personal buildup for

Force Motors Ltd.

ATZ .worldwide 10/2009, as epaper released on 24.09.2009
http://www.atz-worldwide.com

content:

ATZ WORLDWIDE
10 | October 2009 Volume 111
www.ATZonline.com

Electric Steering in Vehicles Top Segment

Lightweight Cockpits

FEA Simulation of Truck Seat Structures for Crash Testing

Human Machine Interfaces – Enhanced Usability in Interior

Crash Test for Tata Nano

Automated Testing on Exhaust Emission Dynamometers

Combination of Human- and Hardware-in-the-Loop Testing

Multidisciplinary Simulation of Vehicles

INTERVIEW

»I see great potential for CNG, especially in India«
Dr. Peter Reif, Magna Steyr

The New VW Transporter

For more information visit:
www.ATZonline.com

COVER STORY

The New VW Transporter

4
A new version of the fifth generation of the **Transporter** model series from Volkswagen Commercial Vehicles has its focus on a new range of engines and upgrades for the electrical and electronic systems. Exterior highlights include a new design for the front end, headlights and mirrors.

More Passion Please!

Dear Reader,

A manager friend of mine recently asked me why Volkswagen is so successful. I thought about it for a moment and answered: „Because they do everything they can to build the best car in every class and in every segment.“ I could also have said: „Because, for two decades now, Wolfsburg has been characterised by passionate engineers and not by financial managers.“

I admit that this is a rather simplified view. Firstly, Wolfsburg also has tight financial management. In the future, only three platforms will be used across the entire Group (with the exception of a few special sports cars). Secondly, many other car plants throughout the world have their share of excellent engineers – but their efforts are often thwarted by corporate politicians. Thirdly, a company‘s ownership structure plays a key role in its long-term thinking. In other words: with private equity breathing down its neck, Volkswagen would never have been able to pursue such a strategy. The DSG, for example, was developed not only because of its technical benefits but also to make use of surplus capacity in an existing transmission plant. If the owners had been financial investors, they would certainly have sold the plant off.

We can be envious of the success of others – but it won‘t stop Volkswagen becoming the world‘s biggest car maker. Or we can learn from it: passion, coupled with expertise and good ideas, results in successful premium products.

Please feel free to contradict me.

Johannes Winterhagen
Frankfurt/Main, 8 September 2009

P. S.: „Premium Lives!“ is the motto of the latest issue of our magazine Automotive Agenda, which was recently awarded the accolade of Business Medium of the Year 2009. Also the result of passionate commitment, by the way.

Johannes Winterhagen
Editor-in-Chief

ATZ WORLDWIDE
10|2009

Organ of the VDI-Gesellschaft Fahrzeug- und Verkehrstechnik (FVT)

Organ of the Forschungsvereinigung Automobiltechnik e. V. (FAT) and of the Normenausschuss Kraftfahrzeuge (FAKRA) in the DIN Deutsches Institut für Normung e. V.

Organ of the Wissenschaftliche Gesellschaft für Kraftfahrzeug- und Motorentechnik e. V. (WKM)

New Version of the Transporter Model Series from Volkswagen Commercial Vehicles

A new version of the fifth generation of the Transporter model series from Volkswagen Commercial Vehicles will hit the roads in the autumn of 2009, with a focus on a new range of engines and upgrades for the electrical and electronic systems. Exterior highlights include a new design for the front end, headlights and exterior mirrors. The interior has also been considerably upgraded using the very latest components from the Volkswagen Group.

1 Development Objectives

Volkswagen Commercial Vehicles is the market leader in Europe and in Germany with the Transporter series in its class. More than one million units of the fifth model generation – known internally as the T5 – have already been built, which is clear evidence of its success. The new version, which will be available in the autumn of 2009, has undergone extensive improvements, focusing on utility, running costs and reliability for both commercial and private customers.

The highly successful concept of the Transporter model series, which is based on variety and flexibility, has been retained. The basic dimensions of the Transporter also remain unchanged. Taking into account all the body variants, engine and transmission combinations and wheelbases, around 460 basic versions of the vehicle are currently produced as standard at Volkswagen's commercial vehicle production sites in Hanover and Poznan. As a result, the T5 with all its model ranges is the vehicle family with the largest number of variants in the Volkswagen Group.

One of the main enhancements to the T5 involved the redesign of the powertrain components. As one of the world's leading manufacturers of diesel engines, Volkswagen is providing new TDI engines for the T5. These engines offer low fuel consumption and compliance with the Euro 5 emissions standard. Another area of emphasis was the adaptation of the new body electronics and electrics systems that are already widely used in other Volkswagen models. On this basis, various new vehicle functions and infotainment systems are now available.

The new front end reflects Volkswagen's brand face. Fresh colours, new trim and a wide range of model upgrades and quality improvements add the finishing touches to the new Transporter.

2 The New Range of Engines

In future, the diesel engines for the T5 will be based on the 2.0 litre, common rail TDI engine that has been successfully introduced into other Volkswagen vehicles, **Figure 1**. The previous range of four- and five-cylinder engines is being completely replaced by only one basic engine, while at the same time the range of engine power options available is being increased. This represents the logical extension to Volkswagen's commercial vehicle range of its successful, long-term downsizing strategy, which aims to improve efficiency.

One highlight is the turbocharging system for the top-of-the-range engines. For the first time, Volkswagen is using regulated, two-stage turbocharging for the Transporter model series. This technology meets customers' requirements for increased power at low engine speeds combined with low fuel consumption.

Because the Transporter is used for such a wide variety of different applications, it is important that it has a balanced range of engine features in order

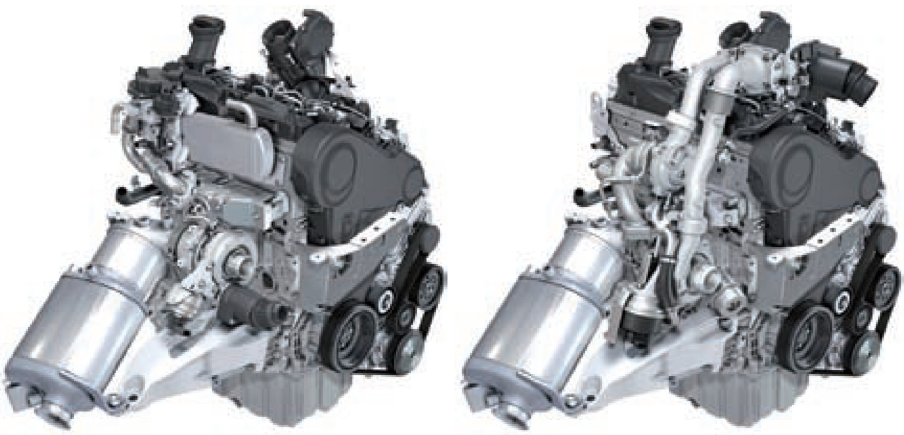


Figure 1: The new 2.0 litre, common rail TDI engine for the T5 (left, mono-turbo with a VTG turbocharger producing 62 to 103 kW; right, bi-turbo producing 132 kW)

The Authors

Dr. Wolfgang Schreiber is Executive Vice President Product Development at Volkswagen Commercial Vehicles in Wolfsburg (Germany).

Dr. Holger Westendorf is Head of Product Development Model Lines at Volkswagen Commercial Vehicles in Wolfsburg (Germany).

Hans Rohlfing is Head of Product Development Model Line T at Volkswagen Commercial Vehicles in Wolfsburg (Germany).

Stephen Neumann is Head of Technical Projectmanagement Model Line T at Volkswagen Commercial Vehicles in Wolfsburg (Germany).

Sarah Manske is Employee Technical Projectmanagement Model Line T at Volkswagen Commercial Vehicles in Wolfsburg (Germany).

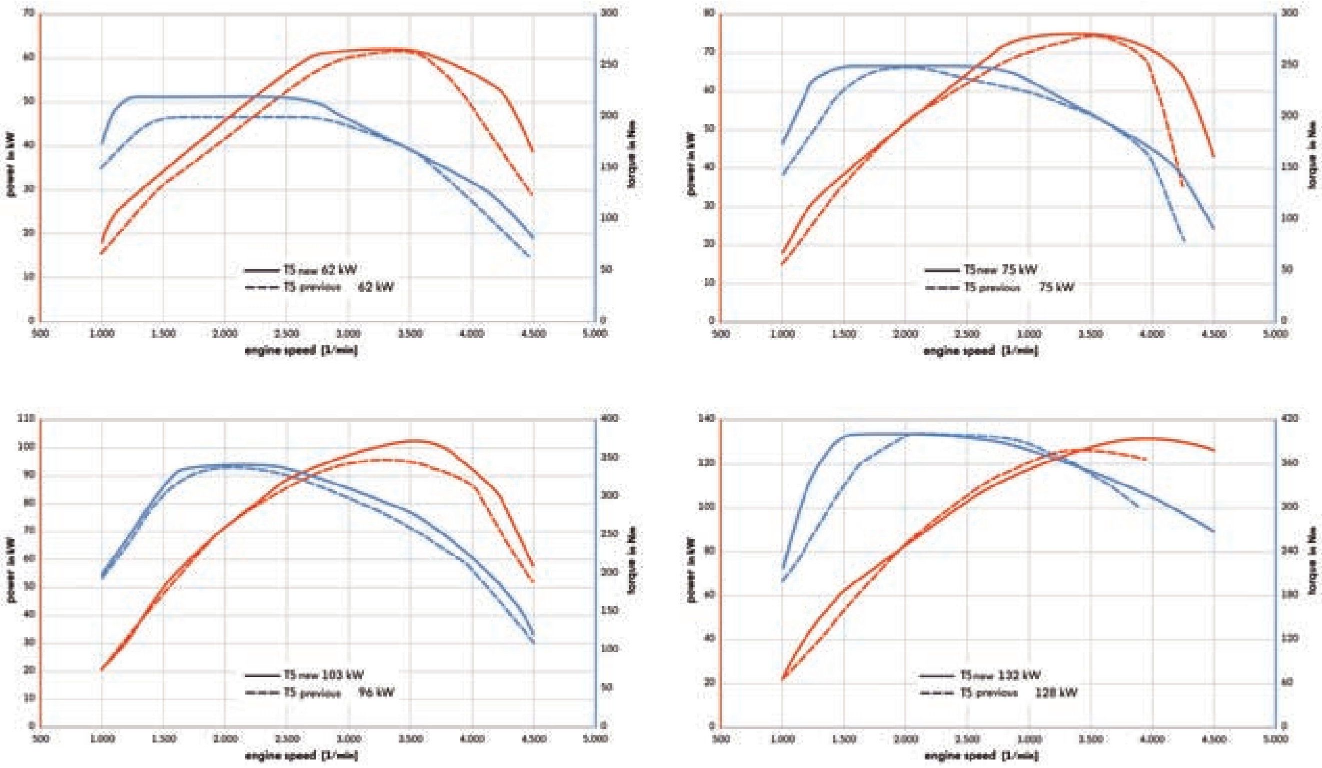


Figure 2: Power and torque curve of the new engines compared with previous versions

to provide the ideal engine for every customer. In spite of the focus on one basic engine, each engine version represents an improvement over the previous model in all the areas which are important to customers, such as performance, fuel consumption, emissions and acoustics, **Figure 2**, **Table 1** and **Table 2**. The current engines are available with power outputs ranging from 62 to 132 kW and torque ranging from 220 to 400 Nm. In addition, the proven 2.0 litre MPI four-cylinder petrol engine, which produces 85 kW and complies with the Euro 5 emissions standard, is still available.

The average fuel consumption and therefore the CO_2 emissions of the Transporter range have been reduced by

Engine-Type		4-Cylinder-Diesel / Common-Rail-Injection			
Displacement	cm³	1.968			
Stroke / Bore	mm	95,5 mm / 81 mm			
Compression		16,5			
Supercharger System		variable-turbine-geometry			two-stage (Bi-Turbo), wastegate
Power Setting	kW	62	75	103	132
max. Torque	Nm	220	250	340	400
Weight (DIN 70020-GZ)	kg	143		153	162

Table 1: Technical data for the new engines

max. Power [kW] at [1/min]	62 3.500	75 3.500	103 3.500	132 4.000
max. Torque [Nm] at [1/min]	220 1.250 - 2.500	250 1.500 - 2.500	340 1.750 - 2.500	400 1.500 - 2.500
max. Speed [km/h]	146	157	173	191
Acceleration 0 - 100 km/h [s]	22,2	17,9	14,7	11,8
Accel. 80 - 120 km/h (5.G) [s]	28,3	21,6	16,0	11,3
Emission Standard	EU5	EU5	EU5	EU5

-preliminary data-

Table 2: Performance of the T5 with the 2.0 litre TDI engine

around 10 %, **Figure 3**. At the same time, all the versions of the Transporter already comply with the Euro 5 emissions standard. A reduction in NO_x and engine-out particulate emissions has been achieved by highly efficient low-temperature exhaust gas recirculation. In all the body and powertrain variants, exhaust gas aftertreatment is provided by a combination of an oxidation catalytic converter and a downstream diesel particulate filter [1].

On the passenger car market, good acoustics plays a major role in customers' choice of vehicle and, in the commercial vehicle sector, increasing attention is being paid to improving acoustics. The use of the common rail injection system and other engine modifications have allowed noise levels in the new engines to be reduced significantly compared with previous versions, without the need for costly secondary measures. The result is that the external noise levels of the new T5 have been reduced by between 4 and 5 dB(A).

In addition to lower fuel costs, the running costs for the new generation of engines have also been optimised by extending the interval for replacing the timing belt from 120,000 km to 200,000 km.

3 Powertrain

3.1 Dual-clutch Transmission

In addition to the improvements to the range of engines, the conventional automatic transmission with a torque converter is being replaced by a seven-speed direct-shift gearbox (DSG). With that, the known dual-clutch transmission technologies from Volkswagen will be available for the first time in the market segment of light commercial vehicles. The DSG is designed for high torques and for vehicles with front-wheel or four-wheel drive. Specific enhancements to the design have made it possible to integrate the DSG transmission into a very compact space, while retaining all its positive features and high levels of efficiency, **Figure 4**. The main objective in the development of the transmission was to reduce fuel consumption, Figure 3.

The DSG will be combined with the engines that produce 103 and 132 kW. The DSG has had to overcome a number of challenges simultaneously. It must be sufficiently robust, durable and economical for use in a commercial vehicle and must also provide a very comfortable ride in the passenger versions of the T5 Multivan.

The first application will be in the Transporter, which, because of its weight and engine torque of up to 400 Nm, requires a particularly high-strength transmission. The DSG now combines the advantages of manual and automatic transmissions for customers in this sector. Drivers who prefer an automatic transmission can leave gear selection to the sophisticated driving programmes, while sporty drivers will enjoy the sequential manual gearshift. When it comes to fuel consumption, the DSG transmissions are at least as efficient as a manual gearbox [2].

As a result, the T5 offers a driving experience that is unique among its competitors. Seventh gear is designed as an overdrive to ensure low fuel consumption, particularly over the long distances that are typical of commercial users. In combination with the new, fuel-efficient TDI engine, the result is a fuel saving of

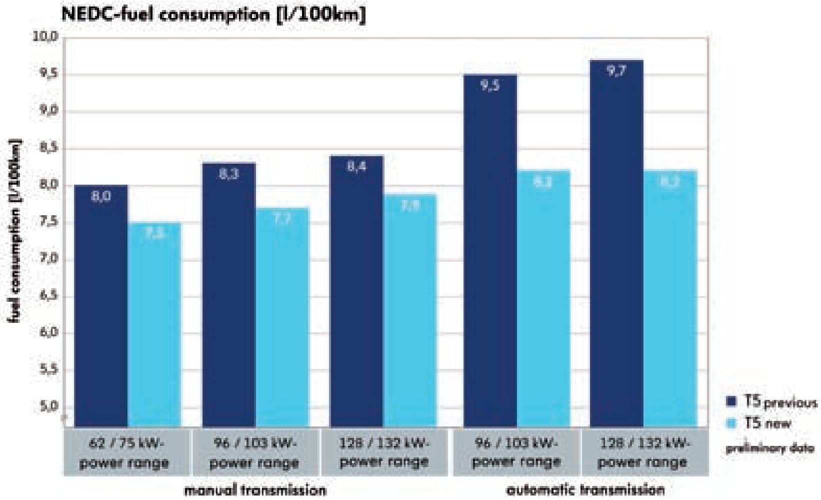


Figure 3: Fuel consumption of the new T5 compared with the previous model

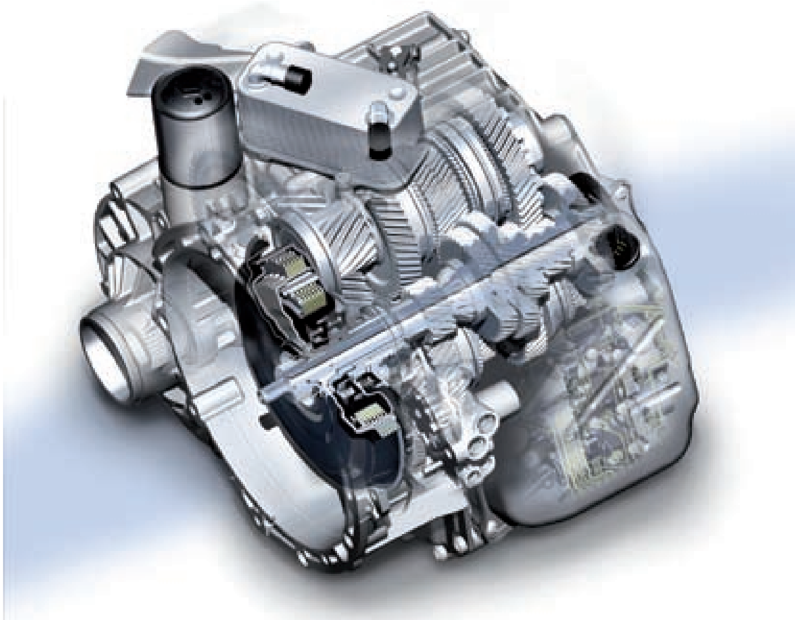


Figure 4: DSG: first used in the new T5 with front-wheel drive and „4Motion" four-wheel drive

Figure 5: T5 Transporter „4Motion“ with 132 kW engine and DSG

Figure 6: New design of the standard and comfort instrument panels

1.5 litres/100 km compared with the previous powertrain. The highly efficient direct-shift gearbox makes a major contribution to this fuel saving, Figure 3.

3.2 Four-wheel Drive

Additionally to the MQ500 manual gearbox, the DSG will be offered in combination with the newest generation of the Haldex coupling (IV), **Figure 5**. The controlled, permanent four-wheel-drive system offers maximum performance in terms of traction, safety, comfort and fuel economy. The optional, mechanically actuated electronic differential lock (EDS), together with the newly designed ESP that has been specially adapted for off-road use, represent a drive concept that offers an excellent level of driving dynamics in on-road use and optimum off-road traction. The on-demand axle-differential lock for off-road starting-traction control is still available.

4 New Electrical System and Electronic Components

The electrical architecture of the new T5 is based on the latest Volkswagen platform. This meant that it was necessary to completely restructure and redevelop all the numerous derivatives and customer-specific versions of the electrical system. Functions previously provided by decentralised control units have now been brought together in one integrated module, the Body Computer Module (BCM). These modifications allow the functions of Volkswagen‘s wide variety of electronic and electric modules to be used in the T5.

The first change which customers will notice is the adapted instrument panel of the T5, **Figure 6**. The instruments have a clear design, carefully selected colours and an intelligent display system for the central multifunction display. When operated manually, the new controls for the air conditioning system interact with the displays for the new infotainment equipment. The user-friendly, multifunctional, three-spoke steering wheel allows the audio system, navigation system, multifunction display and telephone to be used safely and easily.

The RNS 310 and RNS 510 navigation systems are familiar from Volkswagen‘s passenger car range and are a combina-

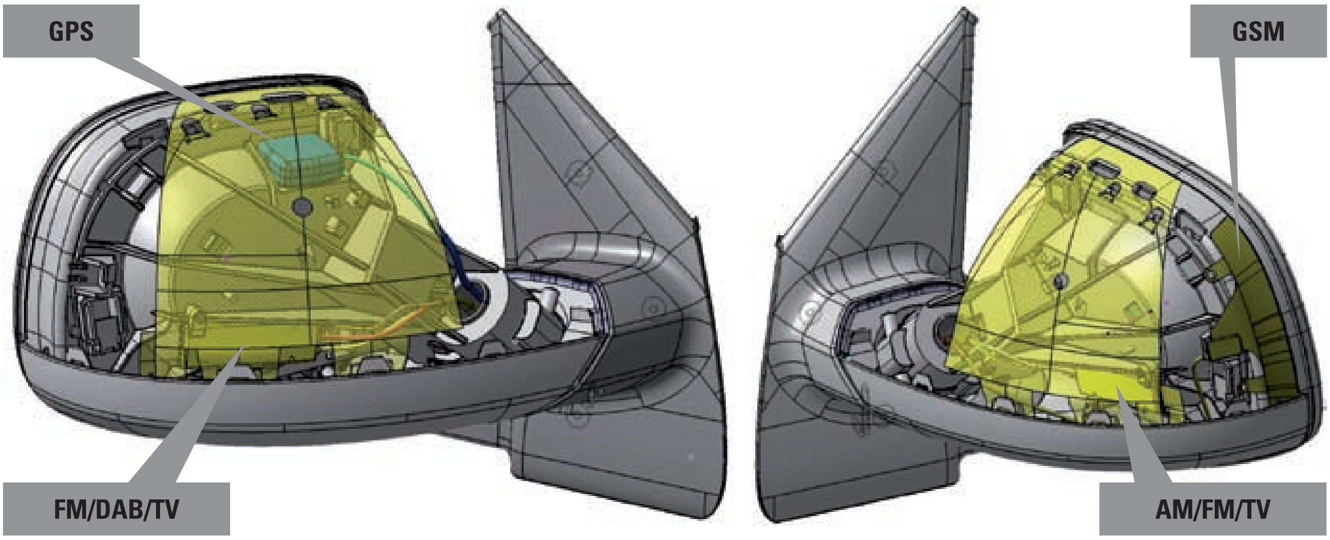


Figure 7: New exterior rear view mirror with integrated antennas

tion of a modern audio system with an accurate navigation function and a clear map display. The touchscreen makes the system easy to use. There are also a variety of options for connecting digital entertainment devices.

The RCD 210 and RCD 310 audio systems have an integral CD player which can also play MP3 files. The RCD 310 also offers DAB digital radio reception for the first time.

Together with the new audio systems, the optional Dynaudio sound system guarantees unrestricted, top-quality audio reproduction.

The antennas for radio, television, telephone and GPS have been moved to the exterior rear view mirrors without any reception restriction, **Figure 7**, which makes the design of the vehicle body significantly simpler.

5 Comfort, Driver Assistance and Safety Systems

The T5 offers a range of new, optional functions which provide increased comfort and safety and are based on technologies that have already been successfully introduced at Volkswagen and have now been adapted for the new model.

For example, the comfort of driver and passengers in the new T5 has been improved. This is clearly noticeable, for example, in the ergonomically enhanced front seats and the single swivelling seats in the passenger compartment. The optional, electric, four-way adjustable lumbar support ensures very good long-distance comfort for the driver.

