COVER STORY

Integrating Powertrains into Vehicles

OPTIMISING
Dynamic Operating Procedures
in the Truck with Manikins

LIGHTWEIGHT DESIGN POTENTIAL
for a Light Commercial Vehicle
with Lightweight Forging

MODELLING
of Joint Dampings
in Engines

/// **GUEST COMMENTARY** Steffen Müller [TU Berlin]   /// **INTERVIEW** Peter Schöggl [AVL]

Autonomous

Dear Reader,

Automated driving has now also become an issue for top-level politicians. It was even mentioned by the US President in his recent State of the Union Address. Barack Obama sees autonomous driving as the future for our century. In his address, he said he wanted to "put tens of thousands of Americans to work building a 21st century transportation system". Obama left it to his Transportation Secretary, Anthony Foxx, to fill out the details a few days later at the Naias in Detroit. Together with Ford, Delphi and Google, Foxx announced that the National Highway Traffic Safety Administration (NHTSA) would be proposing best-practice guidance to industry in the next six months on establishing principles of safe operation for fully autonomous vehicles.

The key point is the interpretation of functional safety. Vehicle manufacturers can submit regulatory interpretation requests to NHTSA, for example as BMW recently did concerning its remote self-parking feature. BMW's assistance system did not at first comply with the safety standards in some federal states, which caused the company to submit a request. Foxx confirmed that the feature now complies with the standards. Such standardisation issues are becoming increasingly important, as the tests are complex and expensive. Open and direct communication must be established not only among OEMs, suppliers and development service providers, but also with authorities such as NHTSA.

Suppliers too are involved in a similar exchange of ideas. For example, Continental has launched an internet platform at www.2025AD.com and invites people to take part in a global debate on the future of automated driving.

But do drivers really want autonomous driving at all? A working group at Arthur D. Little examined the question of which companies are most trusted by end customers to develop a reliable autonomous vehicle to production readiness. Surprisingly, Google and Apple achieved the highest scores – except in Germany, where the capability of the two companies to launch an autonomous vehicle onto the market is trusted by only 14 and 10 % of the respondents respectively. Germans have more confidence in domestic premium manufacturers. For example, 38 % would prefer autonomous vehicles from Audi and Volkswagen, while 37 % would favour models from Mercedes-Benz and BMW. It means that Google und Co., as well as OEMs, still have a lot of persuading to do.

Legal, insurance and technical questions still need to be answered, and the ideal platform for this is the Second International ATZ Conference on Driver Assistance Systems on 13 and 14 April in Frankfurt/Main, where experts will discuss the transition from assistance functions to automated driving. It would be nice if developers can present their finished series-production vehicles in 2025 and proclaim, just like Barack Obama did back in 2008: "Yes, we can."

Dipl.-Ing. Michael Reichenbach
Deputy Editor in Chief
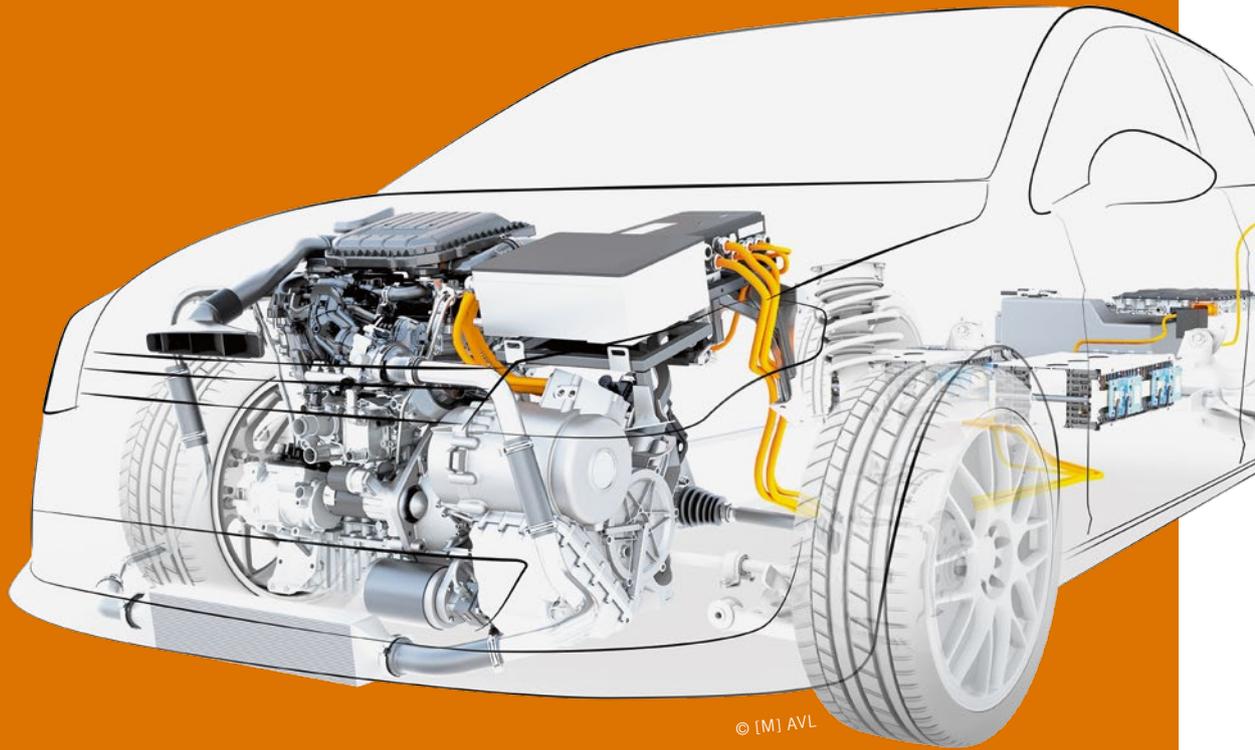
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COVER STORY

Integrating Powertrains into Vehicles

The increasingly stringent legislation on CO_2 emissions that has been introduced in recent years and the accompanying electrification of the powertrain both mean that a new approach is needed to the vehicle package. Scalable platforms are a promising solution because they make it easier to integrate different types of powertrain. Equally, it is more important than ever that the development processes for the powertrain and the vehicle as a whole are fully networked.

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In the Arvida project, applications for the
ergonomic design of dynamic operating
procedures in commercial vehicles are
being implemented and validated.

© Lightweight Forging Initiative

For a medium-sized passenger car, forging
allows a weight reduction of 42 kg in power-
train and chassis parts. How about a light
commercial vehicle?

© University of Stuttgart

At the University of Stuttgart a process was
developed which facilitates the consideration
of joint damping for the simulation of complex
structures such as engines.

© Pablo Castagnola

COVER FIGURE © Volvo

© Volkswagen

Amnon Shashua (left) and Herbert Diess

Volkswagen | Mobileye |
Joint Development of High-precision Maps

Volkswagen is entering into a strategic partnership with Mobileye, a technology leader in the field of automated image processing. The companies signed a letter of intent to this effect at the Consumer Electronics Show (CES) 2016 in Las Vegas. The central focus of the joint venture is camera-based real-time image processing technology which, in conjunction with highly precise digitised maps, is the key to autonomous driving. The technology company Mobileye develops optical sensor systems, which will be used in the front cameras of Volkswagen vehicles in the future.

