceremony of the Memorandum of Agreement between CAR and FKFS on February 2008; from left to right: Prof. Baeslack (OSU), Prof. Bargende (FKFS), Prof. Rizzoni (CAR), Prof. Blum (FKFS), Konsul Kübler (FKFS)

new generation of automotive industry engineers.

Prof. Bargende's Visit

During his six-month stay at the OSU, from October 2007 through March 2008, Prof. Bargende spent a considerable amount of time learning the academic, research and administrative structure of a major US university. He met with deans, department chairs and other university officials, and directly interacted with faculty, researchers and students. His understanding of US engineering education and of sponsored research in the USA was greatly enhanced by these interactions.

Prof. Bargende participated directly in research projects and provided invaluable advice to students and researchers in projects related to powertrain modeling and control. In addition, he digitally recorded video material for short courses in advanced engine technology for use in the OSU-CAR Distance Education program.

He had the unique experience to attend the World Finals events at the Bonneville Salt Flats, the venue of many land speed records (LSR) attempts since the 1950s. The Bonneville Salt Flats are located at the western end of the state of Utah, near the Nevada border, at an altitude of 1800 m. The expanse of the perfectly flat salt-covered surface and the low air density make Bonneville an ideal location for land speed records. Students from the Ohio State University were at Bonneville in October 2007 to attempt a LSR for hydrogen fuel cell vehicles with Buckeye Bullet 2, a 12-m streamliner that set the FIA records for the flying km and flying mile.

Prof. Bargende also presented two very successful seminars at OSU:

- "Homogeneous Charge Compression Ignition in Diesel and Gasoline Engines – Requirements and Potential". OSU CAR seminar, January 15th, 2008.
- "Proudly Introducing: Nickolaus Rudolf Diesotto, Engine of the Future – a Few Remarks about Future Propulsion Systems". Graduate seminar at OSU Department of Mechanical Engineering, January 18th, 2008.

He was involved in organizing various industry visits to CAR, including General Motors, Mahle, and Borg Warner. He participated in many visits and presentations by CAR industrial sponsors, and had a very active role during the semi-annual CAR External Advisory Board meeting in October 2007.

The highlight of Prof. Bargende's sabbatical was a visit to Columbus by the Rektor of Universität Stuttgart, Prof. Wolfram Ressel, in Columbus on February 14th, 2008. On the occasion of this visit, Prof. Ressel and OSU President E. Gordon Gee signed a Memorandum of Agreement between the two universities. This was accompanied by analogous agreements between the OSU College of Engineering and the Faculty of Mechanical Engineering at Universität Stuttgart, as well as an agreement between CAR and FKFS, **Figure**. The visit gave all of the participants the opportunity to exchange ideas and future directions for this partnership.

The Center for Automotive Research

The Ohio State University (OSU) Center for Automotive Research (CAR) in Columbus, USA, is an interdisciplinary center in the College of Engineering. The center is located in a 3,500 m^2 building on the west campus of OSU. CAR conducts interdisciplinary research in collaboration with faculty in the colleges of OSU. It aims to:

- develop energy efficient propulsion systems for the future
- develop new sustainable mobility concepts
- reduce the impact of vehicles on the environment
- improve vehicle safety and reduce occupant and pedestrian injuries
- increase vehicle autonomy and control
- create quieter and more comfortable automobiles.

CAR works in partnership with most major automotive manufacturers and top-tier suppliers. Its government sponsors include the US Department of Energy, the US Department of Transportation, the National Science Foundation and the US Army.

In addition, the Center is involved in graduate education programs culminating in a Graduate Specialization in "Automotive Systems Engineering" and is the home of the Graduate Automotive Technology Education (GATE) Center on Advanced Propulsion Systems, one of eight national centers of excellence established by the US Department of Energy.

Research Institute of Automotive Engineering and Vehicle Engines Stuttgart

The Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart (FKFS, Research Institute of Automotive Engineering and Vehicle Engines Stuttgart) is was established in 1930 in Stuttgart, Germany, as a non-profit foundation and cooperates closely today with the University of Stuttgart's Institute of Combustion Engines and Automotive Engineering (IVK) an many international universities. Public and own-sponsored research activities but also the direct implementation in teaching at the Universität Stuttgart complement the tasks of the institute as a link between both research & development studies and customer projects.

150 employees offer support in simulation, vehicle dynamics, road load studies, NVH, thermodynamics, automotive electronic systems, communication and power networks, alternative vehicle and powertrain concepts. Aims of the FKFS are

– the reduction of emissions simultaneously optimizing the economy and lifetime of all driving
– the advanced development of vehicle efficiency and vehicle comfort
– the increase of active and passive safety.

Various test facilities and vehicles are operated by FKFS, for example a aero-acoustics full-scale and a 1:4/1:5 model-scale wind tunnel, 19 engine test rigs. For analysis own-developed measuring and testing techniques are used. A long-time know-how with development and application of simulation tools complement the portfolio.

Plans

Several concrete steps have resulted from Prof. Bargende's visit to the CAR. OSU and Universität-Stuttgart students have already planned to conduct overseas internships this summer. Further, with the changes under way in the German system of higher education (Bologna process), it is likely that the two institutions will also share graduate courses in their areas of specialty.

In addition to the educational component of the partnership, CAR and FKFS are already actively seeking industry partners to sponsor joint projects. Increasing interest in diesel technology in North America and in hybrid-electric propulsion technology in Europe will certainly provide opportunities for such research collaborations.

Conclusion

Prof. Bargende's American sabbatical at the The Ohio State University (OSU) Center for Automotive Research (CAR) in Columbus was the culmination of many years of partnership. The visit was truly successful in launching this collaboration to new heights. The extended duration of the visit gaves him the opportunity to directly participate in CAR research programs sponsored by the North American auto industry, to work with Ohio State University graduate students and to understand the US university system at many different levels, from undergraduate to graduate instruction, and from sponsored research to administration.

Finally, Prof. Bargende also served as a conduit between CAR and European auto companies, just in the same way in which CAR included him in interactions with its North American industry sponsors. The result of this exchange is a deeper understanding of the operation of the two institutes, and a much stronger and effective partnership will result from this experience. ■

Acknowledgement

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