The interior noise has been reduced by between 1.5 and 2 dB(A) compared with the previous model. Together with the optional acoustic glass, this results in a significant improvement in interior acoustics. Numerous individual modifications to the heating and air conditioning system have resulted in improvements in efficiency and comfort.

A lane change assistant is a system that warns the driver of dangerous situations, for example if there is a vehicle in the blind spot or if vehicles are approaching at high speed. If the lane change assistant detects a critical situation, a warning light in the corresponding exterior mirror housing lights up to warn the driver. The lane change assistant uses a 24-GHz radar system that monitors the areas to the side and rear of the vehicle using a covered sensor under each rear light.

A rear view camera helps the driver when reversing or parking. It is activated when reverse gear is engaged and complements the standard acoustic parking sensors by providing a camera image on the display of the audio/navigation system. In addition, dynamic orientation lines are displayed on the screen and show the path that the vehicle should take as it parks. This enables the vehicle to be parked accurately and also serves as a useful aid for hitching up a trailer.

In the new T5, a static cornering light is provided as an additional light source to illuminate the area which the vehicle is turning into. When the steering wheel is turned or when the turn signals are operated, the light is automatically switched on at road junctions or entrances. The static cornering light is integrated into the fog lamps and illuminates a turning area of several metres at an angle of 35°.

When the occupants leave the vehicle, the dipped beam headlights, the tail lights and number plate lighting initially remain on and are switched off automatically after a short period („Coming home" function). When the driver unlocks the doors using the remote control, these lights are immediately switched on („Leaving home" function). In this way, the car's outside lights help to illuminate the path to the door of the house or to the vehicle in the dark.

The T5 also offers an automatic headlight activation function.

Servotronic is a speed-sensitive power steering system that is now available for the first time in the T5 and as standard equipment in the Multivan Highline. It makes parking easier and offers accurate steering at higher speeds.

The new Transporter generation is equipped as standard with ESP which has some additional functions. For example, in future there will also be an ESP

Figure 8: There is a more obvious styling distinction betweeen the Multivan and the commercial vehicle versions

version for some special vehicles and body manufacturers. The brake assist and hill start assist functions and the electronic differential lock (EDS) are now also included in the range of equipment for special vehicles. The electronic trailer stabilisation system now has an extended range of functions. For vehicles with a large laden/unladen weight ratio, the operation of the ESP system is now load-dependent.

A further innovation is the emergency braking warning system, which indicates heavy braking at high speeds by activating the hazard warning lights.

Low tyre pressure is a frequent cause of flat tyres and punctures. In addition to improving safety, regular checks of the tyre pressure also help to save fuel. The new tyre monitoring indicator in the T5 uses wheel speed sensors to detect tyres running at low pressure.

6 Design

As the most important dimensions have been deliberately kept unchanged, the main feature that differentiates the new model from its predecessor is the design of the front end. The new front includes the visual link between the radiator grille and the headlights that is already familiar from new Volkswagen car models. The upper air intake and the newly designed headlights make up a single strip which, together with the parallel lower air intake, forms a single unit. The new exterior rear view mirrors with their dynamic, symmetrical design add the finishing touch to the new front end. In order to highlight the model lines, the exterior fittings have been carefully coordinated. For example, the Multivan derivatives now have painted trim or black gloss air intake grilles with chrome fittings and their own rear light design, **Figure 8**.

New exterior colours, an optional chrome trim package, 17-inch wheel rims and, for the first time, 18-inch alloy wheels complete the exterior appearance of the new T5.

The interior of the new model is characterised by new trim colours and materials. The Multivan Startline offers a clear additional benefit with the full interior trim. The double passenger seat now has the option of a storage compartment and storage shelf, which is a valuable addition especially for commercial users.

7 Conclusion

The new version of the VW T5 offers utility and reliability for both commercial and private customers. Technologies and systems that are generally found only in high-specification MPVs are now being offered for the first time in the van segment. As a result, the new T5 allows people and goods to be transported easily and in comfort.

References

[1] Rudolph, F. ; Thomfohrde, C. ; Ziesenis, J.; Pott, E.: Die neuen Dieselmotoren der Volkswagen-Transporter-Baureihe. 18. Aachener Kolloquium Fahrzeug- und Motorentechnik, Aachen, 2009

[2] Hadler, J.; Schäfer, M.; Gröhlich, H.; Lindemann, K.: DQ500 – Das neue Volkswagen-Siebengang-Doppelkupplungsgetriebe für hohe Drehmomente. 18. Aachener Kolloquium Fahrzeug- und Motorentechnik, Aachen, 2009

TÜV SÜD

Automotive

Choose certai
Add value.

tank.tech 2009

Congress with accompanying technical exhibition

November 10 – 11, 2009

The Monarch Hotel, Bad Gögging near Munich, Germany

Information online: www.ATZlive.com

In cooperation with

ATZ

TÜV SÜD Automotive GmbH

TÜV®

Dr. Peter Reif
Vice President Engineering and Member of the Management Board, Magna Steyr

"I see great potential for CNG, especially in India"

personal buildup for Force Motors Ltd.

To ensure that mass motorisation in the BRIC countries can take place with environmentally friendly sources of energy, government subsidies need to be extended and there has to be a significant fall in the cost of batteries. ATZ discussed the potential of alternative drive systems in the emerging markets with Dr. Peter Reif, Vice President Engineering, Magna Steyr. He explained the contribution that Magna can make as a supplier of battery and hydrogen storage systems.

ATZ Where do you see the chances of a low-cost approach, such as the one you are pursuing with the Mila Alpin?
Reif This approach allows us to minimise tool costs. What is more, the concept enables the car to be used for several applications, for example as a fun car or a small utility vehicle.

ATZ In which direction is the trend going, towards a hybrid or a gas powered engine?
Reif The vehicle was initially designed with a conventional drive system but can also be equipped with a Compressed Natural Gas (CNG) engine or combined as a hybrid with a CNG drive system. As it is also to have off-road capabilities, we are considering a 100 % electric, all-wheel-drive powertrain.

ATZ Are you building this powertrain yourself, are you buying it in or are you working together with an OEM?
Reif It is not our aim to build or sell the vehicle ourselves. We are trying to win OEM customers in order to go into series production.

ATZ Which are the favoured sources of energy for mass motorisation in the BRIC countries: CNG, electricity or hydrogen?
Reif I would exclude hydrogen for higher vehicle volumes because the storage technology is complex. It is still too early for the fuel cell vehicle. I see great potential for CNG, especially in India. A large number of CNG vehicles are already on the roads there. Electric vehicles could be used in urban areas where large ranges are not required. However, we do not yet have low-cost batteries, which means that electric vehicles are not suitable for these countries.

ATZ Which technology for fuelling and storing liquid hydrogen in hydrogen-powered vehicles do you favour?
Reif I favour pressurised tanks, although one must remember that we are working in a high pressure range in which safety regulations must be very closely observed.

ATZ Magna Steyr wants to be a battery system supplier for car makers. Which components do you supply?
Reif For current projects, we buy the cells and then build the whole system. The safety-relevant components, such as the monitoring system, the battery management and the cooling system, are supplied by us.

ATZ When will you be in a position to supply 100,000 battery units a year and where do you source the cells?
Reif Small-volume series production for a hybrid application in the bus and commercial vehicle sector will begin in September. At the moment, we buy our cells from China. If there is a market demand for higher volumes, we are able to increase our battery production in short term.

ATZ What do you see as realistic for electric vehicles: a leasing model for the batteries or the purchasing of a battery pack?
Reif The cost of the battery makes up a significant part of the total cost of an electric vehicle. Therefore, it makes sense to buy or lease the car with a battery. Leasing or buying only parts of the battery could also be an interesting concept. One can buy a

car with a basic range of 150 km and the customer can then extend the range by buying or leasing a larger battery pack.

ATZ Pure electric vehicles are designed differently from conventional cars that are converted to an electric drive system. In which direction should future developments go?

Reif If one imagines the electric vehicle fleet in ten years' time, it will consist of both converted conventional vehicles and those that were designed as electric vehicles, such as the Mila EV study. We designed the concept as a pure electric vehicle without the constraints imposed by adopting a conventional platform.

ATZ How heavy is the Mila EV and what range is possible?

Reif A version without expensive, weight reducing materials weighs about 1200 kg and has a range of between 150 km and 180 km. However, the range of the car depends on the driving cycle and the definition, whether auxiliary units are switched on or not. Range specifications you find in many publications usually take into account the driving without any auxiliary units switched on. If you use the air conditioning system or the heating, which can only be operated electrically in an electric vehicle, the range is reduced significantly.

ATZ By what percentage would electrification make a car like the Tato Nano heavier and more expensive?

Reif A low range requirement such as 50 km would mean a significant increase in weight. As low cost batteries will not be available on the market in short- or mid-term the price of a low cost car such as the Tata Nano would rise massively.

ATZ What potential do you currently see for hybrid vehicles and vehicles with electric or hydrogen drive systems in the emerging markets?

Reif In China and India, the introduction of low or zero emission cars is being strongly subsidised by the government. In India, there is a trend towards CNG. If electric vehicles are to be used in urban areas, they would have to be state subsidised due to the currently expensive batteries. That is already happening in China. Basically, in urban areas there will be subsidies for electric vehicles or traffic regulations for conventional vehicles that support the market launch. I can't say how far state intervention will go, but it will be applied worldwide.

ATZ China wants to be the world's leading supplier of electric vehicles. What is your forecast?

Reif One must not underestimate China. If what I am expecting occurs – that electric vehicles will be introduced quickly and in large volumes especially in China – the Chinese automotive industry will concentrate on this market. As far as European OEMs are concerned, an understandable reluctance is discernible in this respect. The reason is that huge investment has been made in the past for conventional vehicles and the transmission to a new technology is once again a huge financial burden. This is no doubt easier in a booming market in which investments have to be made anyway than in a market that is stagnating. Therefore, I think it is likely that China will become one of the leading suppliers of electric vehicles.

ATZ Like crude oil, lithium and rare metals are available only in limited amounts. Is mass motorisation with electric or hybrid drive systems feasible at all on a global level?

Reif I guess there is much more lithium for batteries available than we know of today. So I think it is unlikely that the quantities of lithium will not be sufficient to equip a worldwide fleet of cars with batteries.

ATZ If batteries were produced for emerging markets, could the costs be reduced to the price level there?

Reif There is a falling trend for battery prices. However, I do not expect that we will be able to talk about 100 to 150 Dollars per kWh in short term. At market launch the operating costs for electric vehicles will be relatively low. But as the number of electric vehicles increases, the electricity used would have to be taxed in order to provide revenue for building and maintaining the roads.

ATZ Dr. Reif, it has been a pleasure talking to you.

Interview conducted by Roland Schedel

Dr. Peter Reif

has received his Mechanical Engineering Degree from the Technical University Vienna and graduated with a doctorate in 1983. From 1984 the Austrian was experimental technician at the truck division of Steyr Daimler Puch and from 1990 development manager at Steyr Antriebstechnik. Reif works at Magna Steyr since 1998, initially as Head of Engineering at the sites Steyr and St. Valentin, from 2000 as General Manager of the Engineering Center Steyr. In 2002 he was appointed to the Management Board of Magna Drivetrain. Since 2008 Dr. Reif is Executive Vice President and Chief Technical Officer Magna Steyr.

Peter Reif in conversation with Roland Schedel (right)

Electric Steering
Necessary Improvements in Vehicles Top Segment

Electric power steering systems offer considerable potential for energy savings when compared with rack-and-pinion-type hydraulic power steering. At the same time, they play a major part in meeting the increased demands made on vehicle safety, driving comfort and driver assistance. Although their average power input from the vehicle's electrical system is low, enabling their peak power requirements is a major challenge for the development process. To permit nevertheless reliable and economical integration into luxury class vehicles, ZF Lenksysteme GmbH is developing energy-efficient steering systems that cope with extremely high demands for steering power yet require only limited power from the vehicle's electrical system.

1 Introduction

As a result of increasing demands for comfort, safety and in particular reduced energy needs, conventional hydraulically assisted power steering systems in motor vehicles are increasingly being replaced by electromechanical ones. The latter offer, depending on the vehicle configuration and driving cycle, a fuel saving potential of up to 0.4 l/100 km compared with rack-and-pinion-type power steering systems [1]. At the same time, simple electronic inputs of driver-independent additional steering torques allows new functional degrees of freedom at the overall vehicle level. As a result, it is possible, in conjunction with appropriate vehicle environment sensors, to provide a variety of innovative driver assistance and driver information systems, for example park assist or lane departure warning systems.

Although the average power consumption by Electric Power Steering (EPS) is low, coping with peak consumption, for example during parking, does however place a big strain on vehicles' electrical systems. This is EPS systems were launched, initially in the small car class, which due to their low steering power requirements placed only minimal demands on the efficiency of the vehicle systems. Thanks to further technological development of the steering systems on the one hand, and improvement of vehicle electrical systems on the other, the use of electromechanical power steering in the middle class is now state of the art. On the other hand, any further increase in the power output of current EPS systems for vehicles of the luxury class will require additional and often cost-intensive expansions and management systems for the vehicles' electrical systems.

To counter this, a new development approach to the design of electromechanical power steering systems focuses on an efficiency-optimized system design. Since the power losses and hence also the overall efficiency depend heavily on the respective operating point of the steering system, optimization in the area of the full-load characteristic takes precedence. In addition to minimizing power losses, particular attention is devoted to taking account of steering-specific boundary conditions, for example the demands made on driving feel or on the package.

2 EPS System Concept

Depending on the available installation space and on the rack forces required, which differ depending on the vehicle model, four basic EPS concepts have gained ground for the motor vehicles on the market. The subdivision of these concepts is based on the arrangement of the servo unit on the steering gear, **Figure 1**.

In addition to the already widespread EPS concepts with column, pinion or dual-pinion drives, the system variant EPSapa, **Figure 2**, permits universal use in vehicles of both the luxury and small car classes following correct adaptation of the system layout. The assisting power of the EPS drive, arranged axis-parallel to the rack, is transmitted to the rack by means of a belt drive and a ball screw mechanism. Combination of these energy-efficient gear stages thus assures that even the highest rack forces can be managed. As a result, the EPSapa system concept is the ideal basis for efficiency-optimized power steering in luxury vehicles.

Study of the power balance sheet for current EPSapa systems shows that the efficiency at maximum power input is around 50 %, **Figure 3**. With permissible battery currents of typically 85 A approved for the latest 12 V electrical systems, the result is therefore a maximum power output of 500 W for the power steering system [2]. At the same time, the required steering power in luxury vehicles is more than 700 W.

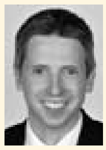
To achieve this power output with constant input currents, the total EPS efficiency must be increased holistically by a wide variety of measures. To do so, detailed knowledge of the loss mechanisms is first necessary. This knowledge can be obtained with the aid of a number of highly specialized development tools at the component level. Taking this as a starting point, it is possible by a limited selection and sensible combination of these tools to identify and then reduce the power losses of the overall system.

3 EPS Components

The core of the electric power steering system EPSapa is not only the already mentioned components of belt drive and ball screw mechanism, but also the elec-

The Authors

Dr.-Ing.
Wolfgang Runge
is Member of the Executive Board, Executive Vice President of the Business field Steering Systems for Passenger Cars and responsible for Research and Development at ZF Lenksysteme GmbH in Schwäbisch Gmünd (Germany).



Dipl.-Ing.
Alexander Gaedke
is Head of the Division Advanced Engineering at ZF Lenksysteme GmbH in Schwäbisch Gmünd (Germany).

Dipl.-Ing.
Markus Heger
is Head of the Department Electrics, Electronics in the Division Advanced Engineering at ZF Lenksysteme GmbH in Schwäbisch Gmünd (Germany).

Dipl.-Ing.
Alexander Vähning
is Development Engineer in the Division Advanced Engineering at ZF Lenksysteme GmbH in Schwäbisch Gmünd (Germany).

Prof. Dr.-Ing.
Hans-Christian Reuss
is Full Professor at the Institute for Internal Combustion Engines and Automotive Engineering at the University of Stuttgart and Member of the Board of Management of the FKFS in Stuttgart (Germany).

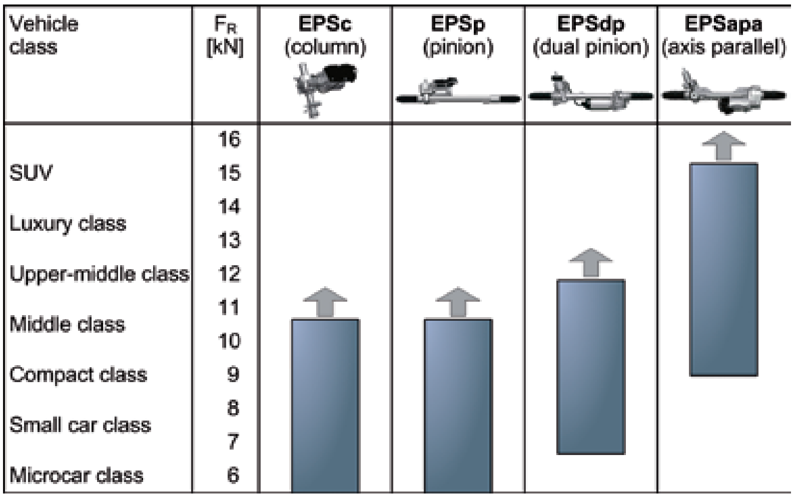


Figure 1: EPS system variants and their application ranges

tric motor and the electronic control unit necessary to operate it, Figure 2. The motor used is a permanent magnet synchronous motor (PMSM).

All the stated components cause, as part of the main power flow, power losses during energy transformation which depend on the respective operating point. Due to system interactions, the components have mutual effects on one another. For example, the pretensioning force of the belt gear results in a radial force acting on the motor shaft and on the ball screw mechanism. To provide a realistic representation of the power losses, these system interactions must be taken into consideration by appropriate steering-specific boundary conditions when they are analysed.

This indicates clearly that the development of efficiency-optimized steering systems requires not only a detailed understanding of the system, but also comprehensive knowledge of all components, **Figure 4**. In this way, the potential and the effects of individual optimization measures can be ascertained with wide-ranging competencies in the fields of electronics, drive and control technology and mechanics. In-house component development work on control units, sensors, electric motors and mechanical gear stages must be particularly emphasized in this connection. For example, the complete circuitry development work including drafting of the wiring diagrams and parts lists can be handled by ZF Lenksysteme. Confirmation and evaluation is achieved by extensive simulations and tests in specially equipped competence centers, for example in an acoustic or EMC laboratory.

3.1 Electronic Control Unit

The electronic control unit (ECU) of the power steering system contains both the control electronics and the power electronics. The technology used here is determined by the space available, the required power and the required quantities. For the power electronics, bare-die technology in conjunction with ceramic substrates offers the best performance. The main advantages here come from the high current carrying capacity, excellent heat dissipation and a compact package.

In view of the input power of the overall system, the power requirement of the control electronics is negligible. The relevant losses of the power electronics can by contrast be split between the DC input circuit, the link capacitors and the AC output stage.

The input circuit represents the interface of the steering system with the vehicle‘s electrical system. The most important task besides the supply of the electric power is the smoothing of the input current in order to enable even the highest EMC requirements of the vehicle manufacturers. The power losses occur in the form of a voltage drop at the ohmic resistors of the vehicle‘s electrical system plug, the EMC chokes and the actual wiring. Hence the efficiency of the input circuit can be expressed on the basis of its power balance with the input voltage and the output stage power as:

$$\eta_{DC} = \frac{1}{2} + \sqrt{\frac{1}{4} - \frac{R_{DC}P_{AC}}{U^2_{DC}}} \qquad \text{Eq. (1)}$$

The link capacitors compensate, as local energy accumulators, for the short-term differences in the current input of the pulse inverter. The loading of the capacitors can be calculated here by splitting the end stage current into DC and AC portions [3]. While the DC portions can be taken directly from the vehicle‘s electrical system, the effective intermediate circuit current depends on the operating point of the electric motor. The power loss caused by this current occurs at the ohmic resistor of the wiring and at the inner loss resistance of the capacitors. Hence the efficiency of the intermediate circuit can be expressed as a function of the effective motor current, the degree of modulation and the power factor

$$\eta_{ZK} = \frac{P_{AC}}{P_{AC} + 2I^2_{eff}M\left[\frac{\sqrt{3}}{4\pi} + \cos^2\varphi\left(\frac{\sqrt{3}}{\pi} - \frac{9}{16}M\right)\right]R_{ESR}} \qquad \text{Eq. (2)}$$

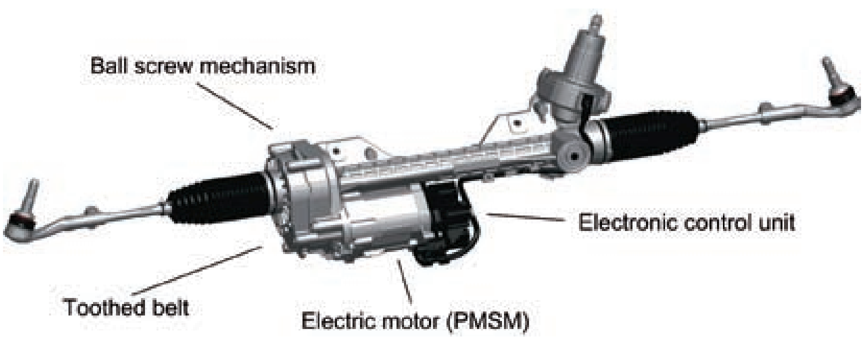


Figure 2: Components of power steering system with axis-parallel drive (EPSapa)

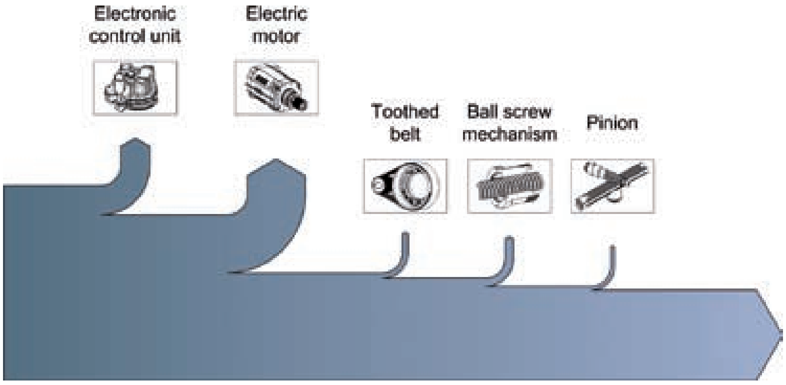


Figure 3: Energy flow of EPSapa power steering

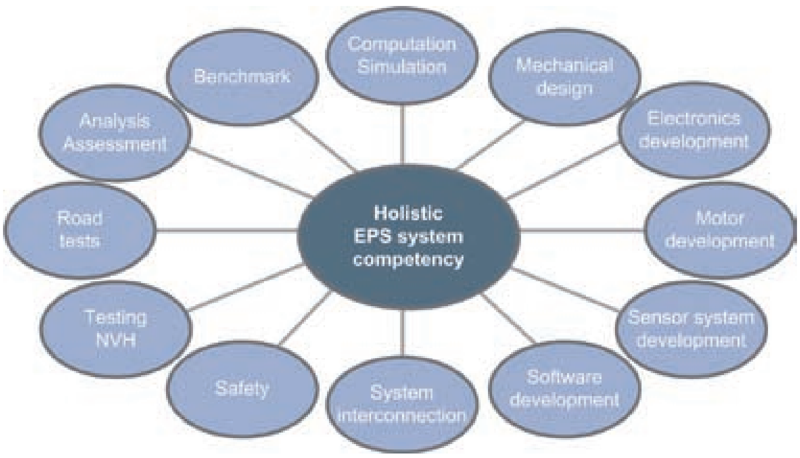


Figure 4: Required competencies for the development of efficiency-optimized EPS systems

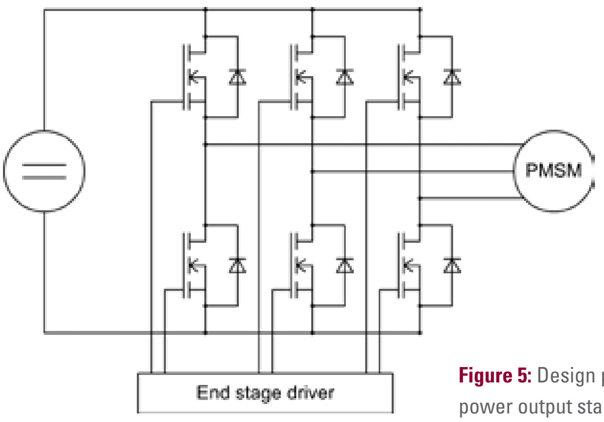


Figure 5: Design principle of an EPSapa power output stage

In the output stage of the control unit, the direct current received from the vehicle's electrical system is transformed by a six-pulse bridge circuit into the three-phase alternating current necessary for operating the electric motor, **Figure 5**. The three half-bridges each comprise two power MOSFETs specially designed for high-current applications and distinguished by low switching and conducting losses. The switching losses result from the rise and fall times of the current and the voltage during the commutation of the phase current. The excess voltages resulting from parasitic inductances due to the high current change must also be taken into account here. Completely parameterized simulation models correctly reproducing these dynamic processes too are provided by the semiconductor manufacturers. Further power losses in the AC part of the control unit result from the ohmic resistance of the wiring and, depending on system configuration, from current measuring shunts or from measures for motor disconnection.