Valeo | Peiker |
French Acquire Connectivity Expertise

Automotive supplier Valeo recently announced the acquisition of Peiker, underlining the French company's intention to strengthen its activities around the vehicle of the future that operates autonomously, integrally and intuitively. The acquisition of Peiker, which is expected to have generated sales of around 310 million euros in 2015 "is likely to boost Valeo's 2016 results", says Jacques Aschenbroich, CEO at Valeo, commenting on the purchase. However, approval by the relevant competition authorities remains pending.

© Peiker

The purchase of Peiker gives Valeo access to technological expertise in the field of networked vehicles

Johnson Controls | Adient Produces Automotive Seating and Interiors

© Johnson Controls

From October 2016 onwards vehicle seats will be manufactured by Adient

Johnson Controls, an automotive supplier special-ised in developing and manufacturing automotive seating components and systems, has called its subsidiary "Adient". This is the name of the busi-ness unit which will be spun off in October 2016 and will be a new publicly traded company making automotive seating and interiors. "Adient is a Latin word that means to accept and advance a situation or a stimulus", said Bruce McDonald, current Johnson Controls Vice Chairman and future Chairman and Chief Executive Officer of Adient. The company will increase its investment in innovation in order to gain market share and provide added value for customers and shareholders. Adient is expected to disclose further detailed financial information in late March or early April 2016.

Preh | **Christoph Hummel Becomes Chairman of the Board**

© Preh

Christoph Hummel

At the beginning of January 2016, Christoph Hummel (49) took over from Dr. Michael Roesnick (62) as Chairman of the Board of Preh GmbH. Dr. Roesnick retired at the end of December after almost 17 years at the head of the company. The change in the management team and the reduction in the number of directors from five to four have also led to a reallocation of responsibility for the individual divisions. As well as chairing the board, the new CEO will also be responsible for the Sales/Marketing, Project Management, Electric Vehicle, Preh IMA Automation and Quality business units.

MAN | **Executive Board Member Bernd Maierhofer Leaves**

© MAN

Bernd Maierhofer

Bernd Maierhofer, Executive Board Member for Research & Development at MAN Truck & Bus, left the company at his own request on 31 December 2015 after 23 years. He and the supervisory board mutually agreed on the rescission of his contract. Maierhofer had been Executive Board Member for Research & Development since 2012 and had previously held various management positions in the executive board. Dr. Carsten Intra, Executive Board Member for Production & Logistics, has assumed the additional role of Executive Board Member for Research & Development.

Renault-Nissan | **Timeline for Autonomous Driving**

© Renault

Carlos Ghosn

Carlos Ghosn, Chairman of the Renault-Nissan Alliance, has set the organisation a target of zero emissions and zero fatalities. In order to achieve this, the Renault-Nissan Alliance will launch more than ten new vehicles with autonomous driving technology over the next four years. By 2020, the alliance partners plan to install the technology in mainstream, mass-market cars which will be available at affordable prices. The new models will go on sale in the USA, Europe, Japan and China. In addition, Renault-Nissan will launch a suite of new applications that will make it easier for people to stay connected to work, entertainment and social networks in their cars.

Dr. Johannes Liebl
Editor in Charge
ATZ | MTZ | ATZelektronik

Making Carefully Considered Investments

Despite the Volkswagen emissions scandal, the automotive industry once again had a record turnover last year, together with high profits. How can it now safeguard its future?

Digital networking is forcing the industry to take a new approach. Driver assistance systems will be the factor that determines purchase decisions. But to ensure its future success, the automotive industry must become more open to other sectors and investments. The climate summit in Paris and the reports on air quality and driving bans which come not from far-away China but from Italy will change our society's system of values even further. We can expect to see very stringent CO_2 restrictions and exhaust emissions legislation being introduced in 2025. The industry must invest more in electrification, but the storage technology and the infrastructure are still inadequate. The short-term solution is plug-in drive systems which need to be more widely used to ensure that we comply with the fleet limits that have been laid down. These investments are unavoidable and must be given the highest priority.

The alternative is to produce synthetic cabonneutral fuels and lubricants from the fossil-based CO_2 emissions from coal and gas power stations which will be generating a large proportion of our electricity in the long term. Laboratory tests have already proved the effectiveness of these processes. This solution will apply not only to new cars, but also to commercial vehicles and the existing car fleet. In addition, the products and infrastructure that we have already invested in worldwide could still be used.

We need to take the next step forward and support this visionary approach. This is a fascinating prospect which we in the ATZ/MTZ Group and at the engine congress in Baden-Baden will continue to support.

Vehicle Interiors for Automated Mobility Strategies

Even though it will be a while before assistance systems for automated driving are fully implemented, OEMs and suppliers are already considering the question of what vehicle interiors might look like when they are adapted to such assistance systems. The first prototypes and concept vehicles are showing the way.

CONVEYING A SENSE OF SECURITY

The vehicle interiors of today and tomorrow have to fulfil numerous and often conflicting demands. Coherence, emotions, comfort, safety and functionality must all merge together to form an overriding whole, while at the same time maintaining the respective brand identity [1]. The most important challenges in the development of interiors include conveying a sense of security. Inseparably connected to this for the end user is also the knowledge that the vehicle is as safe as possible. This aspect of interior design is becoming particularly important on the eve of the introduction of semi-automated and fully autonomous mobility concepts.

For example, studies with test persons at Valeo showed that an automated vehicle only has real added value for the end customer if they are able to make sensible use of the time during automated driving. The opportunity to hand over control to the vehicle in certain situations means that drivers will have new expectations regarding the range of entertainment available in the vehicle. At the same time, however, new solutions must be found in order to build up trust in the driver assistance systems. For instance, drivers want complete system transparency and information on what the vehicle is detecting in its environment and what the vehicle's next course of action is and why [2].

As long ago as 2002 at the Innovation Symposium of what was then Daimler-Chrysler AG, Kay Schattenberg, who was at that time a research assistant in the Human-Machine Interaction department, pointed out: "Putting new technologies into the vehicle is a major step towards the future of the automobile. A further key challenge which research is addressing is to adapt these technologies to people's needs, to recognise their wishes and ideas in advance and to include these in the design of new products and applications."

Twelve years later, Prof. Dr. Herbert Kohler, Head of Group Research & Sustainability at Daimler AG, said on the occasion of the Tecday Autonomous Mobility: "The new centre of Digital User Experience Design allows our designers and engineers in Sindelfingen, Sunnyvale and Beijing as well as in all other international facilities to work in close cooperation on User Experience and User Interaction concepts of the future to create an emotional, intuitive and highly aesthetic design for the most intelligent solutions."