Possibilities for influencing and reducing the power losses of the electronic control unit are large cable cross-sections, input filters, link capacitors with low losses and optimization of the motor control. In this way it is possible, both by optimized setpoint current generation and by a reduction in the switching frequency, for example by adjusted pulse patterns, to considerably reduce the losses in the power semiconductors.

3.2 Electric Motor

The electric motor of the EPSapa is designed as a permanent magnet synchronous motor (PMSM) with inside rotor, **Figure 6**. Advantages of using permanent magnets are the high efficiency, the high power density and the freedom from maintenance.

The output torque of the PMSM is composed on the one hand of the synchronous torque formed by the Lorentz force and on the other hand from the so-called reluctance torque. A high reluctance proportion can be achieved in the motor torque by a specific design of the rotor geometry. By optimization of the phase currents, this enables the required torque to be achieved at the respective operating point with a minimum current load.

The power losses of the electric motor, **Figure 7**, can be split into electrical, magnetical and mechanical friction losses. In EPS applications, the dominant proportion is more than 90 % electrical losses, and hence rises quadratically with the phase current.

One possibility for reducing these electrical or also called copper losses is to reduce the ohmic resistance. The achievable copper proportion in the motor can be influenced here by the winding technique used for the stator. In this way, an optimized winding method can increase the copper proportion by up to 50 %, resulting in a corresponding efficiency improvement thanks to the reduction in the phase resistance that this involves.

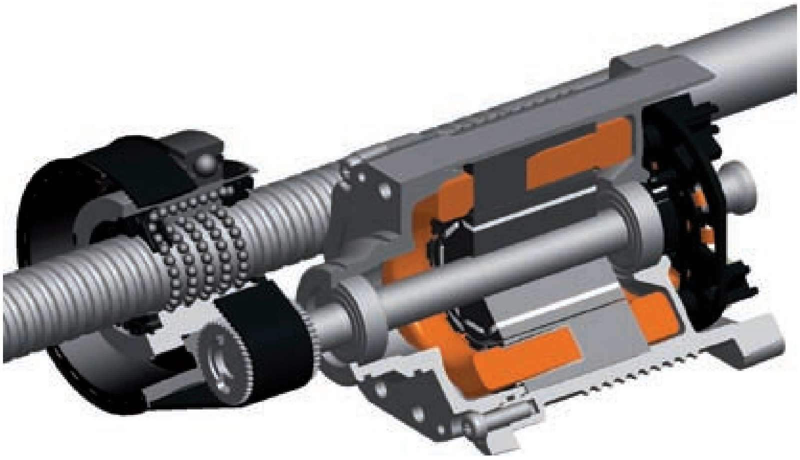


Figure 6: Electric motor and mechanical servo gear of an EPSapa system

A further approach for reducing the copper losses is the optimization of the working characteristic field of the electric motor. By reducing the motor torque and at the same time increasing the speed, a marked increase in the power output can be achieved. The limits to a speed increase are set by the motor control and by the availability of suitable mechanical gear stages.

The motor topology too, meaning the structure of the rotor and stator with regard to the number of slots and pole pairs, is of crucial importance for analysis of achievable efficiencies. For example, studies show that in a comparison of various topologies significant differences result with regard to power losses and hence to efficiency.

3.3 Toothed Belt

The toothed belt gear of the EPSapa is the first gear stage, and it transmits the assistance torque of the electric motor to the ball screw mechanism, Figure 6. The toothed belt as a pulling means offers, as a result of the positive connection to the driving and the driven pulleys, a synchronous and non-slip transmission of the movement. This allows the required pretensioning forces to be reduced to a minimum. Furthermore, the acoustic properties of the toothed belt can be optimized by measures such as helical gearing. This offers at the same time an increased loading capacity and hence also an increase in the maximum drive torques. It must be remembered here that an increased run-off tendency of the belt occurs due to the resultant axial forces, and can be countered by flanged pulleys.

The power losses of the toothed belt gear occur both from the contact between the belt and the toothed pulleys and in the belt itself. The losses in the belt are caused on account of the different elongations in the tight and slack span due to inner friction effects. The power losses during run-in and run-out of the teeth result from the bending processes of the belt, from deformation of the belt teeth and from friction between the belt and the flanged pulleys. The no-load and air friction losses are by contrast negligible in view of the short belt length and low belt speed.

The use of innovative high-performance profiles and material technologies minimizes the elongations and deformations which occur and also the resultant power losses. In addition, the use of toothed belts of low thickness reduces the bending losses to the lowest possible proportion while the toothing runs in and out.

3.4 Ball Screw Mechanism

The second gear stage of the EPSapa power steering is represented by a ball screw mechanism, which translates the rotatory movement of the electric motor to a translatory movement of the rack, Figure 6. Here the balls roll in spirally shaped races on the inside of the ball screw nut and on the outside of the rack, and are connected by means of a ball return system to an endless ball chain. The ball screw nut is driven with the aid of the toothed belt by the electric motor, with the resulting axial and radial forces being received by a ball bearing. The drive torque that attempts to turn the rack is supported in the area of the steering pinion teeth.

The loss mechanisms of the ball screw sub-assembly therefore result from the mounting of the steering nut using ball bearings, from the actual ball screw and from the increased rack friction due to the torque support.

Bearing manufacturers offer calculation methods based on parameters for analysis of the power loss in the ball bear-

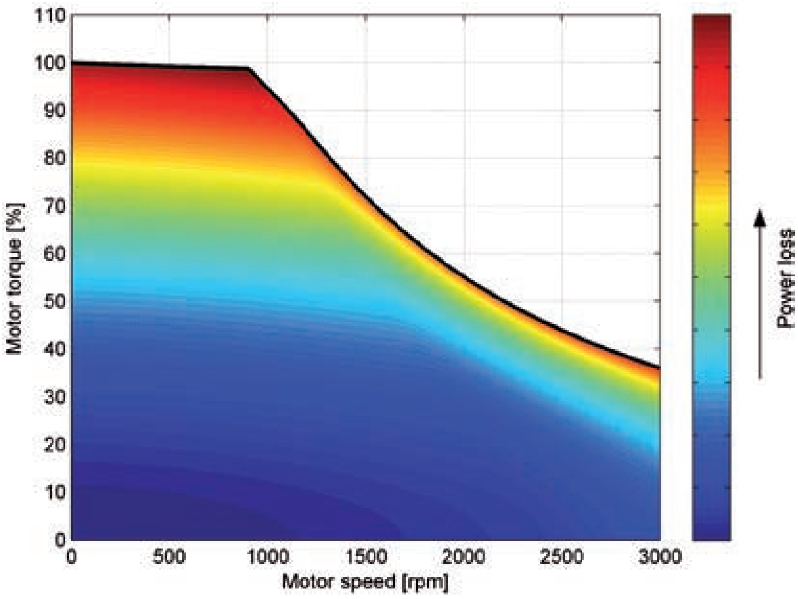


Figure 7: Operating point-dependent power losses of the electric motor

ing. These methods allow the friction torque occurring in the ball screw bearing to be determined as a function of the axial and radial loads.

In the ball screw mechanism itself, power losses occur during the rolling of the balls inside the respective races of the rack and the ball screw nut. It can be shown by analysis of the movement sequence that a sliding and boring movement is superimposed on the rolling operation. To determine ball screw efficiency against the background of these complex processes, calculation methods are available that take into account not only the movement sequences, but also deformations and contact forces according to the Hertz theory, mass inertia effects and variable contact angles [4].

The rack displacement force higher due to the torque support increases - as tests have shown - in a first approximation in linear relation to the drive torque of the ball screw. The load on the steering pinion is reduced here by a rack profiled in Y form in the area of the teeth.

By combination of the correlations as set forth above, it can be shown that the overall efficiency of the ball screw sub-assembly improves in the full-load range as the pitch increases, **Figure 8**. Due to the reduced transmission ratio, the drive torque necessary to achieve a required rack force increases. Although the rack friction and the power losses it involves increase for that reason, this is outweighed by the advantages for the ball bearing and the ball screw mechanism. The efficiency of the ball bearing thus increases since the proportion of approximately constant friction torque relative to the drive torque is reduced. An even more marked advantage is the increase in the pitch, in view of the more energy-efficient contact ratios between the balls and the associated raceways inside the ball screw itself.

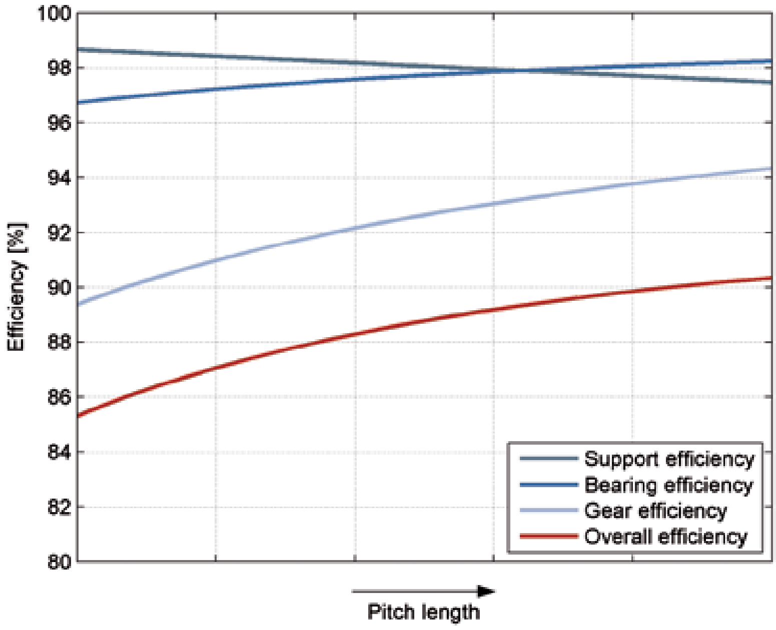


Figure 8: Component efficiencies of the ball screw sub-assembly as a function of the pitch

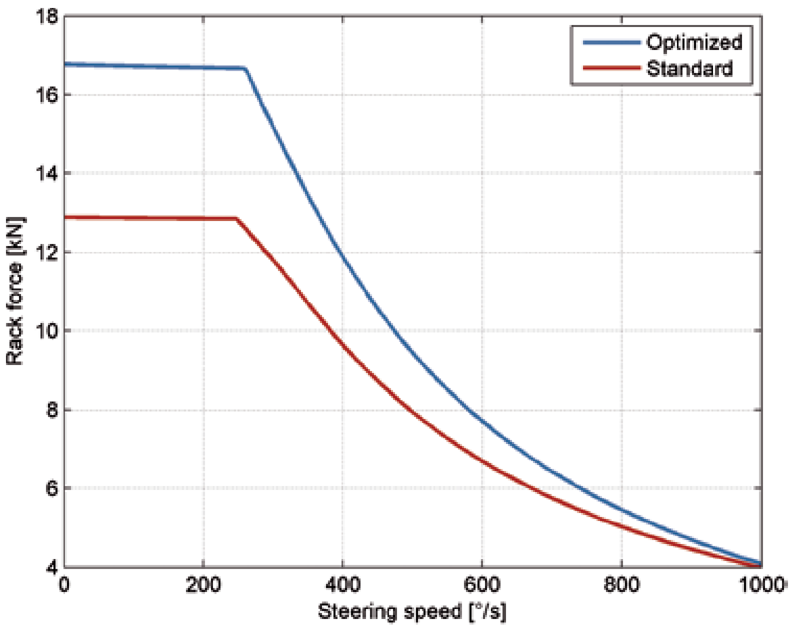


Figure 9: Simulated rack forces of a conventional and of an efficiency-optimized power steering system EPSapa

4 System Optimization

On the basis of the presented methods and procedures, it is now possible to conduct a holistic optimization of the entire power steering system. To cope with the complexity of this task with confidence, the power losses of the individual components can first be described using multidimensional efficiency characteristics.

On the basis of the dominant power losses in the electrical components, Figure 3, the optimization of the drive unit takes top priority in the system design. Expensive computer simulations can be used to show that the power losses of the electric motor and of the control unit can be considerably reduced by an efficiency-optimized overall system design. In so doing, the mechanical gear stages of toothed belt gear and ball screw mechanism must be matched up such that in combination with the drive unit an optimum overall efficiency is attained. With regard to the power losses of current EPS systems, this means that the mechanical transmission ratio between the electric motor and the rack must be increased.

Since the efficiencies of toothed belt and ball screw mechanism are very high in

IMPRINT

ATZ WORLDWIDE

www.ATZonline.com

10|2009 · October 2009 · Volume 111
Springer Automotive Media | GWV Fachverlage GmbH
P. O. Box 15 46 · 65173 Wiesbaden · Germany
Abraham-Lincoln-Straße 46 · 65189 Wiesbaden · Germany

Managing Directors Dr. Ralf Birkelbach, Albrecht Schirmacher
Senior Advertising Thomas Werner
Senior Production Christian Staral
Senior Sales Gabriel Göttlinger

EDITORS-IN-CHARGE

Dr.-Ing. E. h. Richard van Basshuysen
Wolfgang Siebenpfeiffer

EDITORIAL STAFF

Editor-in-Chief
Johannes Winterhagen (win)
Phone +49 611 7878-342 · Fax +49 611 7878-462
E-Mail: johannes.winterhagen@springer.com

Vice-Editor-in-Chief
Dipl.-Ing. Michael Reichenbach (rei)
Phone +49 611 7878-341 · Fax +49 611 7878-462
E-Mail: michael.reichenbach@springer.com

Chief-on-Duty
Kirsten Beckmann M. A. (kb)
Phone +49 611 7878-343 · Fax +49 611 7878-462
E-Mail: kirsten.beckmann@springer.com

Sections
Body, Safety
Dipl.-Ing. Ulrich Knorra (kno)
Phone +49 611 7878-314 · Fax +49 611 7878-462
E-Mail: ulrich.knorra@springer.com

Chassis
Roland Schedel (rs)
Phone +49 6128 85 37 58 · Fax +49 6128 85 37 59
E-Mail: ATZautotechnology@text-com.de

Electrics, Electronics
Markus Schöttle (scho)
Phone +49 611 7878-257 · Fax +49 611 7878-462
E-Mail: markus.schoettle@springer.com

Engine
Dipl.-Ing. (FH) Moritz-York von Hohenthal (mvh)
Tel. +49 611 7878-278 · +49 611 7878-462
E-Mail: moritz.von.hohenthal@springer.com

Heavy Duty Techniques
Ruben Danisch (rd)
Phone +49 611 7878-393 · Fax +49 611 7878-462
E-Mail: ruben.danisch@springer.com

Online
Dipl.-Ing. (FH) Caterina Schröder (cs)
Phone +49 611 7878-190 · Fax +49 611 7878-462
E-Mail: caterina.schroeder@springer.com

Production, Materials
Stefan Schlott (hlo)
Phone +49 8191 70845 · Fax +49 8191 66002
E-Mail: Redaktion_Schlott@gmx.net

Service, Event Calendar
Martina Schraad
Phone +49 212 64 235 16
E-Mail: martina.schraad@springer.com

Transmission, Research
Dipl.-Ing. Michael Reichenbach (rei)
Phone +49 611 7878-341 · Fax +49 611 7878-462
E-Mail: michael.reichenbach@springer.com

English Language Consultant
Paul Willin (pw)

Permanent Contributors
Richard Backhaus (rb), Christian Bartsch (cb), Prof. Dr.-Ing. Peter Boy (bo), Prof. Dr.-Ing. Stefan Breuer (sb), Jörg Christoffel (jc), Jürgen Grandel (gl), Prof. Dr.-Ing. Fred Schäfer (fs), Bettina Seehawer (bs)

Address
P.O. Box 15 46, 65173 Wiesbaden, Germany
E-Mail: redaktion@ATZonline.de

MARKETING | OFFPRINTS

Product Management Automotive Media
Sabrina Brokopp
Phone +49 611 7878-192 · Fax +49 611 7878-407
E-Mail: sabrina.brokopp@springer.com

Offprints
Martin Leopold
Phone +49 2642 9075-96 · Fax +49 2642 9075-97
E-Mail: leopold@medien-kontor.de

ADVERTISING | GWV MEDIA

Ad Manager
Britta Dolch
Phone +49 611 7878-323 · Fax +49 611 7878-140
E-Mail: britta.dolch@gwv-media.de

Key Account Manager
Elisabeth Maßfeller
Phone +49 611 7878-399 · Fax +49 611 7878-140
E-Mail: elisabeth.massfeller@gwv-media.de

Ad Sales Manager
Sabine Röck
Phone +49 611 7878-269 · Fax +49 611 7878-140
E-Mail: sabine.roeck@gwv-media.de

Ad Sales
Heinrich X. Prinz Reuß
Phone +49 611 7878-229 · Fax +49 611 7878-140
E-Mail: heinrich.reuss@gwv-media.de

Display Ad Manager
Susanne Bretschneider
Phone +49 611 7878-153 · Fax +49 611 7878-443
E-Mail: susanne.bretschneider@gwv-media.de

Ad Prices
Price List No. 52

SUBSCRIPTIONS

VVA-Zeitschriftenservice, Abt. D6 F6, ATZ
P. O. Box 77 77, 33310 Gütersloh, Germany
Renate Vies
Phone +49 5241 80-1692 · Fax +49 5241 80-9620
E-Mail: SpringerAutomotive@abo-service.info

SUBSCRIPTION CONDITIONS

The eMagazine appears 11 times a year at an annual subscription rate of 269 €. Special rate for students on proof of status in the form of current registration certificate 124 €. Special rate for VDI/ÖVK/VKS members on proof of status in the form of current member certificate 208 €. Special rate for studying VDI members on proof of status in the form of current registration and member certificate 89 €. The subscribtion can be cancelled in written form at any time with effect from the next available issue.

PRODUCTION | LAYOUT

Kerstin Brüderlin
Phone +49 611 7878-173 · Fax +49 611 7878-464
E-Mail: kerstin.bruederlin@gwv-fachverlage.de

HINTS FOR AUTHORS

All manuscripts should be sent directly to the editors. By submitting photographs and drawings the sender releases the publishers from claims by third parties. Only works not yet published in Germany or abroad can generally be accepted for publication. The manuscripts must not be offered for publication to other journals simultaneously. In accepting the manuscript the publisher acquires the right to produce royalty-free offprints. The journal and all articles and figures are protected by copyright. Any utilisation beyond the strict limits of the copyright law without permission of the publisher is illegal. This applies particularly to duplications, translations, microfilming and storage and processing in electronic systems.

Springer Automotive Media is part of the specialist publishing group Springer Science+Business Media.

comparison with the drive unit, their power losses play only a minor role within the context of a holistic system study. An increase in the transmission ratio leads in both gear stages to a slight increase in the power losses. This is however largely compensated for by the advantages achieved at the same time in the drive unit.

Theoretical studies can therefore verify a potential for increasing the overall efficiency of the EPS by more than 30 % when compared with current systems. This allows, with unchanged input currents, the same rack force level as luxury vehicles to be attained, **Figure 9**. Conversely, the power requirement of electromechanical steering systems in sub-compact, compact and middle class vehicles can also be reduced accordingly with the same power output.

5 Conclusion

Initial system designs indicate that on the basis of the analyses presented here, a significant reduction of the power losses of electromechanical steering systems is possible. This considerably simplifies system integration of the EPS with regard to the power requirement.

It is essential here that the efficiency optimization is achieved in the field of steering-specific boundary conditions, such as costs, acoustics or even steering feel. To facilitate this,, current methods and procedures facilitating the implementation of defined specifications and requirements must be expanded.

References

[1] Vähning, A.; Gaedke, A.; Heger, M.; Runge, W.; Reuss, H.-C.: Analyse des Leistungs- und Energiebedarfs elektromechanischer und hydraulischer Lenksysteme. In: 9. Internationales Stuttgarter Symposium Fahrzeug- und Motorentechnik. S. 377-391, Expert-Verlag, Renningen, 2009
[2] Karch, G.; Mayer, J.; Merz, J.: Potenziale zur Energieeinsparung bei gleichzeitigen Funktionsvorteilen durch moderne Lenkungstechnik. In: 13. Internationaler Kongress Elektronik im Kraftfahrzeug. S. 147-160, VDI-Verlag, Düsseldorf 2007
[3] Kolar, J. W.; Wolbank, T. M.; Schrödl, M.: Analytical Calculation of the RMS Current Stress on the DC Link Capacitor of Voltage DC Link PWM C onverter Systems. In: IEE Conference Publications 1999 (1999), No. CP468, pp 81-89
[4] Wei, C. C.; Lin, J. F.: Kinematic Analysis of the Ball Screw Mechanism Considering Variable Contact Angles and Elastic Deformations. In: Journal of Mechanical Design 125 (2003), No. 4, pp 717-733

„Light Attitude“ Lightweight Cockpits

The „Light Attitude“ prototype from automotive supplier Faurecia combines current lightweight build methods whilst giving us a glimpse of the future: how much weight can we still remove from the cockpit – and which tools can we use to achieve this?

1 Introduction

The car industry is currently in the midst of a profound change. Yet the heated discussions within business and politics are threatening to obscure the real challenges faced by the industry. Car makers should instead focus on finding technical solutions for these critical challenges. Such as: how can the car industry adapt to face the changing global market? How is it responding to the threat of climate change? How can it achieve independence from arbitrary, almost unpredictable developments in fuel prices? And, last but not least: how can it stay flexible in readying itself to meet future government compliance legislation?

One fact is clear: the most efficient use of available resources is the hot topic in current automotive research. This not only involves the development of alternative drive systems running on renewable energy but also the reduction of fuel consumption in general. 80 % of the pollution attributable to cars is not generated as part of their manufacture or recycling but occurs during their useful life. Complementing research into more fuel-efficient engines, vehicle weight reduction is one of the most important factors in improving the ecological footprint for personal car use. ADAC experts calculate that fuel consumption jumps by 0.2 to 0.6 litres per 100 km (depending on the driver and the traffic) for every 100 kg of extra weight. Consumers have long since embraced the concept of thriftiness. Even in the USA, they have turned their backs on heavy-weight SUVs and are now praising hybrid vehicles. Figures from the U.S. Department of Transportation show that public road usage by American drivers fell by 40.8 billion miles in the seven months from November 2007 to May 2008, compared to the same period a year before.

2 The Goal: Lighter Cars

In the course of their development, our vehicles have achieved constant gains in power, comfort and safety. However, one result of all these features and improvements to comfort is that our vehicles have not only become larger but also heavier. Since no one sees any sense in sacrificing today‘s achievements in the future, the challenge is therefore to apply intelligent solutions for reducing weight, while still retaining – and even improving – a car‘s capabilities and comfort. Vehicle weight reduction has been part of the technical specifications for vehicles in the past, but such efforts were generally pushed aside by other relevant factors. Now, however, the topic is top priority – as it has long been in aircraft construction. The value placed on car makers reducing the weight of their vehicles is set to quadruple in the future, according to calculations made by the U.S. Department of Energy‘s National Renewable Energy Laboratory.

With its „Light Attitude“ prototype, Faurecia has attempted to implement these requirements for the car making industry of the future. Complementing the „Happy Attitude“ and „Premium Attitude“ prototypes, this is the third sophisticated concept car designed to showcase the current state of the art – and this time the focus is on vehicle weight reduction. The prototype unveiled last year by the global automotive supplier illustrated the various options offered by developments in product lines such as car seats, vehicle interiors, exhaust systems and front-end modules. Products manufactured by Faurecia can contribute up to 20 % of the total vehicle weight. As a responsible supplier, Faurecia is delivering on solutions to reduce both vehicle weight and emissions, helped by its wealth of experience as a system supplier. From raw materials to subassembly architecture, from improvements to manufacturing to component and module construction: nearly every variable factor is considered. The result of this „crash diet“ applied to both the exterior and interior of the „Light Attitude“ prototype is a substantial reduction in CO_2 emissions.

3 Developing Lightweight Construction Models

Lightweight construction sets out to achieve the same functionality at a lower weight or greater functionality while keeping the weight unchanged. Development work on the innovations in the „Light Attitude“ car therefore began by conducting an analysis of global consumer behaviour and trends in both legislation and the economy. The results were fed into inter-disciplinary workshops at our Michigan-based Innovation Centre with the aim of generating concepts for weight and cost optimisation in the various product areas. A special process was established for defining potential weight benefits. This process analysed specific properties before assigning an index value for „lightweight potential“ from 1 to 8. These calculations also involved the consideration of many criteria such as the degree of innovation, the potential weight reduction, the related market value and the lifetime fuel and CO_2 savings.

Aside from pinpointing the weight reduction index value, two other factors are decisive as regards the degree of technological innovation. The first of these was the employment of lightweight materials for functions previously performed by materials such as metal and plastics. For example, a thin, light, high-performance seat cushion replaces the traditional foam layer in the „Light Attitude“, **Figure 1**. Secondly, the

The Author

Thorsten Süss
is Industrial Design Studio Manager at Faurecia in Hagenbach (Germany).

Figure 1: A thin seat with an ultra-thin seat back: the "Light Attitude" sustainable comfort seat reduces weight by over 15 %

actual function carried out by each component was assessed in terms of its optimum performance – and pared down to performing only this essential role. In the front-end module, for example, each component is assigned just a single function. This module can thus be configured individually for each vehicle type.

Our Innovation Centre was therefore given the freedom to contemplate aspects of vehicle design, manufacture, usage and recycling without being shackled by traditional conceptual restrictions. Innovative substances – often made partially or wholly from natural raw materials – take on new functions to reduce weight in an entirely redesigned component assembly, **Figure 2**. And, since the weight advantages can be achieved by makers during manufacturing at a competitive price point, „Light Attitude“ ushers in a new era of efficiency and success for Faurecia‘s clientele.

Figure 2: Faurecia demonstrates that interiors can be made both interesting and attractive by using a simplified approach to decorative trim

4 Saving Weight in Cockpits

Products made by the various Faurecia divisions can contribute up to 20 % of the total weight of a vehicle. Cockpit manufacturing is one area that demonstrates Faurecia's dedication to achieving weight reductions that can lessen the total emissions of the vehicle. Taken together with the door panels, the cockpit area weighs in at 69–112 kg, depending on the vehicle model. This is already some 7 % of the total vehicle weight. There are a number of ways to reduce weight in this area.

Most interior components carry out more than one function. While the supporting structure contributes mechanical strength, many components are multipurpose – adding decorative elements or improving in-car acoustics. The goal here is to combine functions wherever possible. One possibility is to simplify the cockpit‘s supporting tube by consolidating the tube‘s supporting function with the instrument panel support structure, thus creating a „self-supporting instrument panel“. Synergies between these two functions not only reduce weight but also permit a more compact design. This fact means that the cockpit can be designed to be both shorter and lower, while retaining all of its previous capabilities. This technical innovation can achieve weight reductions of up to 30 % for supporting tubes and instrument panel supports.

Streamlining construction in this way is especially interesting if techniques can be applied consistently across all of the relevant components. By combining a shorter cockpit with slim-line seating, shorter vehicles can be created that still provide passengers with the same amount of interior space. Shortening a vehicle by 25 mm translates into a weight reduction of over 4 kg, **Figure 3**. While this figure may initially seem trivial when compared with the total weight of the vehicle, when matched by material gauge reductions, avoidance of material duplication and other similar tactics, the overall savings are impressive. Savings, one should remember, that apply to the vehicle‘s entire lifecycle and the total number of all vehicles fitted out in this way.

5 Constructive Interior Innovations

One can also achieve weight reduction simply by leaving things out. Working in close collaboration with car interior designers, the „Light Attitude“ prototype has economised on standard coverings in a number of places and laid bare the natural base materials. Car owners will perceive such effects as an aesthetic element and not as „cost-cutting“. The dashboard is „dressed“ with fabric lying flush with the base material: the effect is like a thin t-shirt hugging the skin, instead of a winter overcoat made up of many separate layers. Underneath, the base material is again left in its natural state.

The passenger-side glove box is equipped with an innovative cover system. The passenger sees a piece of materi-

Figure 3: Reducing the vehicle length of a Chevrolet Malibu (2008) about 25 mm saves 4 kg in weight

Figure 4: Foldable glove compartment: the fabric slides away easily

al that seems to be no more than a cloth covering a base surface, but in reality it also plays a structural role. At the touch of a button, the module moves to one side like a curtain being drawn to permit access to the glove box, Figure 4. This is made possible by the self-supporting cockpit technology, which dispenses with a solid metal cross-member. The instrument panel weighs around 2.5 kg less then conventional designs, while simultaneously offering more space for the glove box and other features. When combined with the new lightweight airbag cover, which permits the airbag to be placed nearer to the windscreen, even greater space savings are possible. Overall, the innovations present in „Light Attitude" result in over three kilograms less weight in the cockpit area alone, Figure 5.

As regards the doors, the base surface is left uncovered in many places, rendering the use of dual-layer surfaces unnecessary. Working with audio experts, we designed the door module itself as an acoustic chamber. This means that smaller, lighter speakers can be installed, which can deliver outstanding sound notwithstanding their small stature. Music is provided by the driver's own media player: the device can simply be attached to the integrated docking station. This not only saves weight but also offers the greatest possible flexibility for car infotainment systems of the future.

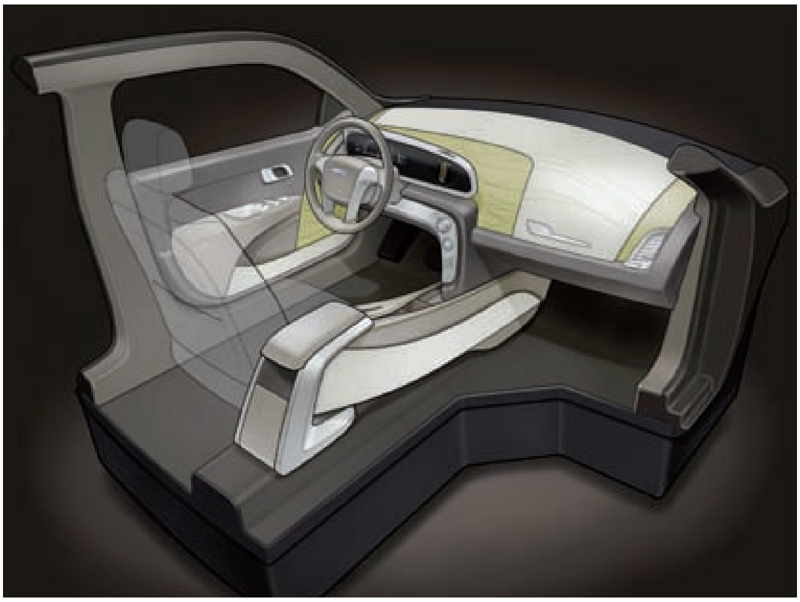


Figure 5: "Light Attitude" interiors by Faurecia show that key interior systems can remain highly functional with natural substrates and fabrics

6 Summary

The „Light Attitude" prototype of Faurecia optimises car manufacturing in the areas of seats, cockpits, doors, acoustics, front-end modules and exhaust systems. All in all, potential weight savings can amount to 30 kg for any vehicle. The model calculation below reveals the huge reduction in CO_2 emissions possible if assembly lines adopted all of the innovations discussed. Assuming an average fuel consumption of 7.1 litres (compact class) per 100 km, each car produces 168.3 g/km of CO_2 (calculated using http://www.dekra-online.de/co2/co2_rechner.html). If one factors a weight reduction of around 30 kg into the estimate from the ADAC, then consumption drops to only 7.01 litres. This translates to an emission rate of 166.1 g/km, resulting in a reduction of 2.2 g/km CO_2.

With 40 million private cars, each averaging 13,000 km a year, the above reduction of 2.2 g/km CO_2 works out as around 1.15 million tons of CO_2 saved a year in Germany alone. This equals the combined annual CO_2 emissions of over 100,000 German citizens (annual estimate of 11 t given by the CO_2 calculator from the Bavarian State Environmental Office at http://www.lfu.bayern.de/luft/fachinformationen/co2_rechner/index.htm). Even when this rough calculation must remain an ideal scenario, it nonetheless indicates the direction that must be taken by the global car making industry. The weight-saving technology demonstrated by Faurecia's „Light Attitude" is showing the car industry the way to a cleaner future. And the power of the consumer purse will also help decide how quickly these and other similar concepts can become a reality. ■

personal buildup for Force Motors Ltd.

FEA Simulation of Truck Seat Structures for Crash Testing

Seat systems for commercial vehicles can rarely be designed without numerical simulation nowadays. In order to increase crash safety, at Isringhausen LS-Dyna has become an integral part of the product development process. Simulation produces reliable results, coinciding to a great extent with real test results which are still mandatory, and can also perform standard tasks, otherwise carried out by real tests.

1 Introduction

Requirements for seats in commercial vehicles are extremely demanding. These seats are the working environment of professional drivers, who spend up to eight hours in such vehicles day after day. Thus, the properties of the seats are particularly important for drivers' health. Isringhausen takes this responsibility very seriously. Besides general seat comfort, shock and vibration absorption, and crash safety are of vital importance in developing Isringhausen seats for commercial vehicles. Ergonomically shaped seats, numerous adjustment possibilities and cushions allowing optimum seat pressure distribution guarantee static seat comfort for the driver. Since vibration of the spine causes back problems – one of the most frequent work related diseases of professional drivers – Isri seats are equipped with a pneumatic suspension system which reduces detrimental vibrations to a minimum, thus protecting the driver's spine. In case of an accident, the seat and its restraint system must minimize risks of injury to the driver. This report explains how modern driver seats with integrated three-point belts are developed at Isringhausen, and how the use of FEA programs like LS-Dyna, distribution via Cadfem, increases occupant safety.

2 Development Process for Seat Structures

FEA simulation is used throughout the entire development process for new seat structures at Isringhausen. FEA simulation enables design engineers to assess the behavior of a seat structure, or of individual components under different load scenarios from a computer screen without the need to produce a physical prototype. Moreover, the design can be optimized during the early stages of development if necessary. Whilst real testing carried out during seat development causes a workload of several days and costs anything up to the four-digit range, simulations on the virtual prototype allow for any number of analyses on different variants in one day only.

Safety-relevant products, such as seat structures, run through numerous optimization loops before production can commence, and simulation contributes immensely to reducing cost and development time. From the start, Isringhausen engineers carry out assessments of structural strength with FEA simulation using an initial, still simple CAD model of the future seat. The findings of this early assessment are then integrated into model design during the initial development phases. FEA simulation is also used continuously during further stages of development for reviewing each step, and its consequences promptly in order to fulfill as many structural strength requirements as possible in the first prototype.

In addition to lower development cost and time, FEA simulation features numerous other advantages. Though real testing demonstrates whether a component is too weak and needs to be reinforced, it does not tell the engineer to what extent the design of an individual component in an assembly meets the necessary requirements, or whether it is overdimensioned. The simulation result however reproduces a component utilization ratio by means of stresses, strains, deformation, and internal forces and moments. Thus, the engineer does not only see which components require a stiffer design, but the simulation also shows the areas which could be designed more cost-effectively without lowering the quality, using a different material or reducing dimensions.

At Isringhausen, LS-Dyna is the tool [1] used for FEA simulation, which comes from the Californian LSTC. In Germany, it is distributed and supported by Cadfem GmbH. This tool is a leading code for the highly non-linear, dynamic simulation tasks widely used in automotive industry.

3 Model Design

Since the quality of simulation results is highly dependent on the quality of the FEA model, an accurate model design is absolutely fundamental. A seat structure consists of many parts with differing strength properties, **Figure 1**. Consequently, the challenge to the simulation engineer consists in finding the ideal degree of detail when designing a model for FEA simulation. A compromise must be found between accuracy and informative value on one hand, and the time and effort required for model design and analysis on the other.

Only load-bearing components are modeled to carry out an FEA simulation for strength analysis of a seat structure. Covers, handles and other parts which are irrelevant for strength will not be considered. Small, geometric features, standard components such as screws, bolts, and locking mechanisms mostly provided with very small gearings, are represented in simplified models.

4 Analysis

The seatbelt anchorage test and crash tests are the two most important load cases in the structural design of a vehicle seat. In the seatbelt anchorage test, it is verified that the strength of the seatbelt anchorage points meet the required legal standards. As shown in **Figure 2**, the load is applied to the seat using two body blocks. Since explicit FEA solvers only allow simulation of very short periods of time, it is

The Author

Dipl.-Ing.
Tore Holene
is CAE Engineer
at Isringhausen GmbH
& Co. KG in Lemgo
(Germany).

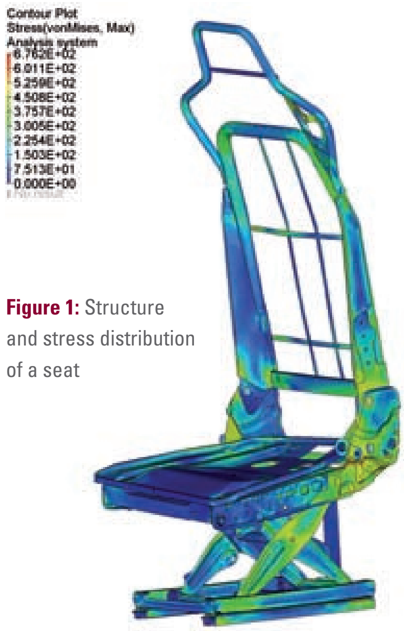


Figure 1: Structure and stress distribution of a seat

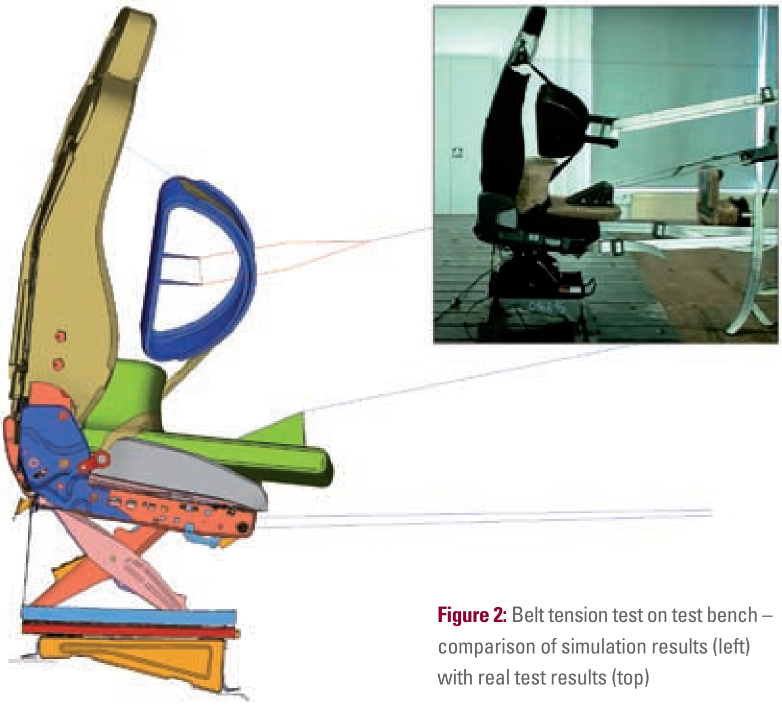


Figure 2: Belt tension test on test bench – comparison of simulation results (left) with real test results (top)

necessary to shorten the test period from approximately 5 s for the real test to a few tenths of a second for the virtual test. At the same time, it is crucial that the inertial forces of the moving parts do not influence the result.

Figure 3 illustrates the crash test. In the early development stages, the crash test is carried out on a rigid test sled, without a steering wheel or other cabin parts. Usually, LSTC Hybrid III rigid body dummies are used for simulation. Besides mere structural strength, accurate interaction between the seat, safety belt and dummy in this simulation has a decisive influence on the quality of the results.

5 Interpretation of the Results

Interpretation of simulation results involves a close inspection of a range of effects. Forward displacement of the upper belt deflection point is of prime importance, and should not exceed the customer's or legal specifications. As analyses are performed with elastic-plastic material data, and tests represent one-off loads, plastic deformation in the material will be assessed rather than stress and strain.

The evalutation of critical screw connections is not carried out on the basis of stress, but rather by assessing the forces acting on the screws – modeled as simple beam elements – and comparing them with the maximum allowable force. Forces and moments acting in locking mechanisms and other components, represented by simplified models, shall be evaluated in the same way, and compared to a maximum value allowed.

6 Comparison with Real Tests

The conditions for the effective use of FEA simulation in seat design are reliable and realistic results that comply with the laboratory results. This cannot be taken for granted, since a FEA model is the simplification of a very complex system with many variables. To be able to work cost-efficiently, many elements – as mentioned previously – have to be modeled in a simplified way. Additionally, material parameters – especially the yield strength – may have variations from one material batch to another. The yield strength can also be increased locally due to cold-forming. Thus the design of quality models requires a lot of detailed knowledge and experience. The comparison of simulation and real testing is limited to values which can be measured and assessed in real tests. Displacements in particular, measured in the test, as well as visible elastic and plastic deformations can be compared.

7 Summary and Conclusion

At Isringhausen, simulation with the program LS-Dyna, distributed by Cadfem, has become an inherent part of seat development for designing structures in regards to crash loads. In view of extensive strength requirements and due to continuously increasing cost and time pressures, FEA simulation has become an essential feature in seat design.

Simulation tools contribute decisively to optimization and implementation in development results. Efficient application of these tools and reproducibility of simulation results will play an important role in other applications in the future.

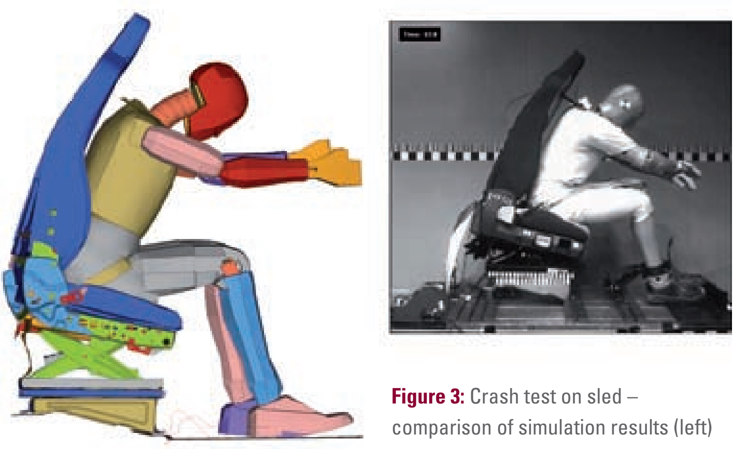


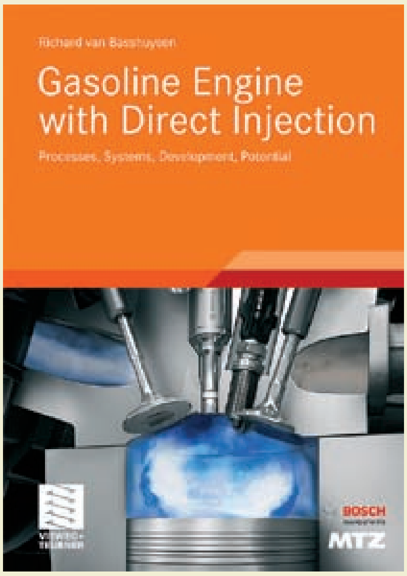
Figure 3: Crash test on sled – comparison of simulation results (left) and real test results (top)

Reference

[1] Livermore Software Technology Corporation (Ed.): Manual LS-Dyna, V971, R4, http://www.dynasupport.com/, 23. July 2009

WWW.VIEWEGTEUBNER.DE

Gasoline Engines are the answer to the challenges of future



Richard van Basshuysen

Gasoline Engine with Direct Injection

Processes, Systems, Development, Potential

2009. xviii, 437 pp. With 399 Fig. Hardc. EUR 49,00

ISBN 978-3-8348-0670-3

Direct injection spark-ignition engines are becoming increasingly important, and their potential is still to be fully exploited. Increased power and torque coupled with further reductions in fuel consumption and emissions will be the clear trend for future developments. From today's perspective, the key technologies driving this development will be new fuel injection and combustion processes. The book presents the latest developments, illustrates and evaluates engine concepts such as downsizing and describes the requirements that have to be met by materials and operating fluids. The outlook at the end of the book discusses whether future spark-ignition engines will achieve the same level as diesel engines.

authors | editors

Dr.-Ing. E. h. Richard van Basshuysen was Head of Development for premium class vehicles and for engine and transmission development at Audi. Today, he is editor of the magazines ATZ and MTZ. The editor was supported by a distinguished team of authors consisting of 22 experts and scientists from industry and universities.