MOBILE LIVING SPACE AS A LUXURY LOUNGE

To provide a realistic look on the future, Mercedes-Benz presented its interior concept of an autonomous luxury saloon as a virtual 360° experience at this event. For the design of the interior, the engineers, designers and futurologists have evolved an interdisciplinary scenario and thought through the freedoms that autonomous driving brings: more space, more time, more ways to interact. "With this visionary interior concept, we are defining the luxury of the future", said Gorden Wagener, Head of Design at Daimler AG. "We have achieved a symbiosis of the virtual and real worlds and realised the most intelligent solutions in highly aesthetic design."
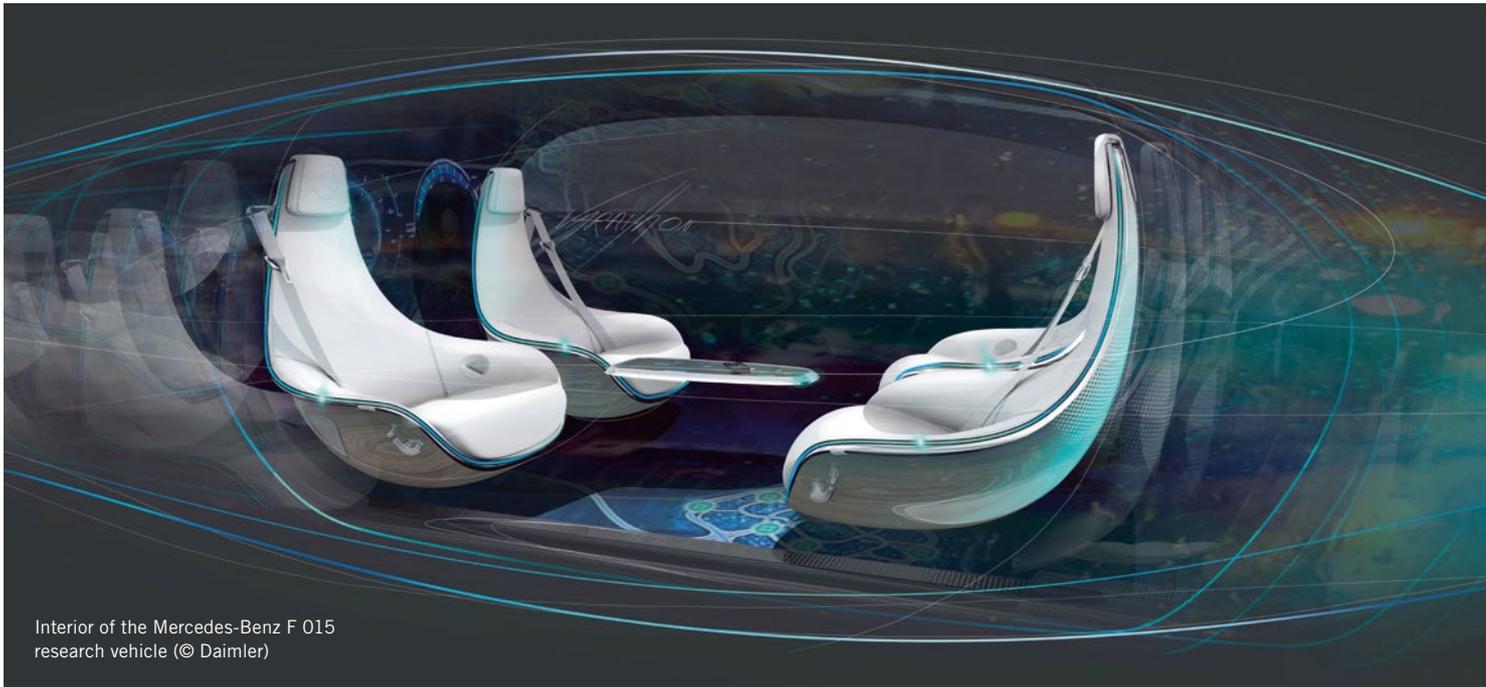
Interior of the Mercedes-Benz F 015 research vehicle (© Daimler)

The pivotal feature of the innovative interior concept is the variable seating system, with four rotating lounge chairs that allow a face-to-face seat configuration. This enables the front passengers to turn around and talk directly to the other passengers while on the move, or to focus their attention towards the front as necessary for manual driving. An extendable steering wheel offers the driver the appropriate options for this purpose.

In the meantime, this concept has been further developed to create the Mercedes-Benz F 015 Luxury in Motion research vehicle. Its basic theme is the continuous exchange of information between the vehicle, its passengers and the outside world. To achieve this, six displays are installed all around in the interior. Passengers are able to interact intuitively with the connected vehicle by means of gestures or by touching the high-resolution screens. As a result, the research vehicle becomes a digital experience space and a retreat for relaxation or working.

The Vision Tokyo design showcar, which was unveiled at the end of 2015, even goes a step further. According to the company, the concept car is an "homage to the urban Generation Z, the cohort of people born since 1995, who have grown up with the new media".

The role of the vehicle has changed for this global generation, the company claims; it is no longer simply a means of getting around, but a digital, automobile companion.

Instead of seats, the Vision Tokyo has a large oval-shaped couch. This lounge-style arrangement allows everyone on board to enjoy the benefits of autonomous driving. With the car in autonomous driving mode, they are able to relax and chat, without having to worry about steering through the dense traffic. Apps, maps and displays emanating from the entertainment system are presented as three-dimensional holograms within the interior space.

If the Vision Tokyo needs to be controlled manually rather than driving autonomously, a seat facing in the direction of travel can be released from the centre of the couch at the front. The steering wheel, too, is then moved from its standby position into driving position.
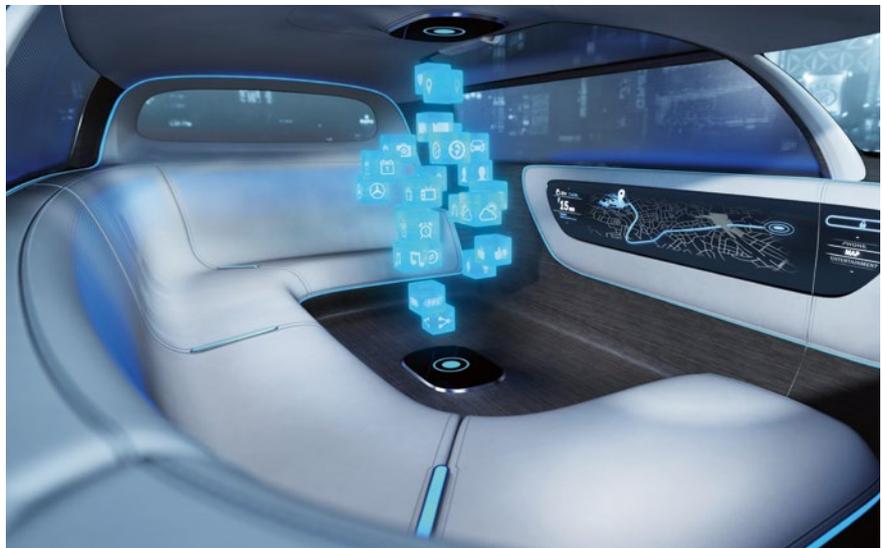
Oval-shaped couch in the Vision Tokyo concept vehicle (© Daimler)