Please send me

Fax +49(0)611.7878-420

____ Copies
Gasoline Engine with Direct Injection
ISBN 978-3-8348-0670-3
EUR 49,00
(+ shipping and handling)

Company | Last name | First name | 321 09 001

Department

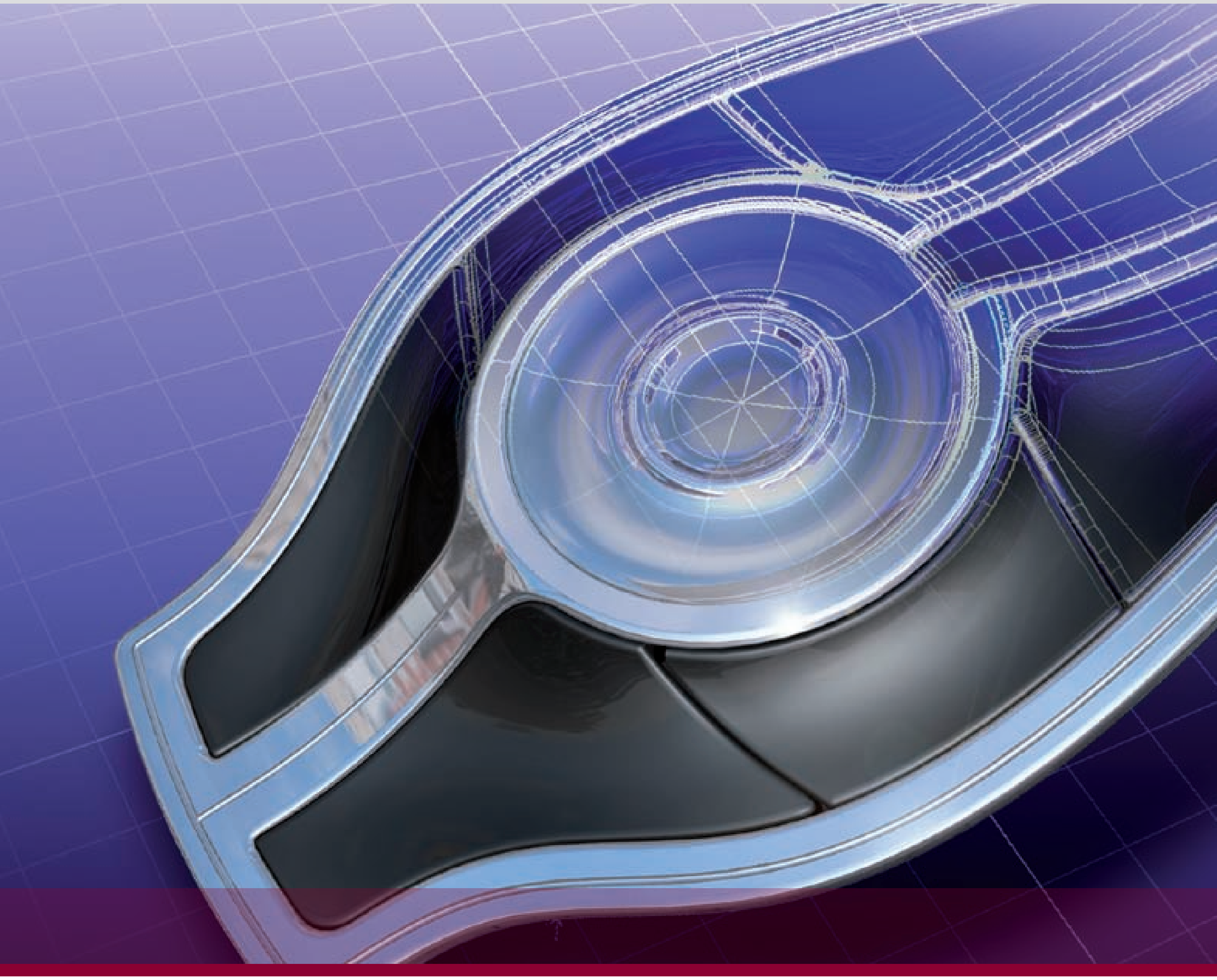
Street name | Postcode/Zip | City, Country

Date | Signature

Please supply at retail price via bookshop or directly from Vieweg+Teubner Verlag. Subject to change without notice. 1|2009.
Managing Directors: Dr. Ralf Birkelbach, Albrecht F. Schirmacher. AG Wiesbaden HRB 9754

TECHNIK BEWEGT.

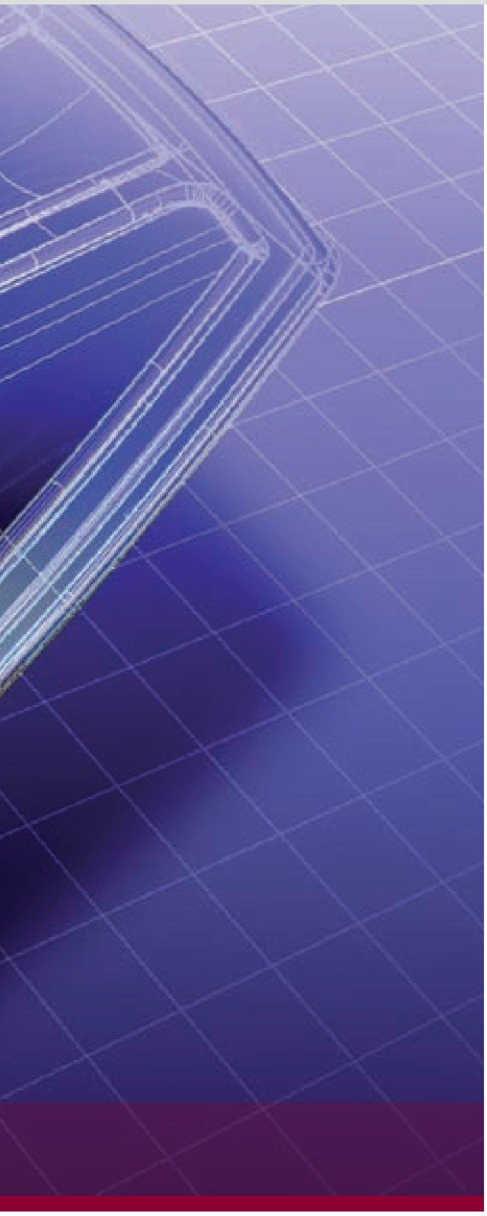
VIEWEG+TEUBNER



Innovative Human Machine Interfaces

Enhanced Usability in Vehicle Interior

Vehicle interior Human Machine Interfaces (HMI) are currently undergoing major changes. Besides innovative, modern and high quality design which car manufacturers use as a major differentiating factor, new technologies driven by consumer expectations conquer the market. Valeo gives an overview of innovative interfaces responding to these demands and ergonomic aspects to be taken into account during their development.



1 Influencing Factors on Interior Human Machine Interfaces

Enhanced functions like the internet, e-mail, camera systems are entering cars; navigation systems are becoming a standard. In order to support these functions displays are gaining in importance, touch screens are finding their way into vehicles and interfaces connecting nomadic devices like MP3 players, GPS devices and mobile phones are being put in place.

These evolutions mean car manufacturers are confronted with new challenges. In a more and more competitive automotive market the interior as differentiating factor has become very important, even more so with the arrival of Asian manufacturers. In addition, end customers are demanding the possibility of individualization of the interior, not only during vehicle acquisition but also when using the vehicle for example, depending on their mood or when adapting to a new nomadic device.

Consumer interior HMI expectations, which are influenced today by home, wireless and portable trends outside the vehicle, are another major market driver. Flush, touch sensitive surfaces like those found on smart phones and the continued rise of connected consumer devices allowing always-on data availability everywhere and in-vehicle connectivity, are only part of fast changing consumer expectations in auto multimedia.

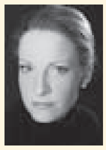
All these influencing factors lead to the integration of more functions in the same or a smaller packaging space. Simultaneously cognitive load must be reduced for drivers who are more and more burdened with high traffic volume and interactivity in the vehicle.

2 Ergonomic Information Processing

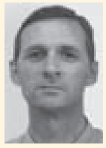
Today's driving situations are characterized by high information density created through higher traffic volume, faster traffic and an important increase in in-vehicle functions. An American study on Driver's exposure to distractions in the natural driving environment has revealed that drivers adjust their audio controls on average 7.4 times an hour. Manipulation time was measured with 5.5 seconds for each adjustment [1]. European studies have shown that during the use of interior HMI glance time may typically range from 0.6 to 1.6 seconds with a mean glance time to approximately 1.2 seconds. A car moving at 48 km/h will travel over 15 m in that time [2]. Hence the objective is to reduce drivers' eyes-off-the-road and hands-off-the-wheel time, thereby significantly improving road safety.

In order to avoid growing regulatory pressure based on similar findings associations and initiatives have been set up by automotive manufacturers in Europe, Asia and NAFTA each providing guiding principles for HMI design and implementation to reduce driver distraction. Princi-

The Authors



Stephanie Schliffski
is Marketing Director at Valeo Interior Controls – Comfort Enhancement in Annemasse (France).



Stéphane Vanhelle
is Product Line Director at Valeo Switches and Controls in Annemasse (France).

Jean-Marc Tissot
is Ergonomics and Prospective Manager at Valeo Switches and Controls in Annemasse (France).

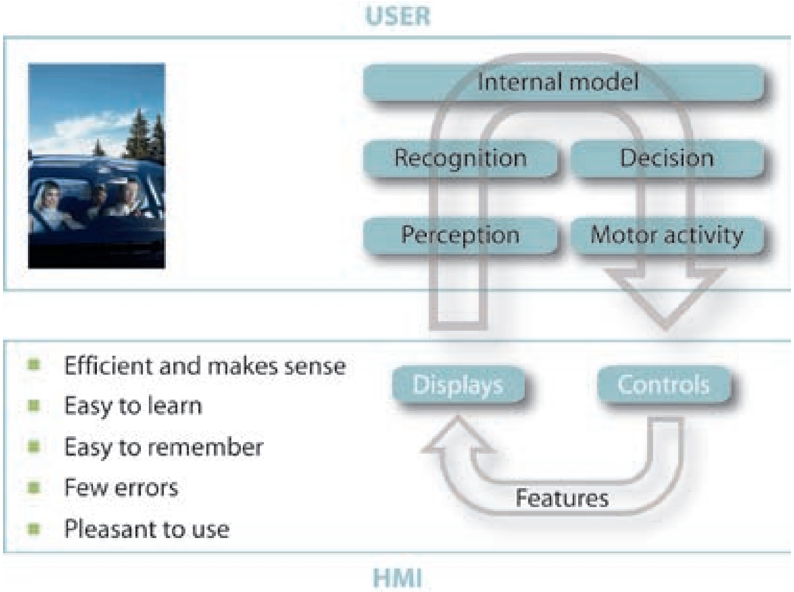


Figure 1: HMI input-output model

ples treated are for example minimization of keystrokes or duration for completion of tasks, task interruptability, clear feedback to driver when functions are activated, consistency in interaction and location of buttons, to mention only a few.

Figure 2: e-Media system

These examples demonstrate that OEMs and suppliers must take a holistic approach when developing interior interfaces, bringing together engineers, stylists as well as usability and ergonomics specialists in one team.

In order to support car manufacturers in their search for HMI solutions that respond to these safety issues and for new market trends Valeo has been working on different innovative interfaces.

The basis for these innovative developments are, amongst others, customer surveys and ergonomics and usability studies under static and dynamic conditions. The objective of these studies is the evaluation of input devices and use processes from input to output, **Figure 1**.

It was evaluated how efficient and useful the system under examination was and how fast the driver can learn and retain it. Use of the system must remain efficient after an extended period of non-use without new introduction into the system. In order to reduce the driver's cognitive workload the system must follow "one rule" – maximize attention on the primary task of driving. The system must be explicit, consistent and has to accept interrupting data input at any moment. Error recovery must be optimized.

3 Multi-control Interfaces

The first in-car multi-control interface, integrating a multitude of functions in one device without the addition of switches, entered into series production in 1998. It consists of a Turn-Press(-Tilt) knob placed in the tunnel area and interacting with a display. Functions integrated are generally infotainment, telephone, navigation and vehicle setting functions. The first systems were judged as complicated and distracting – by not having direct access buttons users got lost in deep menus. Since then OEMs and suppliers have worked on system improvements, optimizing the interfaces and making them more intuitive. The Valeo e-Media System, **Figure 2**, is an intuitive operating concept consisting of three multifunctional joysticks and direct access buttons allowing fast access to infotainment and comfort functions.

Each of the three joysticks represents a dedicated "world" – audio, climate and

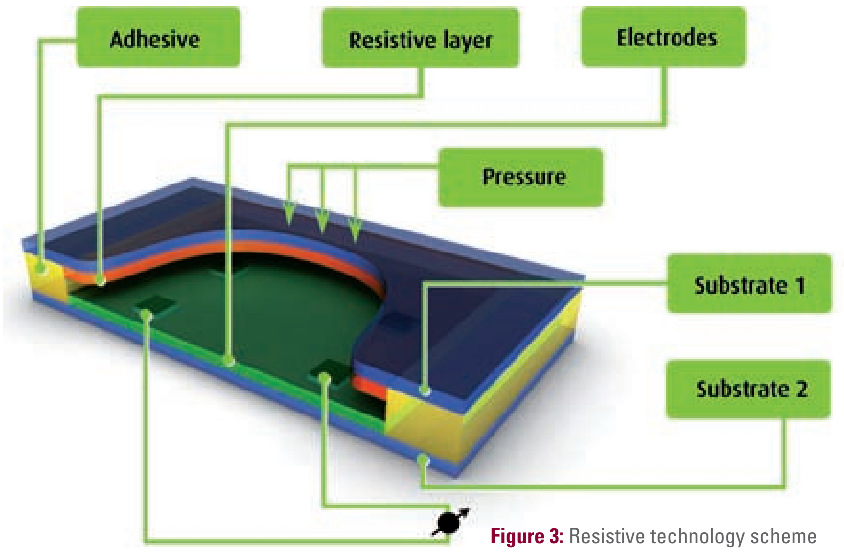


Figure 3: Resistive technology scheme

navigation/phone. The respective menu appears directly on the screen through touch detection via capacitive sensors integrated in the joysticks. Consequently the menu depth has been reduced and the user does not have to pass through different menu levels in order to access the respective main functions. The system is completed with direct access buttons for safety applications or functions needing fast response like e.g. answering the phone or activating the air recycling function. The display graphics represent the hand movements, rendering the system intuitive and easy to use. The number of otherwise necessary switches has thus been greatly reduced. Thanks to their stand-alone architecture, the number of joysticks can vary according to the number of functions, while keeping the same electronics board. This solution can be completely or partially implemented in the tunnel area for enhanced comfort but also in the middle console area in smaller vehicles. The display screen is preferably integrated close to the windshield for comfort and safety reasons (keep-eyes-on-the-road).

4 Touch Sensitive Input Devices

Multi-control interfaces can be evaluated today as differentiating factors for many vehicle manufacturers and carlines. In a further attempt to create brand identity, OEMs opt to place major emphasis on characteristic surface design in the centre stack area, integrating modern and high quality materials in gap-free and curved surfaces. In this environment conventional bulky buttons with gaps are detrimental to the esthetic design. Touch sensitive input devices, integrating in these surfaces gesture based or push functions, are one response to progressive styling demands. One solution Valeo is proposing based on these market demands is touch sensitive input devices that can be integrated in the complete area of the middle console. These intuitive HMIs are mainly based on gesture recognition. The user can for example slide his finger over a surface in order to scroll through a menu or enter his destination in the navigation system via writing recognition.

The resistive technology, **Figure 3**,used for these applications is activated through pressure on the surface. The activation force can be adapted according to customer demands and applications. New design possibilities have resulted in a variety of suitable surfaces, from metallic to shaped to imaginative print. The flat basic assembly of these touch sensi-

Figure 4: Touchpad with black panel keyboard

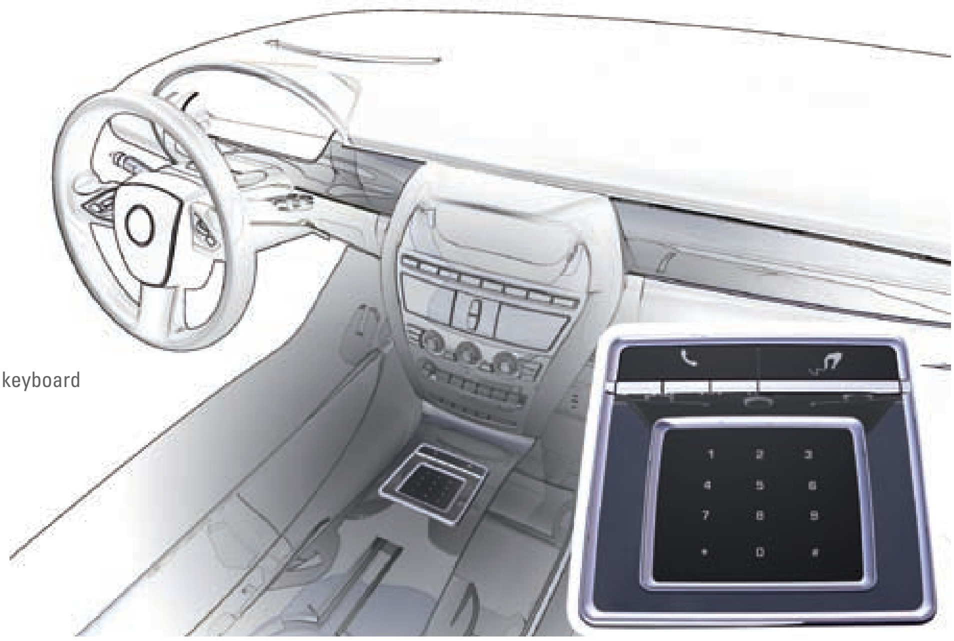


Figure 5: "Senseative" seat adjustment

tive devices responds to today's limitations in packaging space.

In order to improve user comfort and ergonomics, a combination with other technologies is possible. The black panel effect, Figure 4, provides, for example, contextual information and makes active areas visible only when the function can be activated. The activation is acknowledged to the user through an integrated software configurable haptic, sound or light feedback.

The advantage of this technology for the user is natural and easily comprehensible handling, necessitating however a dedicated choice of applications and a specific concept of interactions. A simple transfer of menus/ interactions used with current switches proved to be inappropriate during customer clinics.

Other applications outside the centre stack area have been validated. One example is the "Senseative" electric seat control, Figure 5. With "Senseative", simply moving the finger across the control is enough to understand how this intuitive system works. The four possible movements of the seat are represented by four segments. Once the ON button is pressed, the user slides his finger on one of the segments to move the corresponding part of the seat.

Integrated resistive technology allows the controls to be used with bare hands and when wearing gloves. Accidental seat movements are prevented by the electronics, which require the finger to move in a pre-defined direction and to remain pressed until the required position is reached. This smooth, flat system integration provides a robust system preventing accidental damage and reduces the number of tooling and process components.

5 Evolution in Centre Stack Architecture

In the current market situation and the accompanying increasing pressure on cost, diversity management with a simultaneously rising proportion of electronics and software has become a major challenge in the automotive industry. Estimations predict that electronics will rise from 20 % of total vehicle costs in 2005 to around 40 % in 2015 [3]. The same tendency applies for software, with 4.5 % in vehicle value in 2000 to approx. 13 % in 2013 [4].

By this token centre stack architecture is subject to a paradigm shift, with hardware and software becoming increasingly independent of each other. A major target is the reduction in the number of references per component, multiple use of common hardware and software parts over different platforms and vehicles, whilst still allowing for differentiation. This leads to higher production quantities, as well as reduced application and validation costs. A standard responding to these major challenges in automotive electronics and software is Autosar. This open industry standard, created by a group of OEMs and 1st tier suppliers in 2003, supports the management of E/E complexity associated with dramatic growth in functional scope. Exchangeability and scalability of solutions within and across product lines has become easier. For the HMI user interfaces, design changes over the lifetime of vehicle platforms have been simplified and perceived quality for visible parts has increased. Overall, modifications, upgrades and updates for all product parts has become more flexible. In 2004 Valeo became a member of the Autosar consortium and has since integrated the standard in pre- and series development projects.

6 Integrated Control Panel Modules

Valeo has realized this new system architecture as well as various technical solutions answering to today's market interests and brought them together in an Integrated Control Panel Module, the so-called Faceplate, with audio, climate and switch modules, Figure 6. Based on the black panel effect, integrated in conventional switches, individual functions can be activated contextually. Switches only become active, i.e. visible when the function is available or requested.

When the hand approaches the available symbols light up fully through proximity detection integrated into the surface, based on capacitive technology. When the hand moves away the non-used system dims. This reduces energy consumption on the one hand and on the other lessens distraction to the driver during night driving. Furthermore when touched, the current status of a button is displayed on the bezel through additional capacitive touch detection within a dedicated row of switches. The status changes as soon as the button is pressed.

A USB port is hidden within the row of switches and revealed when its button is pushed. In order to gain additional packaging or storage space the audio interface is integrated into a unit which moves forwards and downwards when activated. The CD slot integrated behind is exposed. The space for the CD player can alternatively be used as storage space.

Figure 6: Integrated control panel

The turn-press-knobs have distinctive premium haptics. Detents have been implemented through magnetic indexing. This non wear contactless technology assures high quality and constant haptics over the whole lifetime.

7 Future Prospects

Interdisciplinary cooperation forms the basis for the development of intuitive and easy-to-use innovative interfaces. End user needs and demands have to be understood and verified during customer clinics. Replacing current HMIs by new modern ones is not sufficient. Interfaces influenced by today's consumer products have to be adapted to the automotive world, and appropriate applications must be defined with a suitable input-output process, taking into account safety issues. Close cooperation between the OEM and supplier is therefore important from the beginning. Through the development of intelligent solutions, glance times and driver distraction will be minimized right from the start. Architectural constraints like limited packaging space, the demands of modern design and evolutions in electronics architecture must also be taken into account.

In order to create homogenous surfaces and interface concepts the next developments will involve the integration of displays and touch screens in a complete system approach. These technologies bring further opportunities to current developments, like variable overlapping contextual symbols or homogenous haptics within the whole interface system. Modern design through complete gap-free surfaces, for example in the centre stack area, can be achieved, **Figure 7**. Bringing together Valeo's know-how in ergonomics, usability, mechanical and electronics architecture is a decisive factor in the creation of an esthetic and reliable HMI system. All system parts have to be perfectly coordinated, offering the end customer an appealing and intuitive user interface.

Figure 7: Integrated touch sensitive user interface

References

[1] Stutts, J.; Feaganes, J.; Reinfurt, D.; Rodgman, E.; Hamlett, C.; Gish, K.; Staplin, L.: Driver's exposure to distractions in their natural driving environment, 2005

[2] Pickering, C. A.: Gesture Recognition Driver Controls. In: IEE Computing & Control Engineering (2005), pages 27-40

[3] Biagosch, A.; Knupfer, S.; Radtke, P.; Näher, U.; Zielke, A. E.: Automotive Electronics – Managing Innovations on the road, McKinsey Brochure, 2005

[4] Kalmbach, R.; Dannenberg, J.: Automobile Technology 2010, Mercer Management Consulting, 2001

personal buildup for Force Motors Ltd.

Crash Test for Tata Nano
Affordable: Yes! And Safe?