Nissan's interior visions in the IDS Concept vehicle (© Nissan)
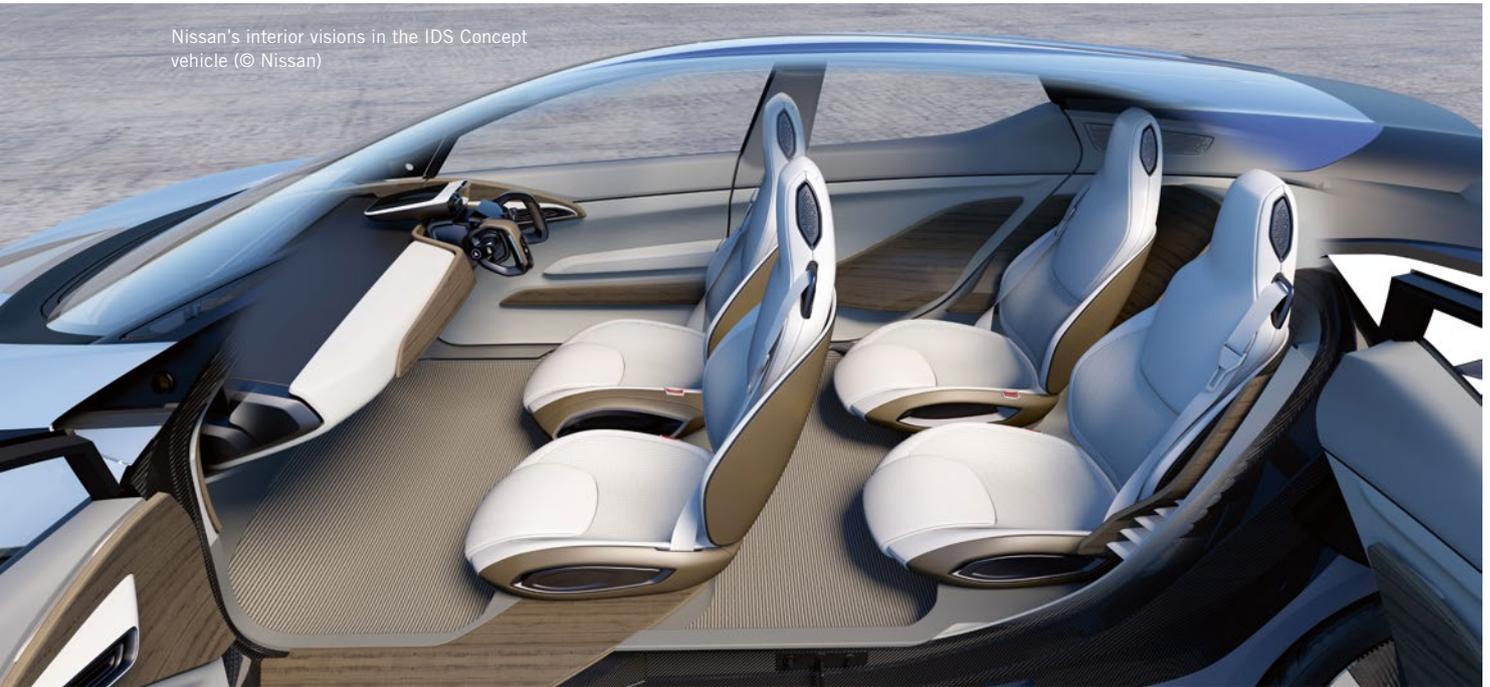
COMPARABLE VISIONS

Nissan's visions of future mobility are very similar. They are illustrated by their concept vehicle IDS Concept, which was also presented in autumn 2015 at the Tokyo Motor Show. The IDS Concept is a hatchback saloon with a long wheelbase that offers space for four adults. The hollow structure of the A-pillars helps to improve visibility by reducing blind spots and also contributes to the feeling of open space.

According to Nissan, the cabin becomes even more spacious when the driver selects Piloted Drive mode. In this mode, the steering wheel recedes into the centre of the instrument panel and a large flat screen comes out. Various driv-

© YFAI

Han Hendriks
Vice President Advanced Product Development & Sales at Yanfeng Automotive Interiors

//

2 QUESTIONS FOR ...

ATZ _ Han Hendriks, automated driving is on everyone's lips. What are your visions for the interiors of automated vehicles?
HENDRIKS _ We are working intensively on this question and are developing technical solutions which intelligently use the changed cockpit environment and which will match the lifestyle of future generations. If cars drive autonomously and the occupants no longer have to concentrate on the traffic, there will be a need for new mobility concepts and additional storage space. We presented some examples of how life in the vehicle can be made more comfortable in the future at the IAA in Frankfurt.

Are you referring to your Innovation Demonstrator 2016 concept vehicle?

Yes. This innovation demonstrator features more than 30 technologies – most of which are already market-ready – that will improve interior comfort and convenience in autonomous driving in the future. As soon as the vehicle is switched to auto-drive mode, the steering wheel automatically retracts to create more space. A rotating table extends from the newly designed centre console and, in combination with the seat back upper which rotates 18° outward, allows the driver and front-seat passenger more space to interact more comfortably with each other, as well as with rear-seat passengers. This is what the new mobile freedom might look like from today's perspective.

More storage space for handbags, mobile phones and other things that passengers consider necessary during autonomous driving (© YFAI)

ing-related operations are handled either automatically or by voice and gestures from the driver. The interior, which is comprised of natural materials such as mesh leather, is illuminated by soft light. All four seats rotate slightly inwards, facilitating easier conversation.

Manual Drive mode is quite different. The interior transforms again to put the driver in control. All seats face forward; the steering wheel appears along with instruments and a head-up display that shows the route and other driving information. The interior lighting switches to blue, a colour that the company claims stimulates the ability to concentrate. "In every situation, it is about giving the driver more choices and greater control. And the driver will remain the focus of our technology development efforts", said Nissan's CEO Carlos Ghosn at the Tokyo Motor Show.

SUPPLIERS' ACTIVITIES

It is not only vehicle manufacturers but also suppliers who are already working intensively on the interiors of autonomous vehicles. With its Innovation Demonstrator ID 16, the new interior supplier Yanfeng Automotive Interiors (YFAI), which was formed as a joint venture between the companies Yanfeng Automotive Trim Systems and Johnson Controls in summer 2015, is clearly thinking in a similar way to Daimler and Nissan.

Swivelling seats, large tables and connectivity for mobile phones are now standard components of autonomous driving. And just like their smartphones, the passengers can customise the interior to their own individual taste. The YFAI designers have many solutions up their sleeve for driving in 2025 which will turn the car into an extended living room and workplace. Intelligently equipped surfaces, including such features as surface heating and display functions, increase the utility value in the vehicle interior. Further refined ambient lighting concepts combine feel-good design with subconscious signalling functions.

What is more, YFAI believes that storage space in the vehicle is becoming increasingly important, as passengers will take more things on board in order to occupy themselves with other activities during autonomous driving. For that reason, the newcomer is working on new and larger storage possibilities and on practical, easy-to-access storage areas that will allow all kinds of objects to be stowed easily and safely. For example, there is an additional storage box for a handbag and a compartment for a mobile phone.

EXAMINING BEHAVIOURAL CHANGES

The French supplier Faurecia is starting one step earlier. Together with the Center for Design Research at Stanford University, Faurecia first wants to study potential behavioural changes among the passengers of autonomous vehicles. They have already identified several areas that the automotive industry should focus on to mitigate consumer apprehension towards autonomous driving modes.

The most important points include creating a sense of security among the passengers and more user-friendly control systems. For example, the research partners report that drivers often find the use and interface of these systems complicated and sometimes turn them off, thus reducing their benefit.