A four-seater car for less than 2,000 euros? Surely, that could never meet standard safety regulations – one might think. But that opinion Tata demonstrated to be incorrect at Mira's crash test facility in the UK in July 2009.

Introduction

Unveiled in January 2008 and launched in March this year, the Nano was the realisation of Ratan Tata's dream: "I observed a family riding on a two-wheeler – the father driving the scooter, his child standing in front of him, his wife seated behind him holding a little baby. It led me to wonder whether one could conceive of a safe, affordable, all-weather form of transport for such a family."

Technical Features

The Nano meets these requirements and offers a passenger compartment with space for four adults. With a length of 3.1 m, a width of 1.5 m and a height of 1.6 m, the Tata Nano has the smallest exterior footprint for a car in India, but is 21 % more spacious than the smallest car available today in this country. A high seating position makes it easy to get into and out of the car. Its small size coupled with a turning radius of just 4 m is suited to its main purpose: providing transport in developing countries and mega cities.

It is equipped with an engine designed with help from FEV in Aachen (Germany). It is a 625 cc two-cylinder petrol engine that develops around 29 kW. And despite being low-priced and small, the Nano meets all of the safety legislation for the Indian market: full frontal impact into a solid barrier at 48 km/h, ECE R12 specification, a static door crush test and a roof crush test. That is a fact. Besides being crashworthy, all the safety items on the Nano are compliant with Indian regulations, which are in turn aligned with European legislation. Examples of such items include mirrors, seatbelts and anchorages, seats and their anchorages, the steering wheel and the effort required to turn it, glass, lighting and signalling devices, brake components, the fuel tank, wheel rims and tyres, external projections and all latches.

The Tata Nano crash test demonstrated, that the car is prepared for future safety requirements

Meeting Safety Requirements

The Nano, which was launched earlier this year, is destined for the Indian market and does not necessarily need to meet European safety requirements. Dr Clive Hickman, Head of Engineering at Tata Motors Limited, pointed out: "The purpose of the tests that we undertook at Mira was to demonstrate that the vehicle structure is appropriate for European legislation." As to the design of the Nano, Hickman explained: "As part of the initial design brief, our target was to construct a modular body in which structure could be added to the base vehicle to enable us to meet the safety legislation required for Europe: the ECE offset frontal impact with a deformable barrier. This is expected to become law in India in about three years' time." The ECR 94 norm specifies a 40 % offset crash at 56 km/h.

In order to prepare for this demanding impact, the Nano has been equipped with a driver's airbag. In addition, Hickman's engineers reinforced the front longitudinal structure and added a structure to the front of the vehicle behind the bumper and on the bulkhead. Additional structure has been added to the front doors. All of these enhancements can be added to the body-in-white on the assembly line for the base vehicle and have a weight of 18 kg. Nevertheless, even this version will not be the European version of the Nano announced for 2012. The vehicle for the European market will be 15 cm longer and 5 cm wider. It will be equipped with a turbocharged version of the engine and a five-speed transmission and will be designed to achieve a four-star rating in the Euro NCAP test.

Conclusion

In conclusion, the current Tata Nano designed for the Indian market meets and exceeds that market's legislative requirements. Indian legislation is due to change in 2012 and will in fact be based on the present European standards. With the introduction of some structural modifi-

Despite being low-priced and small, the Nano meets all of the safety legislation for the Indian market, which are in turn aligned with European legislation

cations, the Nano is well prepared for these future requirements. This was impressively demonstrated by a crash test and officially verified by Nic Fasci, expert at the Vehicle Certification Agency (VCA). The VCA is the designated UK Vehicle Type Approval authority.

The fascination of the Nano is based on its rational low-price concept and its proven safety. In this regard, it proves that safety and low price can go together provided that the vehicle is designed from the very beginning to achieve such a goal.

Roland Schedel

"The Nano will be able to achieve an NCAP four-star rating"

Interview with Clive Hickman, Head of Engineering at Tata Motors Limited

ATZ What was the reason for this crash test demonstration?
Hickman The reason was to demonstrate that the Nano's structure is appropriate for European safety legislation.

ATZ Why didn't you go for the Euro NCAP test?
Hickman When we bring the vehicle to Europe in 2012, the NCAP regulations will have changed from what they are today. The Nano for the European market will meet the NCAP four-star regulations at that time, whereas the vehicle that we have today would not meet the same criteria in 2012. Therefore, we thought it was most appropriate to show that the vehicle meets the requirements of today and not necessarily those of three years ahead. When we bring the Nano to Europe, the car will be about 150 mm longer and it will be able to achieve an NCAP four-star rating.

ATZ What major improvements does the Nano need in order to meet the Euro NCAP regulations?
Hickman Current Indian legislation does not require airbags to be fitted. When we bring the car to Europe to meet all of the NCAP ratings, we will put in all of the airbags for both frontal and side impacts.

ATZ Coming back to the Nano for the Indian market, are you on your launch schedule or behind it regarding the production figures?
Hickman Looking at our original production plan, we have to acknowledge that the problems that we encountered, and which have been well documented elsewhere, have put us behind. But I think that we are ahead of the production figures from the strategy that we have now put in place. The new plant is on track for starting production in January 2010 and the plant that we are using at the moment is working very well for us as an interim solution.

ATZ The electric version of the Nano is scheduled to make its debut in 2012. Will it be a fully electric version, a version with a range extender or another solution?
Hickman We are already working on an electric Nano and we have a development vehicle running in India today. It is a fully electric vehicle and it will be based on the same basic powertrain that we are installing in the Indica Vista electric vehicle. The Vista electric vehicle, which will be launched in September 2009, is a four-seater, fully electric passenger car with a range of up to 200 km.

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

Automated Testing on Exhaust Emission Dynamometers

The use of driving robots for exhaust emission testing on dynamometers has been discussed repeatedly in recent decades. However it has not yet been established. Mercedes-Benz has developed a system for automated performance of exhaust emission tests on chassis dynamometers that realizes the advantages of a robot, but avoids the known problems.

1 Elimination of Test Driver Influence

Demands on reproducibility of emission- and fuel-consumption measurements on chassis dynamometers have increased significantly in recent years and will continue to rise.

Declining absolute quantities of emissions to be measured and improvements in measurement technology bring the influence of the test driver on the measurement more into focus. Shortened development times require a reduction of the number of emission tests that are executed, but this can only take place if the significance of the total result remains unchanged.

Through the use of driving robots reproducibility of exhaust emission test results can be increased. However, driving robots have to be adapted to the vehicle and a learning cycle has to be carried out.

This is very time consuming, especially on dynamometers. Therefore, conventional driving robots do not represent an alternative to human test drivers in exhaust emission laboratories.

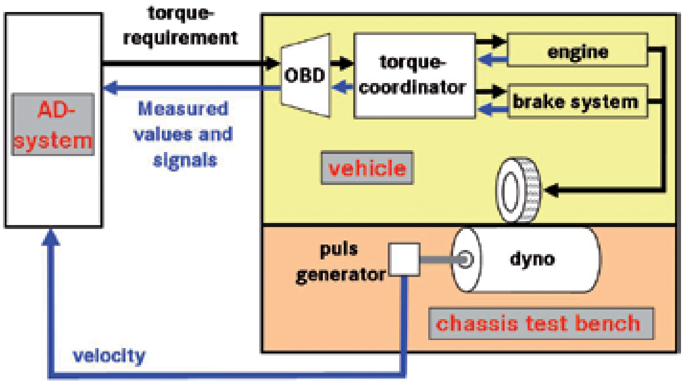


Figure 1: Schematic setup of dynamometer and AD system for automated driving

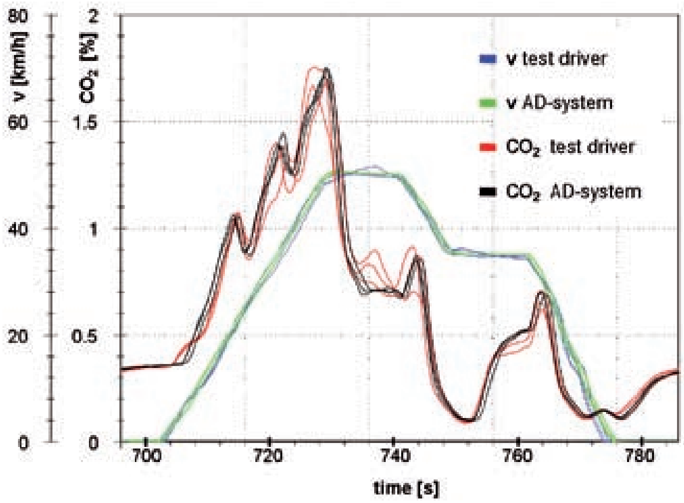
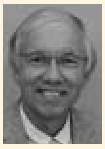


Figure 2: Comparison of driving quality of a test driver with the AD system for automated driving (three measurements per variant)

The Authors

Dipl.-Ing. Christoph Koehlen is Head of the Emission Certification Laboratory at Daimler AG in Stuttgart (Germany).



Dipl.-Ing. (FH) Norbert Komoschinski is Head of Development of Diagnostic Systems for Aggregates Control at Daimler AG in Stuttgart (Germany).

2 New System for Automated Driving

The system Mercedes-Benz developed for automated driving (AD) replaces the test driver in the vehicle and thus eliminates his influence on the measurement. However, it can only be used for vehicles with automatic transmission.

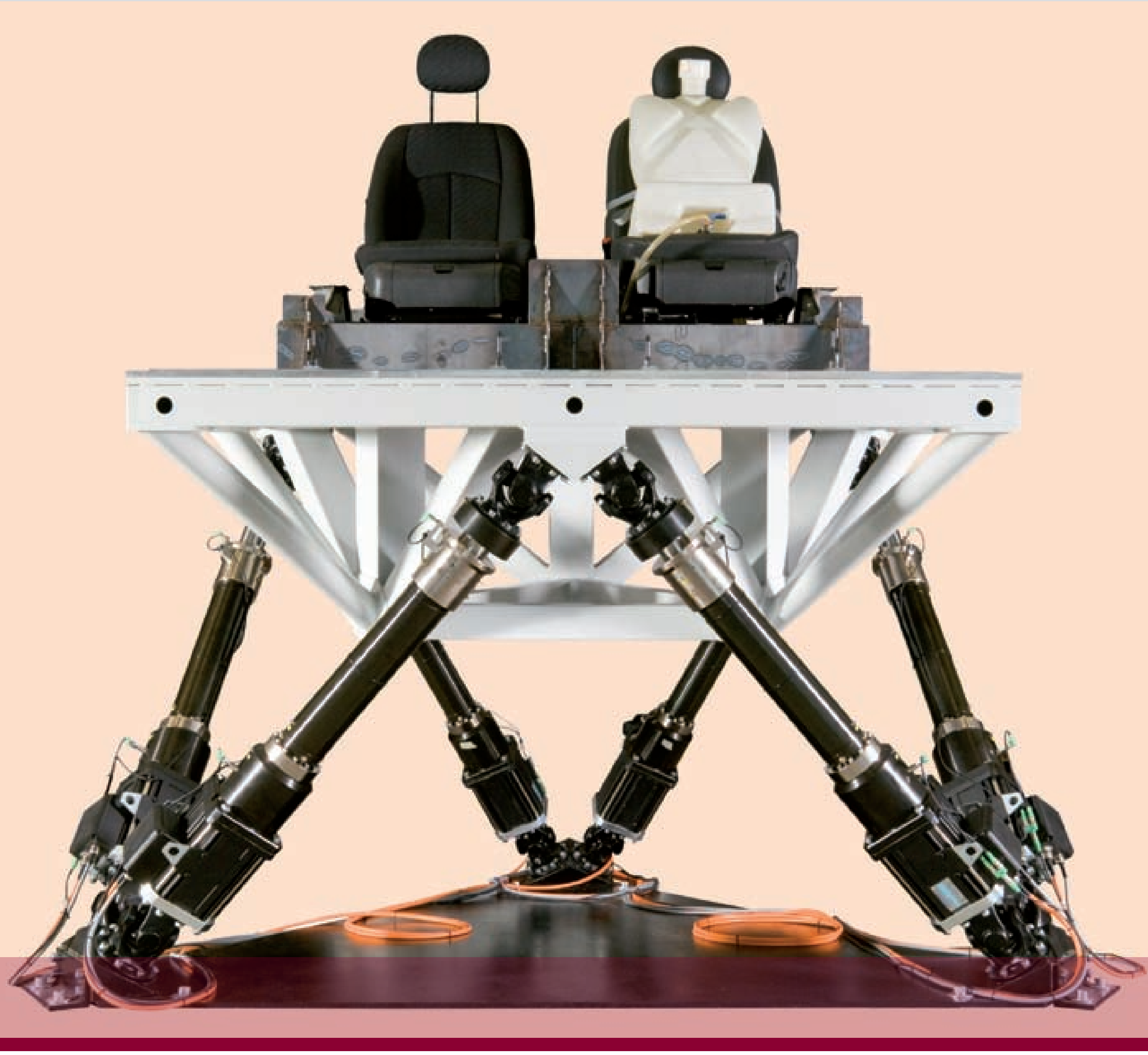
The test bench manager arranges the test vehicle on the emission dynamometer and connects the vehicle with the OBD box to the AD system (PC-based system with control device and monitoring system). Via this interface positive or negative moments are requested in order to accelerate or to speed-down the vehicle, **Figure 1**. The vehicle coordinates the torque-requirement internally, so that either the engine control unit or the traction control system is addressed to realize the required torque. At the OBD interface information of the control units are available. The vehicle speed signal is provided by the dynamometer. As the driving cycle and all other required parameters are handed over by the test site automation system to the AD system, any cycle can be performed.

Comparisons between a test driver and the AD system show that the speed patterns of several rides with the AD system are more in line with each other than those of a test driver.

In **Figure 2**, three speed patterns of a test driver are compared with three speed patterns of the AD system. Shown is a cut-out of the urban part of the New European Driving Cycle (NEDC). The speed patterns of the AD system are much more reproducible than the ones of the driver.

Sometimes speed pattern of the test driver sporadically leave the scatter band of the other tests. This directly effects differing CO_2 emissions. Especially in the case of fuel-consumption optimizations when potentials of a few percent have to be identified, the sum of such differences is a problem. To statistically secure measurement results, exhaust tests have to be repeated several times. Since the legally defined test cycle requires a soaking time at a temperature of 20 °C, this cooling down period must be considered. Because of this the extension of the statistical basis of measurement campaigns leads to a significant retard of the development process. Besides the vehicle control parameters (speed, torque, etc.) as well the emission results (CO_2, HC, NO_x and CO) are more reproducible when using the AD system.

Through the use of the AD system, the number of emission tests can be reduced for each variant without loosing statistical certainty. The AD system offers a wide range of applications in development and production which goes from wear- and endurance-testing to adaptation driving in production. ■



personal buildup for Force Motors Ltd.

Combination of Human- and Hardware-in-the-Loop Testing Reduces Development Time

To date combined human- and hardware-in-the-loop testing (H^2iL) is underutilised in the automotive industry. However, since many years the aerospace industry has proved that the combination of the two testing technologies offers both safety and cost savings. Moog indicates that H^2iL is also attractive for OEMs and Tiers, as it could lead to shorter product development times.

The Author

Peter Onesti
is Technology
Development Manager
of Moog in Nieuw-
Vennep (Netherlands).

1 Introduction

H^{2}iL has been employed for many years in the aerospace world to reduce research and development time. In doing so, new prototype components have been developed and validated on test systems in real world conditions with a human-in-the-loop to get actual pilot response and perception.

In the automotive world, this method of testing is not often used but definitely needed. Applying the concepts of including the driver-in-the-loop with hardware based testing and development could reduce the number of prototype vehicles required and the number of hours spent on race track or proving ground testing. As with all testing methods, the method has limitations. This paper identifies some of them and presents solutions to bring development further into the lab.

2 Traditional Hardware-in-the-Loop Testing

As an example of traditional hardware-in-the-loop testing, consider the testing of a V8 engine with a fuel saving multi-cylinder cutout feature. To test the impact this feature will have on vehicle refinement and drivability, without installing the engine in a real vehicle, the engine can be evaluated with hardware-in-the-loop simulation, **Figure 1**. In this example, the engine or the engine and transmission are attached to a dynamometer and the engine is instrumented with accelerometers, torque cell, speed transducer and any other desired transducers necessary for testing. The engine/dynamometer is coupled to a software simulation package with a full real time vehicle model.

The drive file that is used for running the system is a time history file that was previously collected, having critical information such as engine speeds, torques, accelerations as well as vehicle speeds and torques, wheel accelerations and any other desired data. The actual torque and/or speed for the engine are controlled by an engine dynamometer. In this scenario, the development engineers want to determine the effects of switching between eight and four cylinders on the behaviour of the vehicle.

This HiL configuration has following advantages compared to testing without simulation:

- Reduced track and road testing results in lower costs.
- In a HiL environment it is possible to repeat a certain scenario to assess the changes that have been made to the hardware one on one.
- All simulated parts of the vehicle can be modified quickly and "on the fly." In the example, the effects of the cyl-

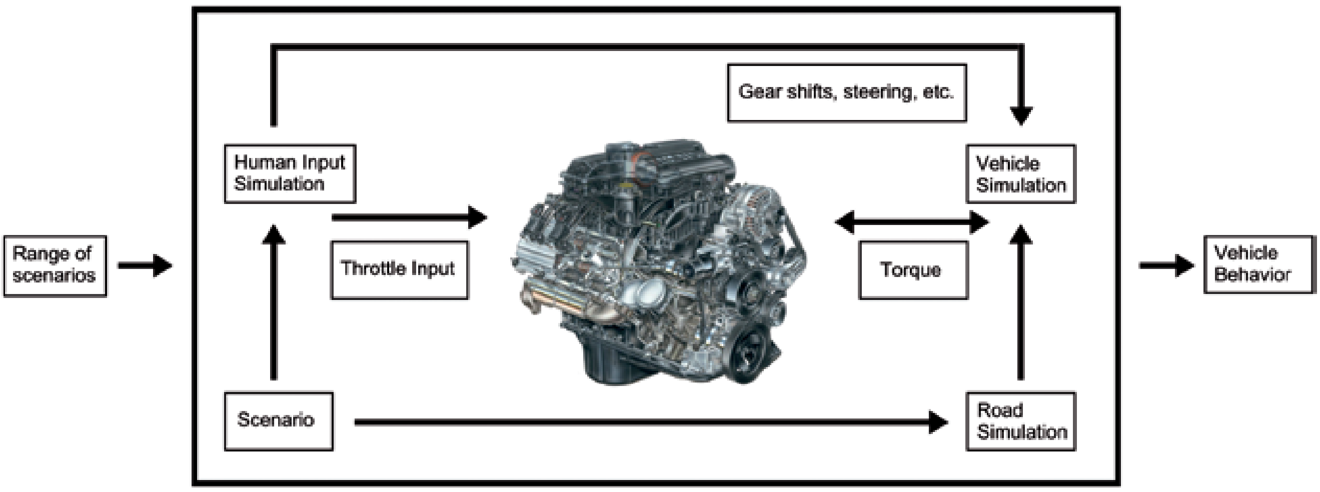


Figure 1: Typical hardware-in-the-loop simulation

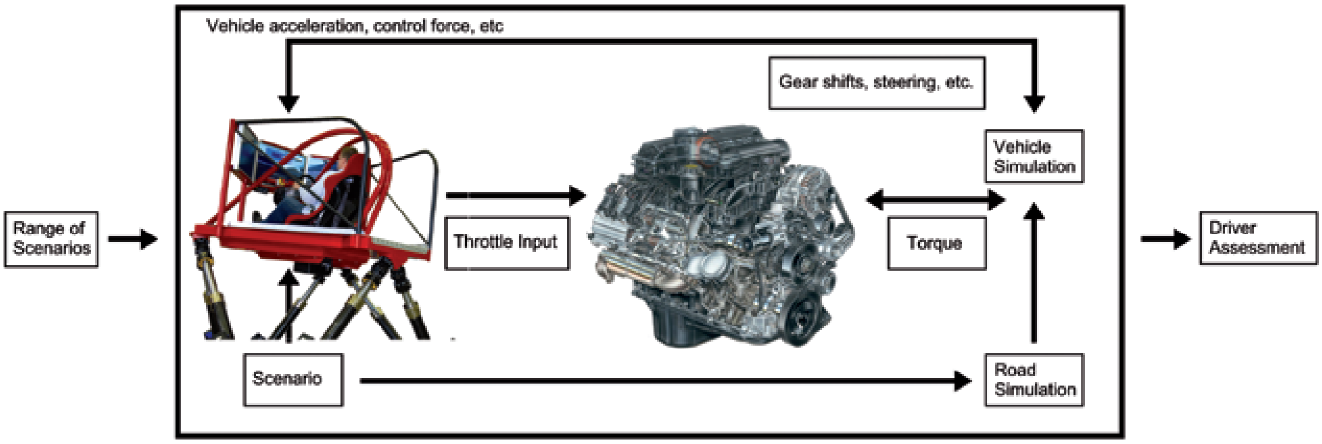


Figure 2: Hardware-in-the-loop/human-in-the-loop – proposed automotive example

inder cut-out can be tested on various vehicles the engine will be used in and many different types of drivers can be simulated.

- The test can be automated to a large extent. If many scenarios have to be tested it is possible to have the test rig play out the scenarios repeatedly and collect the data automatically.
- Hardware-in-the-loop testing can be accomplished without putting the driver or the vehicle at risk.

3 Limitations of Hardware-in-the-Loop Testing

The main limitation of HiL testing comes from the fact that the final assessment of the vehicle behaviour is subjective and is provided by the driver. There is a high degree of interaction between driver and almost all components in a real vehicle. A change in hardware can result in different behaviour of the driver leading to different results than the change was intended to achieve.

In HiL testing the driver is involved in the process, but there is no driver interaction. The developer has to estimate based on the measurement data which change will please most drivers and then select a couple of them to try out on the test track. Recording the scenarios is time consuming and expensive, so it is difficult to change or add scenarios, should the developer need extra test runs.

There have been some systems where the test rig itself has been made “human rated” – where a person interfaces with the vehicle under test. For example, a “driver” is often included in vehicle testing using a four-post test system. However, this is most simply achieved with more or less a complete vehicle. It is also difficult to create the right degree of “immersion” for the driver. Immersion is the term used in simulation to express the degree of realism as experienced by the driver.

4 H²iL Testing for Automotive Applications

Consider the application presented in section two, traditional hardware-in-the-loop testing. The powertrain is still driven and tested on a dynamometer. By replacing the simulated driver input with a full six-degree of freedom (6-DOF) motion simulator and an actual driver-in-the-loop, the H²iL simulation is created. In this testing scenario, the driver of the motion simulator drives a vehicle model on mapped proving ground roads while the power train operates on the dynamometer, now coupled to the motion platform, **Figure 2**. In this configuration, the initial automotive system development can be brought into the laboratory and some advantages may be realised over just hardware-in-the-loop testing:

- Immediate driver feedback can be obtained. Drivers can respond instantly and give qualitative feedback on the direction of a solution. Evaluating the differences between multiple drivers can provide instant feedback. By recording driving habits for given conditions on this new design, objective driver metrics can be developed.
- New scenarios can be created and recorded for playback without ever leaving the laboratory. Virtually any road or climatic conditions can be simulated. Development time and test time are reduced.
- Using H²iL, the same road section may be replayed over and over while making subtle system changes.
- Dangerous road conditions can be tested in safer more controlled environments. Drivers will not be subjected to dangerous road or ambient conditions since they will be operating the simulator. Track scenarios may be taken to the limit of performance on the new design.
- Driver aids can be deployed to improve driver performance or train drivers to perform specific manoeuvres. The performance of each lap can be recorded. Deviations to this lap performance can be observed as vehicle hardware is modified or swapped. Laps can be superimposed on screen so a driver has reference to previous performances. This can aid a driver in operating the “vehicle” on a certain part of the track consistently and repeatedly. If a component does not respond well on a certain part of the track, just that part of the track can be evaluated repeatedly while recording the results. This can offer strong driver evaluation especially in racing scenarios.