REDUCING APPREHENSION

This approach by Faurecia and Stanford University is already very significant because one of the key aims is to reduce apprehension towards autonomous vehicles. For example, according to a study by Dekra, German drivers in particular are very sceptical towards autonomous driving. The report says that only 8 % of those questioned in Germany believe that completely autonomous cars will be successfully introduced in the next ten years. 32 % expect that it will take more than 20 years, while a further 31 % even believe that completely autonomous vehicles will never become reality.

These latest survey findings are in agreement with scientific research. For example, scientists at the Technical Uni-

versity of Darmstadt [3] report on extremely varied estimations regarding a market launch: "All options are mentioned – with predictions ranging from 10 or 20 years to never. This is also due not least to the fact that there is little understanding of the range of functions of an autonomous vehicle."

DIFFERENT DEFINITIONS

The Humboldt University in Berlin and the DLR (German National Aeronautics and Space Research Centre) are also observing a lack of clear definitions [4]. We sometimes speak of automated driving or driverless vehicles, and on other occasions of semi-automated or fully autonomous driving. "Often, it is not clear what kinds of means of transport are involved, which concrete possibilities and potentials and which risks are related to them and which challenges need to be overcome on the way towards autonomous driving", the authors write [4].

Dekra CEO Stefan Kölbl even believes that vehicle technology itself is not the crucial factor: "After all, a number of manufacturers have already proven that vehicles are technically capable of driving autonomously. Various manufacturers have already proven from a technical point of view that vehicles are able to drive autonomously." For him, the real challenges lie more in the framework conditions, which require "very clear standards, regulations and controls" in this respect.

OUTLOOK

Against this background, it must be understood that nice ideas for possible interiors for automated vehicles are at best a visionary view into the future. Before these interiors can be realised, there is still a lot of basic work that needs to be done. Not only technically, but also with regard to legislation and, not least, the ability for innovations to be approved and licensed for use.

Stefan Schlott

REFERENCES
[1] Schlott, S.: Die Sehnsucht nach Einzigartigkeit stillen. In: ATZ 113 (2011), No. 11, pp. 870-871
[2] Reilhac, P.; Moizard, J.; Kaiser, F.; Hottelart, K.: Cockpit Concept for Conditional Automated Driving. In: ATZworldwide 118 (2016), No. 3, pp. 42-46
[3] Matthaei, R.; Reschka, A.; Rieken, J.; Dierkes, F.; Ulbrich, S.; Winkle, T.; Maurer, M.: Autonomes Fahren: Handbuch Fahrerassistenzsysteme – Grundlagen, Komponenten und Systeme für aktive Sicherheit und Komfort. Wiesbaden: Springer Fachmedien, 2015, pp. 1139-1165
[4] Lenz, B.; Fraedrich, E.: Gesellschaftliche und individuelle Akzeptanz des autonomen Fahrens. In: Maurer, M.; et al. (Ed.): Autonomes Fahren – Technische, rechtliche und gesellschaftliche Aspekte. Berlin, Heidelberg: Springer-Verlag, 2015, pp. 639-660

WHAT DO WE THINK?

"Driving the Lawyers"

According to a study by PwC, it will take another five to ten years before autonomous driving really takes off. The automotive industry is already doing its homework. But the inhibiting factors are laws, regulations and international agreements that stem from an analogue era. It is a fact that many relevant regulations have long since been overtaken by the state of the art in technology. It is now high time that they were adapted to the possibilities of the digital age. The industry therefore has a dual challenge at the moment. It must continue to develop its technology while at the same time trying to convince the ministerial lawyers and drive them forward. A thankless task.

Stefan Schlott
is Correspondent of the ATZ.
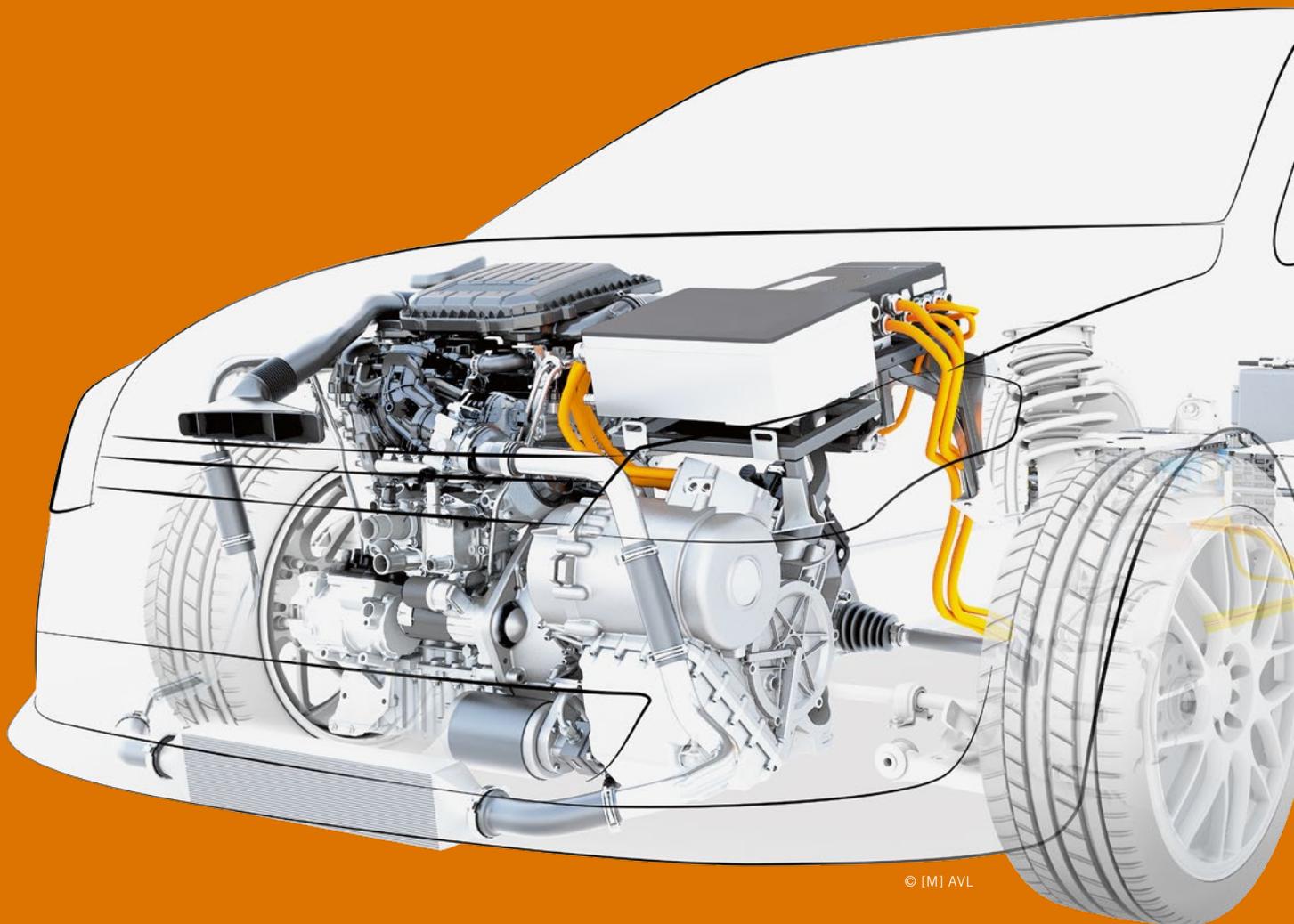
Integrating Powertrains into Vehicles

The challenge of making powertrains as compact as possible and finding smart solutions for integrating them into vehicles is almost as old as the history of the motor car. The increasingly stringent legislation on CO_2 emissions that has been introduced in recent years and the current target of 95 g CO_2/km by 2020 are making this subject more important than ever. Additional exhaust treatment systems, engine downsizing and alternative drive concepts are the key features in the discussion. In addition, engine mountings will have to perform new tasks. On the one hand there is the reduction in the installation space available with alternative drive concepts and the need for agile handling, while on the other there are demands for increased isolation from vibration. This means that conflicts between the requirement for a stiff bearing concept, soft engine mounts and reduced damping are almost inevitable.

It is clear that current and future development trends require a new approach to vehicle packages. Scalable platforms are an obvious solution. They simplify the process of integrating different types of powertrains from different performance classes and auxiliary equipment because of their standardised, modular architecture. The largest proportion of development costs is currently being spent on reducing CO_2 emissions, but according to Peter Schöggl from AVL: "Driver assistance systems are in second place". This concerns not only the important subject of safety, but also the use of driver assistance systems to reduce emissions and, most importantly, predictive driving and increasing driving pleasure.

This last factor will play a considerable role in ensuring that low-emission cars appeal to customers. These 95 g/km cars can only make a significant contribution to the calculations if they are actually sold. Emotional factors will continue to be important in future and will still have a key influence on the decision to buy. Drivers' fascination with low-emission cars will be determined by attributes such as dynamics, handling, sound and ride comfort, alongside fuel consumption and emissions. We will only be able to achieve the required targets by ensuring that a networked development process is in place for both the powertrain and the vehicle.

Alexander Heintzel

Volvo Powertrain Integration into Complete Vehicle

The Volvo XC90 is the first car application on the new Scalable Product Architecture (SPA) of the company. As part of the SPA, a new domain based electrical architecture – an Autosar 4 network with a FlexRay backbone – is employed. Due to this architecture, complex demands even for the integration of different powertrains of the Volvo Engine Architecture (VEA) arise.
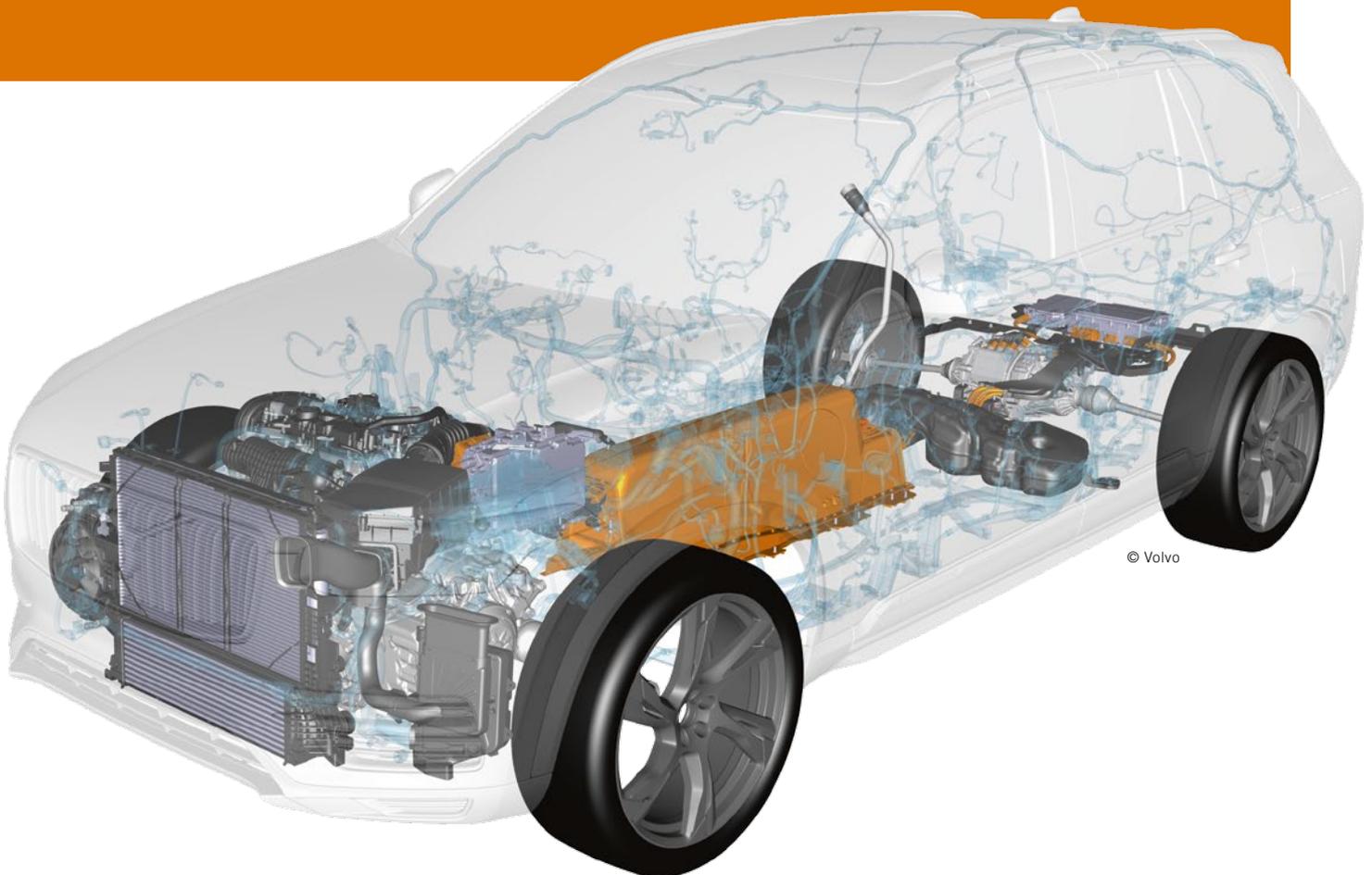
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PLATFORM STRATEGY

Since autumn 2013 Volvo Car Group has launched Drive-E powertrains based on the Volvo Engine Architecture (VEA) [1], and in summer 2014 a new vehicle platform, SPA (Scalable Product Architecture) was presented. As part of the SPA, a new domain based electrical architecture has also been developed.

In 2015 Volvo Car Group launched the all new XC90, the first car application on the new SPA. The Drive-E powertrains in the XC90 are all based on the compact and modular gasoline and diesel engine architecture VEA. The engines on the new architecture are paired with installation- and exhaust aftertreatment systems designed for a maximum degree of uniformity and modularity in the line-up containing of various fuel types and power positions. In the XC90 the powertrains were for the first time integrated in the completely new domain based electrical architecture, a world first Autosar 4 network with a FlexRay backbone used to separate different applications areas. The launch of the powertrain line-up of the first model year of XC90 was completed during autumn 2015, and consists of, besides the internal combustion engine powertrains, the all new gasoline plug-in hybrid.