5 Other Applications

5.1 Cockpit Evaluations

When a truly representative vehicle cockpit is available or required, configuration in **Figure 3** can be used. It shows a basic 6-DOF simulator platform with complete control position replicated. This simulation allows for determining the drivability of the components without having the complete vehicle. The driver can evaluate the comfort of seats, the drivability and feel of interior components, the ergonomics of the interior design.

This setup can reduce time to production and allows for OEMs to get design verification and feedback before the complete vehicle is ever manufactured. This may be of benefit when different performance characteristics are desired from the same powertrain and vehicle platform.

Figure 3: Using simulation equipment for component development

5.2 Suspension-in-the-Loop

Vehicle suspension systems are constantly being developed to improve ride and handling, while reducing both suspension and vehicle mass. Mission critical components must be lighter and often manufactured with new materials. Development requires validation in real world environments. With H^2iL, validation can be achieved in the laboratory by coupling a full 6-DOF durability test system to a 6-DOF driving simulator, **Figure 4**. Here the H^2iL approach allows "drivability" of the suspension to be evaluated with a range of vehicles.

Drivers can evaluate suspension candidates or vehicles candidates almost "on the fly" by changing the vehicle model in the simulator. The suspension then can be driven in different conditions or vehicle models without ever being installed in an actual vehicle or driven on an actual road. The suspension may be easily modified well before vehicle release dates. This process permits rapid evaluation and comparison testing of a wide range of suspension configurations and components in a very short time period and in a wide range of test conditions.

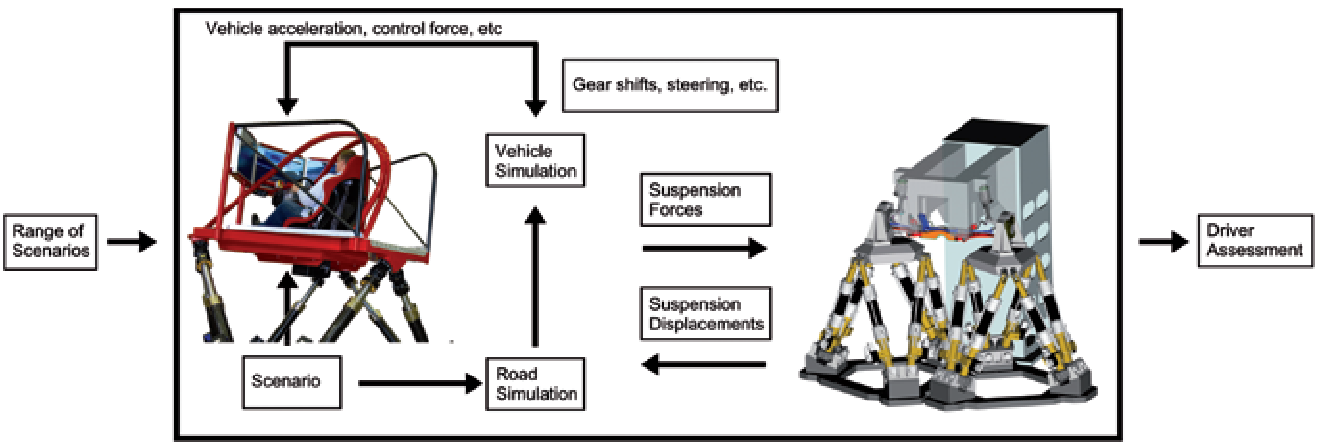


Figure 4: Using H^2iL for suspension testing

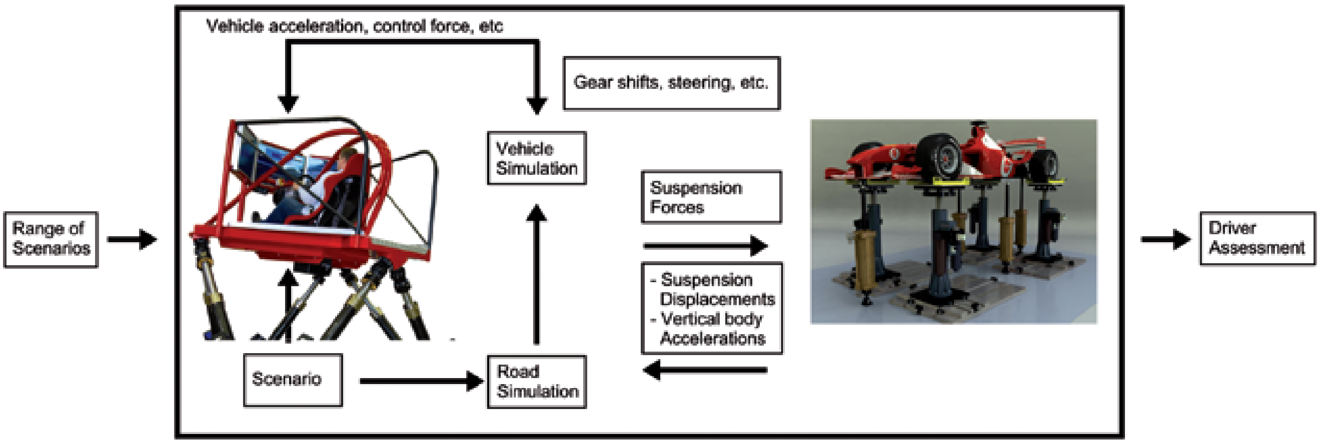


Figure 5: Using H²iL for racing suspension testing

5.3 Four- and Seven-Poster-in-the-Loop and Total Immersion

Race vehicles are frequently set-up and evaluated on multi-post test systems to evaluate or modify suspension and aerodynamic influences for given track conditions. Driver perception and feel on the real track are considered invaluable pre-race evaluations, and yet they are inherently missing from most laboratory testing. In an H²iL set-up, **Figure 5**, the actual vehicle is tested on the multi-post test system and coupled to a 6-DOF simulator with a full vehicle model of the race car and a full track model.

Suspension loads and displacements are induced to simulate aerodynamic loading that the vehicle experiences while on the given racetrack. However, the H²iL driving simulator couples the suspension testing in the laboratory to the driver allowing them to "sense" candidate suspension set-ups and tuning, and the race car's potential aerodynamic responses under driven track conditions.

A common pitfall for recent attempts by the automotive industry for human-in-the- loop simulation is to attempt "total immersion". Total immersion simulators, **Figure 6**, are generally used to

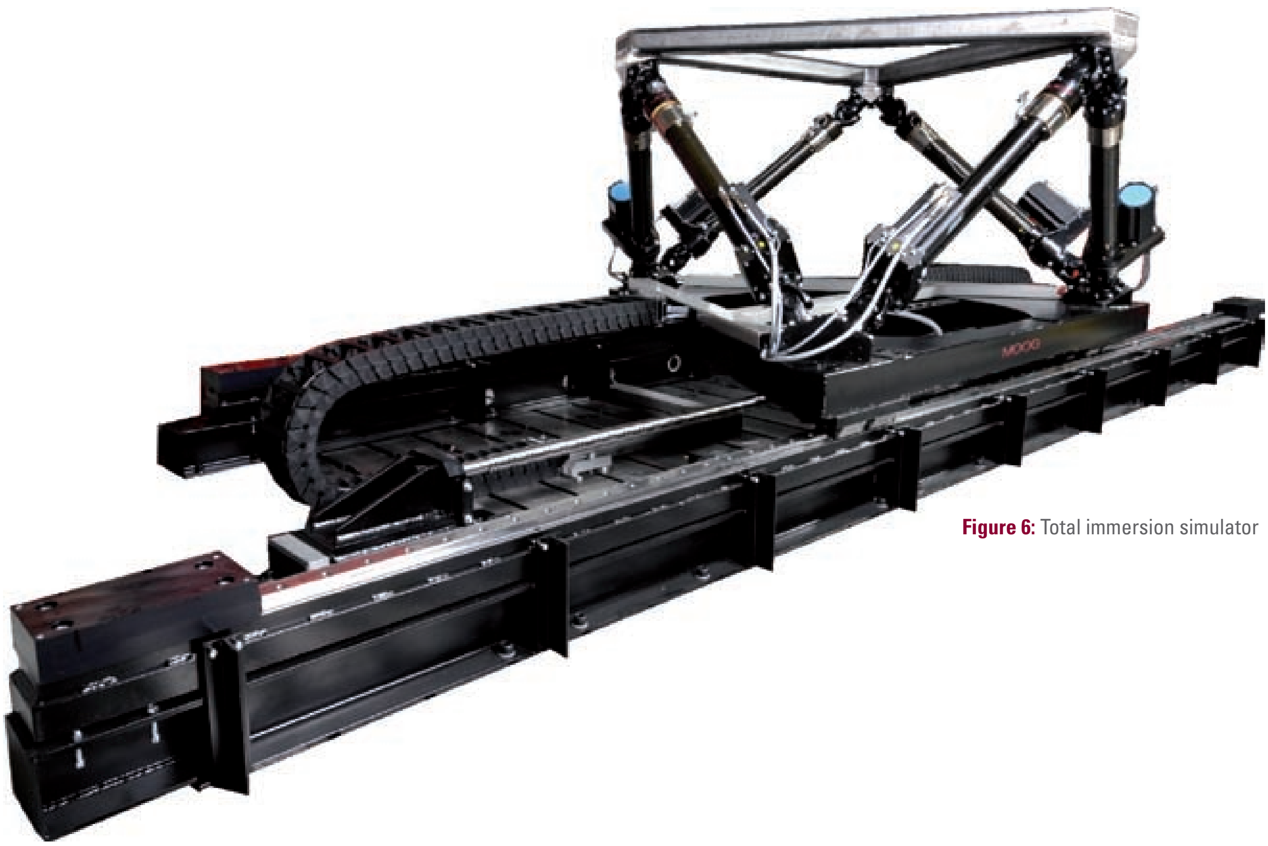


Figure 6: Total immersion simulator

study maximum workload and human factor influences on design. Their extreme cost and inevitable compromises do not make a lot of sense for the purpose of the H²iL simulations described in this paper.

Rather then aiming for 100 % realism, H²iL is most successful when focused on a specific issue under test. For example, when lane change manoeuvres are tested in the field, a simple straight road with a centre line suffices. This should then also be true for H²iL demonstrations. A simple dash to road reference in the simulation and road speed feel are desired. However, if one looks to improve lateral motion and feel of the lane change, a slider "channel" under the normal 6-DOF simulator that makes the low frequency accelerations and displacements possible can be envisioned.

Full immersion on the other hand is not at all required. Experience tells that when people are asked to focus on certain behaviour (that is very well simulated) they very naturally ignore less then perfect behaviour – for example maybe from sudden hard braking, for which the simulator is not set up and which is not of interest.

5.4 Combine One or More Hardware Components

The ideal way of working would be to start out with a completely virtual new vehicle model and use driver assessments to refine and improve the vehicle model until the desired product performance characteristics are achieved.

Once acceptable vehicle performance models are developed, they can be incorporated in prototypes. These vehicles can be tested and as new learning occurs, they can be substituted into the simulation. Now the virtual vehicle becomes closer to the real vehicle with every component added. These rigs do not have to be at the same physical location. They are coupled by high speed digital connections. Once all essential components have been put in the loop and assessed by different driver/road scenarios the final test will always have to be on the road. This test will be purely to verify all virtual, HiL and H²iL work done.

6 Conclusion

H²iL testing is done by connecting the simulator hardware and software to an actual test system with real components attached and performing testing by driving on simulated roads. This simulation in turn generates the necessary loads, accelerations and displacements to drive the components as if they were in the actual vehicle on the actual road.

Then the feedback of the components is fed back into the simulator to allow the driver to get the feel or drivability of the components. The H²iL testing is a very viable form of validating design of vehicles and vehicle components. This is a process that has been employed for many years in the aerospace industry and will prove to be the way of the future for the automotive industry. As proving ground and track time becomes more costly and as shortened programme timescales drive parallel development to become the norm, the need for H²iL will become more interesting and important to the OEMs, Tier Suppliers and race teams. ■

Peer Review ATZ|MTZ

Peer Review Process for Research Articles in ATZ and MTZ

Steering Committee

Prof. Dr.-Ing. Stefan Gies	RWTH Aachen	Institut für Kraftfahrwesen Aachen
Prof. Dipl.-Des. Wolfgang Kraus	HAW Hamburg	Department Fahrzeugtechnik und Flugzeugbau
Prof. Dr.-Ing. Ferit Küçükay	Technische Universität Braunschweig	Institut für Fahrzeugtechnik
Prof. Dr.-Ing. Stefan Pischinger	RWTH Aachen	Lehrstuhl für Verbrennungskraftmaschinen
Prof. Dr.-Ing. Hans-Christian Reuss	Universität Stuttgart	Institut für Verbrennungsmotoren und Kraftfahrwesen
Prof. Dr.-Ing. Ulrich Spicher	Universität Karlsruhe	Institut für Kolbenmaschinen
Prof. Dr.-Ing. Hans Zellbeck	Technische Universität Dresden	Lehrstuhl für Verbrennungsmotoren

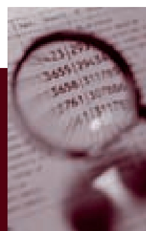
Advisory Board

Prof. Dr.-Ing. Klaus Augsburg	**Dr.-Ing. Markus Lienkamp**
Prof. Dr.-Ing. Bernard Bäker	**Prof. Dr. rer. nat. habil. Ulrich Maas**
Prof. Dr.-Ing. Michael Bargende	**Prof. Dr.-Ing. Martin Meywerk**
Dr.-Ing. Christoph Bollig	**Prof. Dr.-Ing. Klaus D. Müller-Glaser**
Prof. Dr. sc. techn. Konstantinos Boulouchos	**Dr. techn. Reinhard Mundl**
Prof. Dr.-Ing. Ralph Bruder	**Prof. Dr. rer. nat. Cornelius Neumann**
Dr. Gerhard Bruner	**Dr.-Ing. Lothar Patberg**
Prof. Dr. rer. nat. Heiner Bubb	**Prof. Dr.-Ing. Peter Pelz**
Prof. Dr. rer. nat. habil. Olaf Deutschmann	**Prof. Dr. techn. Ernst Pucher**
Dr. techn. Arno Eichberger	**Dr. Jochen Rauh**
Prof. Dr. techn. Helmut Eichlseder	**Prof. Dr.-Ing. Konrad Reif**
Dr.-Ing. Gerald Eifler	**Dr.-Ing. Swen Schaub**
Prof. Dr.-Ing. Wolfgang Eifler	**Prof. Dr. sc. nat. Christoph Schierz**
Prof. Dr. rer. nat. Frank Gauterin	**Prof. Dr. rer. nat. Christof Schulz**
Prof. Dr. techn. Bernhard Geringer	**Prof. Dr. rer. nat. Andy Schürr**
Prof. Dr.-Ing. Uwe Grebe	**Prof. Dr.-Ing. Ulrich Seiffert**
Prof. Dr.-Ing. Horst Harndorf	**Prof. Dr.-Ing. Hermann J. Stadtfeld**
Prof. Dr. techn. Wolfgang Hirschberg	**Prof. Dr. techn. Hermann Steffan**
Univ.-Doz. Dr. techn. Peter Hofmann	**Dr.-Ing. Wolfgang Steiger**
Prof. Dr.-Ing. Günter Hohenberg	**Prof. Dr.-Ing. Peter Steinberg**
Prof. Dr.-Ing. Bernd-Robert Höhn	**Prof. Dr.-Ing. Christoph Stiller**
Prof. Dr. rer. nat. Peter Holstein	**Dr.-Ing. Peter Stommel**
Prof. Dr.-Ing. habil. Werner Hufenbach	**Prof. Dr.-Ing. Wolfgang Thiemann**
Prof. Dr.-Ing. Roland Kasper	**Prof. Dr.-Ing. Helmut Tschöke**
Prof. Dr.-Ing. Tran Quoc Khanh	**Dr.-Ing. Pim van der Jagt**
Dr. Philip Köhn	**Prof. Dr.-Ing. Georg Wachtmeister**
Prof. Dr.-Ing. Ulrich Konigorski	**Prof. Dr.-Ing. Jochen Wiedemann**
Dr. Oliver Kröcher	**Prof. Dr. techn. Andreas Wimmer**
Dr. Christian Krüger	**Prof Dr. rer. nat. Hermann Winner**
Univ.-Ass. Dr. techn. Thomas Lauer	**Prof. Dr. med. habil. Hartmut Witte**
Prof. Dr. rer. nat. Uli Lemmer	**Dr. rer. nat. Bodo Wolf**
Dr. Malte Lewerenz	

Scientific articles in ATZ Automobiltechnische Zeitschrift and MTZ Motortechnische Zeitschrift are subject to a proofing method, the so-called peer review process. Articles accepted by the editors are reviewed by experts from research and industry before publication. For the reader, the peer review process further enhances the quality of ATZ and MTZ as leading scientific journals in the field of vehicle and engine technology on a national and international level. For authors, it provides a scientifically recognised publication platform.

Therefore, since the second quarter of 2008, ATZ and MTZ have the status of refereed publications. The German association "WKM Wissenschaftliche Gesellschaft für Kraftfahrzeug- und Motorentechnik" supports the magazines in the introduction and execution of the peer review process. The WKM has also applied to the German Research Foundation (DFG) for the magazines to be included in the "Impact Factor" (IF) list.

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

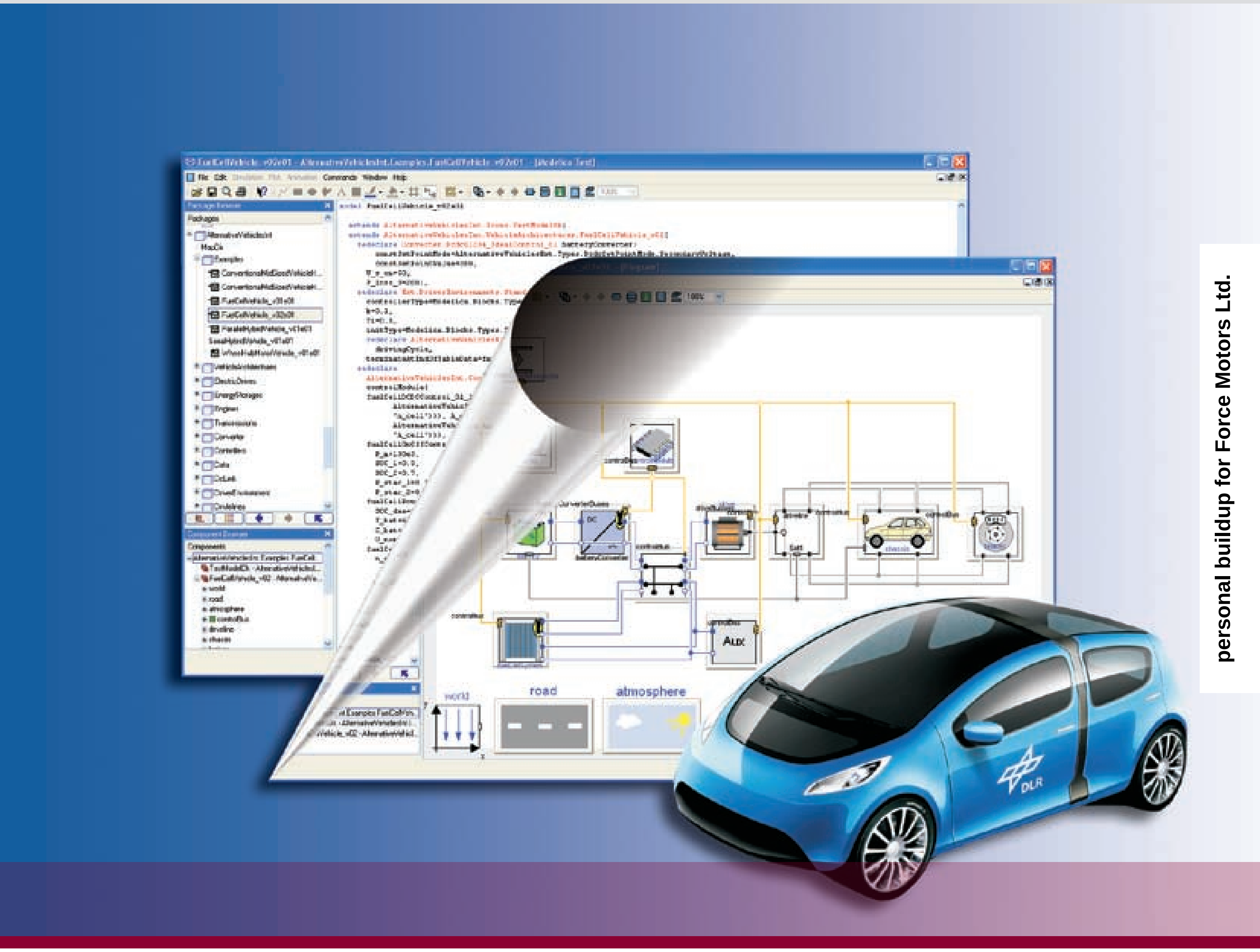


ATZ Peer Review

The Seal of Approval for scientific articles in ATZ.
Reviewed by experts from research and industry.

Received ....
Reviewed ....
Accepted ....

Seal of Approval – this seal is awarded to articles in ATZ/MTZ that have successfully completed the peer review process



Multidisciplinary Simulation of Vehicles

Multidisciplinary simulation of vehicles assists in gaining a better understanding of the vehicle as a complete system, as well as in the systematic development and evaluation of potential ways to increase efficiency and also reducing transport-related CO_2 emissions. The AlternativeVehicles library developed by the German Aerospace Center (DLR) contains models of vehicle-specific single components, subsystems, and total vehicles at varying levels of detail. This allows various powertrain concepts to be investigated and optimised in terms of their energy efficiency.

1 Introduction

Climate change, legal requirements, and increasing environmental awareness among the general population are presenting the automotive industry with a new challenge. It is for this reason that manufacturers and suppliers have embarked on a search for new technologies and concepts that could lead to further reductions in fuel consumption and emissions. Model-based development tools have been utilised for quite some time in order to keep down the development overheads associated with new concepts.

The Institute of Vehicle Concepts (FK) of the German Aerospace Center (DLR) has developed its own software library, AlternativeVehicles, for this purpose. The AlternativeVehicles library makes it possible to carry out multidisciplinary vehicle simulations of alternative powertrains. The basis for this library is the object-oriented modelling language Modelica and the simulation environment Dymola from Dynasim AB.

This paper explains the characteristics and advantages of Modelica and describes the structure of the AlternativeVehicles library. An application example contrasting various powertrain concepts is also presented.

2 Object-oriented Modelling in Modelica

Modelica is an object-oriented modelling language that is suited for component-based, hierarchical structured modelling of hybrid dynamic systems drawn from a range of physical disciplines [1]. The physical behaviour of the components can be described using algebraic equations, ordinary differential equations, and algorithms, whereby each in turn can be dependent on discrete state variables. As far as possible, the delimitation of the components follows their physical interfaces, which are defined by the flow of energy. The coupling of components is therefore independent of the system state. This correlation with the principles by which the real-world systems operate is the reason why the models correspond to the systems they represent not only in terms of functionality, but also in their structure, which provides the greatest possible level of transparency and manageability.

Whereas signal-oriented modelling allows the sequential calculation of every model variable to be derived from the direction of the signals, this is not the case with the object-oriented approach. Here, by contrast, a system of differential-algebraic equations is generated from the implemented equations and algorithms, which must usually first be symbolically manipulated before it can be solved efficiently [2]. The solution behaviour and computation speed of the simulation model produced are largely dependent on the quality of this symbolic treatment of the system of equations.

Because the formulation of the model is independent of how it is coupled to the whole system it is easier, when compared to signal-oriented modelling, to create flexible model libraries of complex physical components and to combine these with one another. Over the last few years, considerable efforts have been made to make component libraries available, particularly for simulation tasks in the automotive field. The European Eurosyslib project [3] alone covers a total of 19 partners who are working on libraries and tools for use with the system simulation in Modelica.

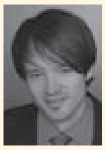
Alongside the modelling of the physical systems, it is always necessary to also have a model of how the system is controlled. The signal-oriented modelling also supported by Modelica is suited to this purpose. The Modelica standard library includes corresponding block libraries that support both continuous and time-discrete signals.

3 The AlternativeVehicles Library

The AlternativeVehicles library has been developed in order to allow system level simulation of longitudinal dynamics and, in particular, of fuel consumption for alternative powertrain and vehicle concepts. The components contained in the library, **Table 1**, are therefore oriented towards the most currently relevant alternative vehicle concepts, namely battery-powered vehicles, hybrid vehicles, and fuel cell vehicles. Electric propulsion and the storage of electrical energy play a significant role in all of these concepts.

In addition to these, thermal management is also important, particularly in

The Authors

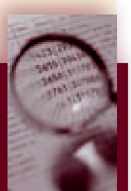


M.Sc.
Dirk Hülsebusch
is Research Associate in the Alternative Powertrains Department at the DLR Institute of Vehicle Concepts in Stuttgart (Germany).

Dipl.-Ing.
Jörg Ungethüm
leads the Simulation Group of the Alternative Powertrains Department at the DLR Institute of Vehicle Concepts in Stuttgart (Germany).

Dipl.-Ing.
Thomas Braig
is Research Associate in the Alternative Powertrains Department at the DLR Institute of Vehicle Concepts in Stuttgart (Germany).

Dipl.-Ing.
Holger Dittus
is Research Associate in the Alternative Powertrains Department at the DLR Institute of Vehicle Concepts in Stuttgart (Germany).



ATZ Peer Review
The Seal of Approval for scientific articles in ATZ.
Reviewed by experts from research and industry.

Received .... July 08, 2009
Reviewed .... July 13, 2009
Accepted .... July 23, 2009

Table 1: Component models of the AlternativeVehicles library

Physical domain	Component model
Conventional powertrain	Engine, transmission
Electrical powertrain	Electrical machines/generators, transformer
Energy storage	Batteries, double layer capacitors, flywheels
Cooling system	Heat exchangers, pumps, fittings
Fuel cell system	PEFC-Stack, compressor, expansion machine, recirculation pump, humidifier, Separator, media models for anode and cathode gas
Auxiliaries	General electrical load, air conditioning system
Vehicle environment	Tracks, driving cycles, environmental conditions
Vehicle control system	Component control, subsystem control, control strategy

the case of fuel cell vehicles. The corresponding component models are available in the library, thereby allowing representations of various alternative vehicle architectures to be created with low overheads. Systems for utilisation of waste heat flows, such as thermoelectric generators, can also be modelled and simulated using the components contained in the library. The main components of the library are validated by measured data. This allows statements to be made regarding energetic efficiency in the vehicle as a whole.

Examples of the models in the library include longitudinal dynamic models of a fuel cell hybrid vehicle, a battery vehicle, and a parallel and serial hybrid. The library will be supplemented successively with new vehicle configurations. Because of the wide range of possible applications for the library, it is sensible to prepare various models that are adapted to the key features of each individual problem. During the implementation, it was possible to draw from other freely available model libraries and, specifically, the PowerTrain library [4], also developed by the DLR, which contains components for the simulation of conventional powertrains. The Vehicle Interfaces library [5] is of particular importance. This is a library of interfaces for use with vehicle models designed to guarantee that model libraries from various providers can be combined with each other to produce a complete model. It also ensures that all models built on this library have a uniform external appearance.

Central components used in alternative powertrain systems are batteries, double-layer capacitors, and fuel cell systems. The following sections therefore examine the modelling of these components in more detail.

3.1 Batteries

The AlternativeVehicles library provides parameterised battery models at various levels of detail for a wide range of requirements. The simple battery model only considers the ohmic losses. Characteristic maps are used to specify the values of internal resistance and open-circuit voltage corresponding to various currents, temperatures, and state of charges.

For analyses that focus on dynamic processes, the library includes an impedance-based model in accordance with [6]. In addition to the ohmic resistance (R_i), this also considers electrochemical effects such as double layer (C_{DL}), charge transfer (R_{CT}), solid electrolyte interface (R_{SEI}, C_{SEI}), and diffusion ($\underline{Z}_W$). **Figure 1** shows the impedance-based model of a lithium-ion cell in Modelica.

Parameters for the impedance-based model are determined using impedance spectroscopy of individual cells. Taking the impedance spectra gained by this means, it is possible to determine the parameters of the electrical equivalent circuit with non-linear regression analysis. The algorithm adapts the model parameters until the sum of the deviations in magnitude and phase between the simulation and the measured values is minimal.

Modern batteries for hybrid and electric vehicles consist of several hundred individual cells, which are connected in series and parallel according to requirements. A simplification was introduced at this point in the battery model to keep the calculation time within acceptable

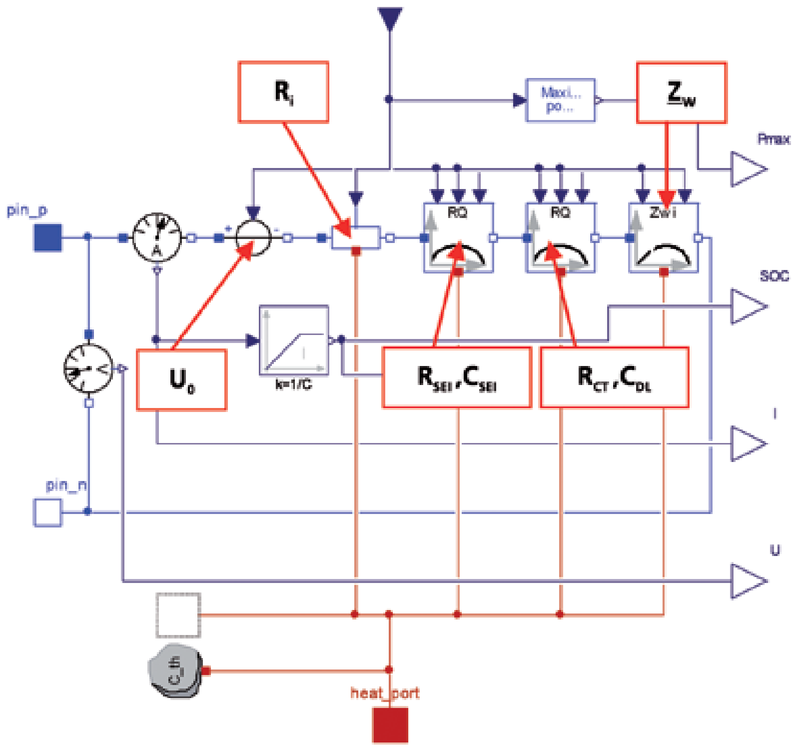


Figure 1: Impedance-based model of a lithium-ion cell in Modelica

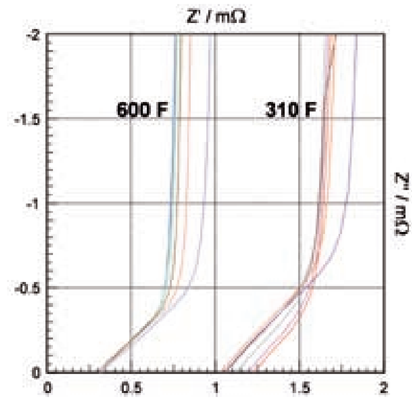


Figure 2: Nyquist diagrams of double layer capacitors with 310 and 600 F at various charging voltages

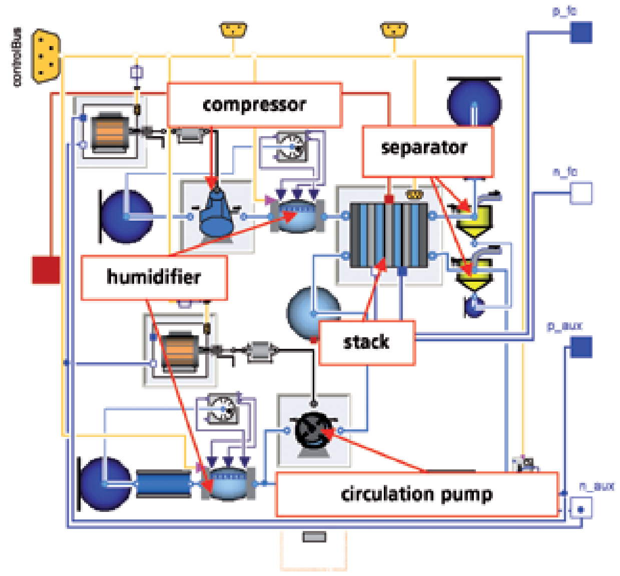


Figure 3: Implementation of fuel cell system model in Modelica

limits. It is assumed that all cells within the battery behave identically. Battery voltage and current are thus calculated from cell voltage and current using the current/voltage divider rule.

Thermal power loss is also determined in addition to the electrical behaviour. Using a suitable thermal model, it is possible to simulate the heating and cooling behaviour of the cell or battery, in order to establish the necessary cooling capacity of the battery, for example.

3.2 Double-layer Capacitors

As a further energy storage, particular for high peak power, double layer capacitors (supercapacitors) are in development. Various detailed models are also available in the AlternativeVehicles library for these storage devices. The model depth in this case ranges from simple models using idealised capacitors and ohmic resistance, through to models with voltage-dependent capacity [7] and complex impedance [6]. Depending on the modelling depth, the model is parameterised using current-voltage measurements or impedance spectroscopy and fitting algorithms.

At the Institute of Vehicle Concepts for example capacitors of 310 and 600 F at various charging voltages were measured by impedance spectroscopy, **Figure 2**. It can be seen clearly here that the 600 F double layer capacitor demonstrates considerably lower ohmic resistance than the 310 F capacitor. As with the battery model, not all cells are calculated individually at the module level, rather the connection between the stack and the individual cell is produced using current and voltage division.

3.3 Fuel Cell Systems

Modern fuel cell vehicle propulsion systems almost always use PEFC (polymer electrolyte fuel cell). Currently the model library therefore only considers this type of fuel cell system. Nonetheless there is a wide range of variants among the system architectures that have been implemented. For example, there can be significant differences in the pressure levels, the type of humidifier, and the type of hydrogen storage, with these differences having a major effect on the system components.

The system model is built up from zero-dimensional models of the main components. On the cathode side these are the air compressor, air-turbine, humidifier, heat exchanger, and water separator, **Figure 3**. There are additional models of hydrogen circulation pumps for the anode side. The fuel cell stack is implemented as a separate component comprising the anode and cathode reaction, the pressure losses, and the water transport. Special fluid models are available for the simulation of the media states and the water balance. Using this modelling approach, it is easy to construct different system architectures from the available components and to analyse these with respect to the dynamic behaviour determined by the media transport mechanisms. A simplified model is provided for system simulations that require high computational speeds. The simplified model assumes quasi-stationary states and dispenses entirely with the reproduction of media induced effects. The auxiliary energy requirement is interpolated from table values, as is the polarisation.

4 Application of the Alternative Vehicles Library: Comparison of Different Powertrain Concepts

The AlternativeVehicles library is suitable for a variety of different applications. In the past it has been used to carry out investigations into plug-in concepts [8]. Beyond this, the library has been utilised in an industrial contract to assess the future energy requirements of vehicles with electrical energy storage in order to analyse their effects on the electricity grid. The library has also been applied in conjunction with the Vector21 evaluation model developed by the Institute of Vehicle Concepts. Taking various predefined scenarios as a basis, this model is able to make forecasts relating to what proportion of a future vehicle fleet will use each individual type of powertrain technology and the influence that this will have on CO_2 emissions [9]. In the following exemplary application of the li-

Table 2: Definition of reference vehicle

Parameter	Unit	Value
Maximum velocity	km/h	150
Acceleration (0–100 km/h)	s	14
Internal combustion engine power	kW	53
Vehicle mass	kg	1050
Drag coefficient c_d	1	0.31
Frontal area A	m²	2
Rolling resistance k_{r0}	1	0.01

Table 3: Dimensioning of the powertrains

Parameter	Unit	REV	BEV	FCV
Vehicle mass	kg	1293	1245	1231
Electrical traction power	kW	55	55	55
Electrical energy storage capacity	kWh	16.2	24.3	3.2
Primary energy converter power	kW	35	–	55
Primary energy storage capacity	kg	30	–	4

brary, various alternative powertrain concepts are simulated to provide a comparison of their respective energy consumption and CO_2 emissions.

4.1 Vehicle Selection and Technical Assumptions

Of the multitude of possible powertrain concepts, the following are considered for this illustration: a battery electric vehicle (BEV), a range extender vehicle (REV) with a petrol engine, and a fuel cell vehicle (FCV). A conventional vehicle with a petrol engine is used as a reference vehicle according to the definition in **Table 2**.

One particularly important consideration for alternative powertrain concepts is the electric-only range. This has an influence on the dimensioning of the energy storage device and consequently on the mass of the vehicle. For the battery-powered vehicle (BEV) this is established as 80 km in actual use and for the vehicle with the range-extender (REV) it is 50 km. The assumed range of the fuel cell vehicle (FCV) is 400 km.

The driving style or driving cycle is an important criterion in determining the actual range of electric vehicles. In order to achieve realistic results, this example makes use of the Artemis driving cycles [10], which cover a broader range of maximum and average speeds in comparison to the New European Driving Cycle (NEDC).

Alongside driving style, the power consumed by air conditioning has a major influence on the actual electric range. All auxiliary equipment is represented as a combined single load of 1 kW. The overall mass of the vehicle is derived mainly from the specific masses of the powertrain components and the energy storage unit, with the traction batteries assumed to deliver 80 Wh/kg and 50 % useable capacity. The fuel cell system is assumed to achieve 3.2 kg/kW, with the hydrogen tank contributing a weight-related storage capacity of 4.8 %.

4.2 Simulation and Results

The rating of the simulated vehicles and powertrain concepts is based on the assumptions in Section 4.1. Dimensioning of the battery capacity for the BEV and REV and the hydrogen tank for the FCV is based on the energy requirements of the vehicles, including auxiliary equipment, using the Artemis driving cycles. It is assumed here that 29 % of driving is urban, 45 % road, and 26 % on motorways. A summary of the most important parameters relating to the simulated vehicles and powertrain concepts is given in **Table 3**.

With the simulation results of the REV, a distinction is made between the two operating modes: charge-sustaining mode (CS mode) and charge-depleting mode (CD mode), **Figure 4**. In CD mode the electrical storage device is drained until the minimum allowable state of charge (SOC) is reached. After this point, the energy supply is provided by use of the internal combustion engine-generator unit in CS mode, allowing the state of charge to be maintained in a defined range.

With the REV, the energy demand in CD mode is relatively low and approximately equivalent to that of the dedicat-

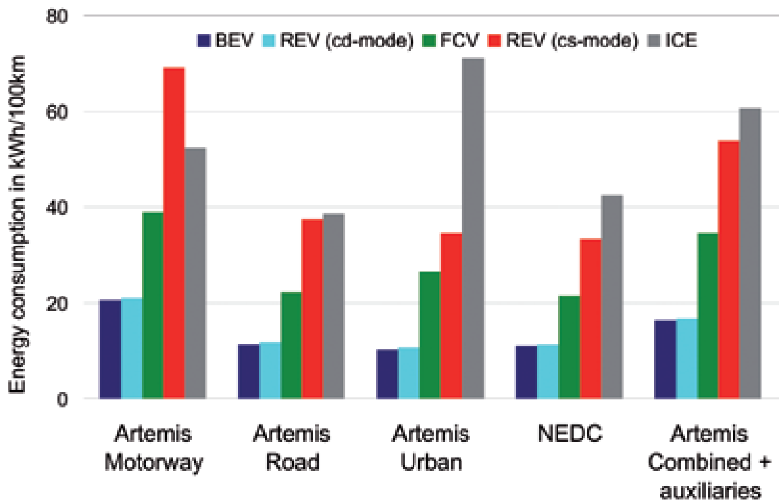


Figure 4: Energy consumptions for different driving cycles and powertrains

ed battery electric vehicle (BEV). By contrast, the energy consumption of the REV rises massively in CS mode when the internal combustion engine-generator unit is running, and for the Artemis motorway cycle it is even higher than the energy demand of the conventional vehicle (ICE). This behaviour can be attributed to the multiple conversion losses in the long energy conversion chain (ICE – generator – electric motor). In the Artemis urban cycle, the REV is able to offer very large reductions in energy consumption compared to a conventional vehicle due to recuperation of energy.

The fuel cell hybrid (FCV) places between the BEV and REV for all driving cycles, which can be ascribed to its system efficiency of 40 %, compared to efficiencies of 70 % for the BEV and 20 % for the REV (CS mode). It is also clear to see that the energy consumption in the combined Artemis cycle with auxiliary equipment is about 30 % higher for all powertrain types when compared to the NEDC without auxiliary equipment. This observation also corresponds to increased consumptions with conventional vehicles today.

The well-to-wheel CO_2 emissions are largely dependent on the primary energy source, **Figure 5**. Manufacturing and recycling are not included in the vehicle CO_2 emissions. As such, electrical energy from renewable energy sources results in the lowest CO_2 emissions. With the current German energy mix and hydrogen from natural gas, the emissions rise markedly. The highest CO_2 emissions are generated by the conventional vehicle powered by fossil fuels. It can also be seen here that all the powertrain variants produce significantly higher CO_2 emissions when using the combined Artemis cycle with auxiliary equipment as opposed to the NEDC.

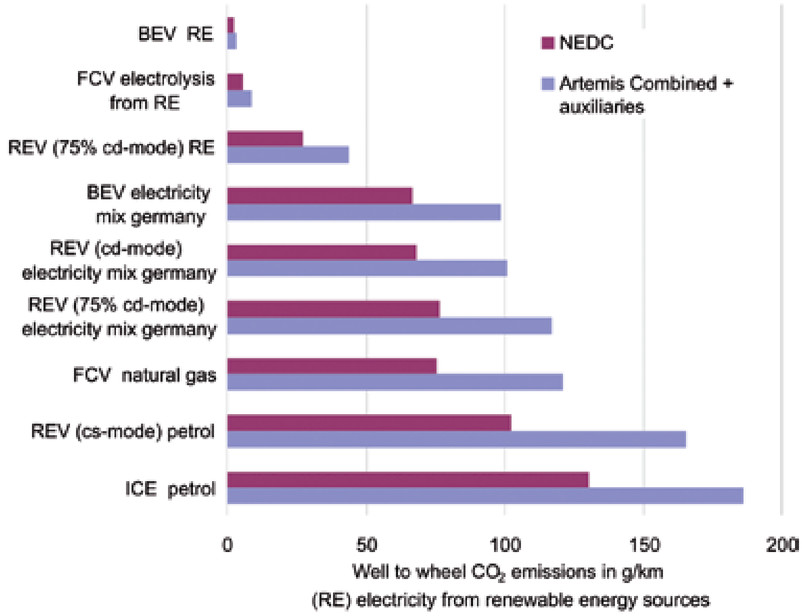


Figure 5: Well-to-wheel CO_2 emissions for different powertrains

5 Summary and Outlook

The AlternativeVehicles library by the German Aerospace Center (DLR) is a powerful software tool for the energy flow analysis of alternative powertrains. At the present state of development, all the major components and alternative powertrain variants have been catered for. Models included in the library range from parameterised component models to whole vehicle models featuring various powertrain concepts. The object-oriented, component-based approach allows models to be developed further and new powertrain configurations to be added.

In addition to ongoing updates to and expansion of the library, there are plans to construct a hardware-in-the-loop environment. This will allow control units to be developed in conjunction with the library and sub-systems to be tested under conditions close to those of a real vehicle. It will also be possible to link the library to the climate roller test bench and driving simulator at the DLR, thereby allowing, among other possibilities, the development and testing of forward looking driving strategies.

References

[1] Fritzson, P.; Olsson, H.; Otter, M.: Modelica Specification. September 2007

[2] Fritzson, P.: Principles of Object-oriented Modeling and Simulation with Modelica 2.1. Piscataway, NJ [et al.]: IEEE Press [et al.], 2004

[3] Bichet, F.; Brozzu, P.; Otter, M.: Eurosyslib Project Profile. Itea2 Program. Information Technology for European Advancement. www.itea2.org

[4] Schweiger, C.; Dempsey, M.; Otter, M. : The Powertrain Library: New Concepts and New Fields of Application. In: Schmitz, Gerhard [Ed.]: Proceedings of the 4th International Modelica Conference, pp 457-466, 4th International Modelica Conference, Hamburg, Germany, 2005-03-07/08

[5] Dempsey, M.; Gäfvert, M.; Harman, P.; Kral, C.; Otter, M.; Treffinger, P.: Coordinated Automotive Libraries for Vehicle System Modelling. 5th International Modelica Conference, Vienna, 2006

[6] Buller, S.: Impedance-Based Simulation Models for Energy Storage Devices in Advanced Automotive Power Systems. Dissertation, RWTH Aachen, 2002

[7] Zubieta, L.; Bonert, R.: Characterization of Double-Layer Capacitors for Power Electronics Applications. IEEE Transactions on Industry Applications, Vol. 36, No. 1, January/February 2000

[8] Schmid, S. A.; Hülsebusch, D.; Stiftl, J.; Ungethüm, J.; Pohl, S.: Bewertung von Fahrzeugkonzepten mit seriellem Plug-In-Hybrid-Antrieb: Modellierung, Betriebsstrategien und CO_2-Bilanz. In: 6. VDI-Tagung Innovative Fahrzeugantriebe, Dresden, 6. und 7. November 2008

[9] Mock, P.; Hülsebusch, D.; Ungethüm, J.; Schmid, S. A.: Electric Vehicles – A Model-based Assessment of Future Market Prospects and Environmental Impacts. EVS24 International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium, Stavanger, 2009

[10] André, M.: Real-world Driving Cycles for Measuring Cars Pollutant Emissions. Part A: The Artemis European Driving Cycle. Institut National de Recherche sur les Transports et leur Securité (INRETS), Bron, 2004

Acknowledgements

The authors would like to extend their thanks to the German Federal Ministry of Education and Research for supporting the further development of the AlternativeVehicles library through the framework of the European ITEA2 project Eurosyslib.