These technologies are among the major cornerstones on which Volvo products will be based on for a long time to come. Not only do they consti-

tute the technical base for Volvo Cars in meeting existing and future environmental and safety regulations, but they are also enablers for meeting the customer demands in the premium segment.

ENGINE ARCHITECTURE

The main objective of the Drive-E powertrain strategy was to establish a flexible single engine platform for both gasoline and diesel engines. The four-cylinder engines have a high degree of commonality within, and between, the two fuel families. Furthermore, the power span of both the gasoline and diesel engine sub-families was from the beginning planned to contain all variants, from entry level up to the top-of-the-line plug-in hybrid. When the roll-out of the first generation Drive-E engines was completed during 2015, Volvo Cars had reduced the number of engine architectures managed in Volvo vehicles, from eight in peak, to one.

The strategy of letting the SPA-based XC90 only feature the compactly designed 2-l four-cylinder engines created opportunities, in terms of front packaging, for several technical and attribute improvements, e.g.:
– a front structure designed to comply with the crash safety legislations of tomorrow
– a double wishbone suspension for improved handling performance
– a short front overhang, which is a key contributor to premium car proportions, **FIGURE 1**.
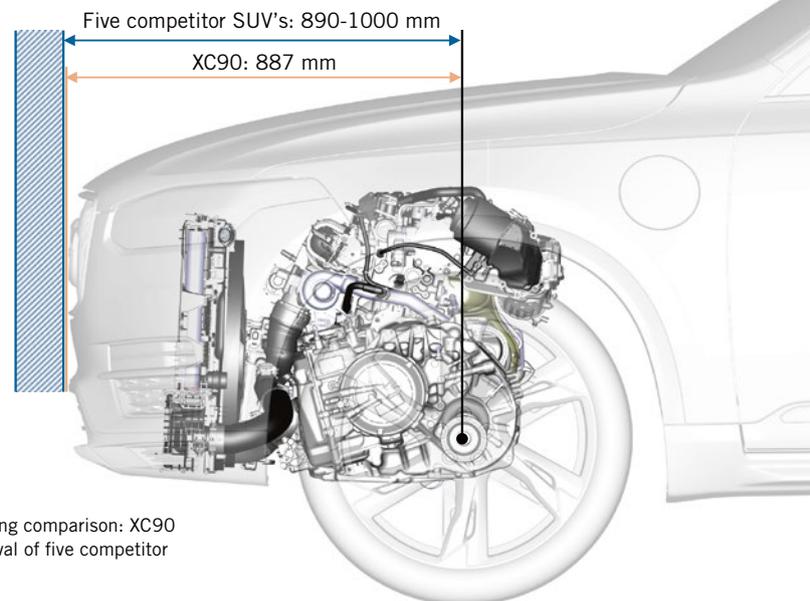
FIGURE 1 Front overhang comparison: XC90 versus min-max interval of five competitor SUV's (© Volvo)

The wide range of power levels of the compact engine family was achieved mainly by use of modular boosting. This was done in collaboration with the development of the commonised exhaust gas aftertreatment system [2] and other interfacing systems with the common target to reach a high degree of commonality in the powertrain integration.

DRIVE-E POWERTRAINS IN CAR

The powertrain mount system was in the XC90 challenged to install four-cylinder high torque engines transversally and with a premium SUV attribute profile. Multidisciplinary Design Optimization (MDO) was used to develop a robust system for all power levels with optimised NVH, driveability and vehicle dynamic performance. The mounts were positioned close to the Neutral Torque Axis (NTA) of the engines in order to reduce idle and wide open throttle vibrations. Advantages with the NTA mount system are that the forces generated by torque are controlled by the torque-rods, for which the body is less vibration sensitive, and the powertrain modal behaviour can be tuned by the torque-rods independently of the load carrying mounts. All interfaces are common to reduce complexity and cost.

For the Air Induction System (AIS) the positions of the turbo compressor in- and outlets, charge air cooler and throttle connections are fixed, which enables high degree of commonality of the AIS, **FIGURE 2**. The AIS is adapted for the different boosting systems of the engines: single- or two-stage turbocharging or a combination of super- and turbocharging. To enable the high power outputs of the compact 2-l engines, much care was taken to optimise the airflow through the AIS and the stand alone charge air cooler, in XC90 located beneath the radiator and condenser. Low pressure losses were achieved by extensive use of Computational Fluid Dynamics (CFD).

The demand for a short front overhang of the XC90 determined the engine installation position. However, the limited space in front of the engine together with high demands on charge air cooling and climate performance became a challenge for the cooling module. The goal was to develop a modularised system for all SPA vehicles by reusing and combining technical solutions. The cooling


= Unique parts
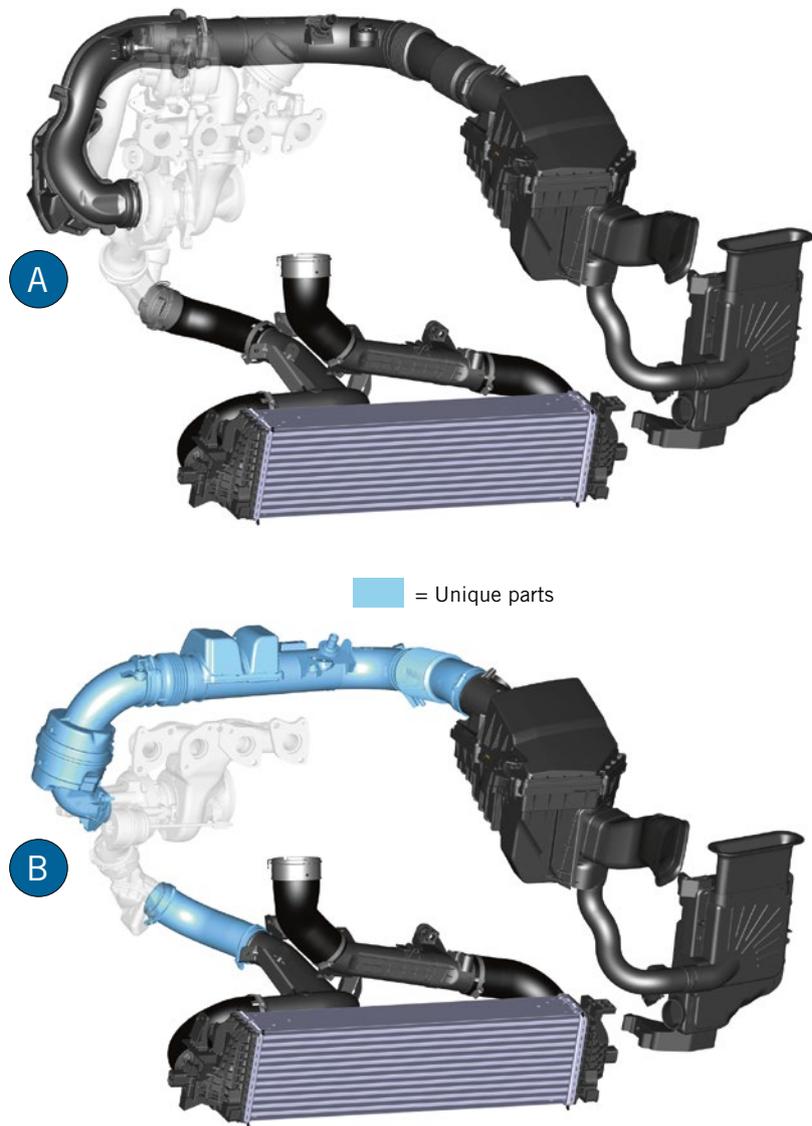
FIGURE 2 Comparison between AIS for 2.0-l diesel two-stage turbo engine (A) and 2.0-l gasoline single-stage turbo engine (B) (© Volvo)

module and many of the surrounding parts are common for both diesel and gasoline variants.

AWD – WITH OR WITHOUT ELECTRIFICATION

All Wheel Drive (AWD) is offered in two different ways depending on powertrain variant. A mechanical AWD system, utilising state-of-the-art coupling technology, is offered as standard, or option, in the non-hybrid variants. However, in the T8, the flagship position of the XC90, the powertrain is a plug-in hybrid. Here the propulsion in the rear is realised by an Electric Rear Axle Drive (ERAD) [3] unit, which means no propeller shaft is used, **FIGURE 3**.

The XC90 T8 battery pack is installed in the tunnel between the front seats which is beneficial with respect to safety and weight distribution. Furthermore, localised in the tunnel, rather than above the rear axle, the battery does not interfere neither with the space in the third row in the seven-seater version, nor the luggage compartment.

ELECTRICAL ARCHITECTURE

The XC90 introduces a domain based electrical architecture [4]. It has a world first Autosar 4 based network and a

Plug-in hybrid with ERAD (Electric Rear Axle Drive)

Conventional mechanical AWD system
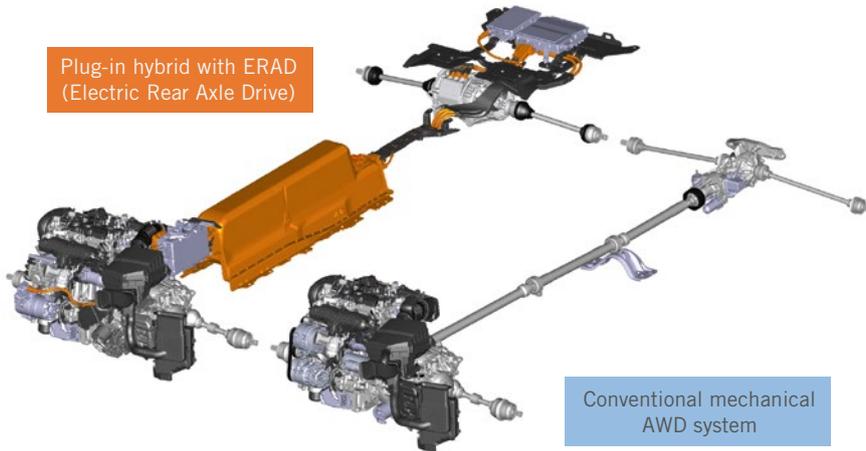
FIGURE 3 Two variants of AWD technology (© Volvo)

FlexRay backbone. The physical architecture is separated from the logical, where logical domains are guiding functional design, **FIGURE 4**. By this a major part of the computing power can be handled within the different domains, thus optimising the bus load. This creates room for future functional growth. Engine control is part of the Vehicle Dynamics domain together with all control for propulsion, steering and chassis.

Scalability is a key concern for the architecture, and future growth is expected to house electrical drive [5] of different configurations and full Internet integration. Even autonomous drive is supported, starting with the DriveMe project launching 100 cars to customers in 2017.

ELECTRICAL ARCHITECTURE STRATEGY

The SPA strategy includes 1) de-coupling of functional growth, e.g. active safety and propulsion and 2) separation of physical concerns, e.g. exposure of communication busses and data integrity. This is achieved by a domain based architecture using a FlexRay backbone linking domain master ECUs, and behind them clusters of ECUs connected primarily via CAN and LIN. The physical domains are different from the logical. By this e.g. HMI implementation is separated from control logic as HMI is defined as a separate logical domain, **FIGURE 4**. Additionally, most of the vehicle layer software are pushed to the domain masters, simplifying requirements on cluster ECUs. These strategies reduces the complexity of the architec-

ture, even with increased functional content and number of ECUs, **FIGURE 5**.

Autosar 4.0 basic software is standard for all ECUs. XML descriptions as defined by Autosar are key element cross the development process used for data exchange between tools, components definitions and implementation specifications etc. Energy efficiency of the electrical architecture is gaining importance and Autosar partial network concept is used to shut down any parts not needed for current mode of operation.

All in all, the combination of a domain based approach and Autosar 4.0 has proven to carry all required features for the new XC90, and is the framework for further development into the autonomous drive era.

### ENGINE CONTROL MODULE STRATEGY

The challenge defining the new Engine Control Module (ECM) was both HW and SW. For HW, the I/O content was derived to support the complete Drive-E engine family, hybridisation and vehicle interface. To that, I/O was added for support of non-ICE features such as cooling fans and AC, topped with spares to manage inevitable feature growth during the ECM lifespan.

The SW platform target a single ECM strategy supporting multiple vehicle platforms, both non-Autosar and Autosar. Important is scalability to manage all Drive-E powertrain variants, from entry level to plug-in hybrid. New upcoming features will require constant evolution during the lifespan of the system.

The chosen solution based on Tier 1 offerings and known preconditions, was to stay with a conventional ECM solution controlling the ICE, parts of hybrid propulsion and some subsystems such as cooling system. This solution creates a platform that supports generic scalability, where commonality includes everything from the ECM box and connectors down to the PCB.

The final result was six HW population variants that support eight engine variants, four gasoline and four diesel, over three different vehicle lines. The ECM base SW exist in two variants, Autosar for SPA and non-Autosar for the older vehicle lines with the majority of the engine control SW being common and independent of gasoline or diesel.

Logical architecture domains
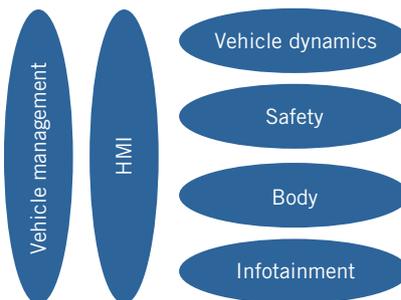
- − Encapsulation of similar functionality into domains
- − Stable dependencies between domains
- − Enabler for domain oriented integration

Physical architecture domains
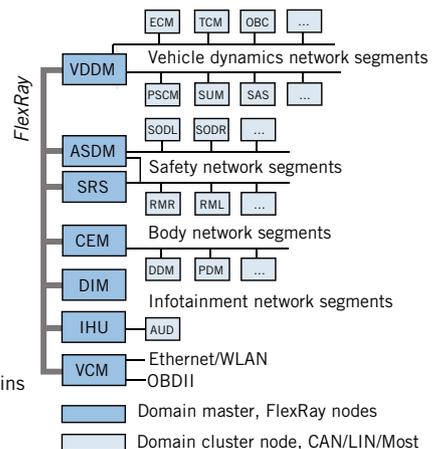
**FIGURE 4** Logical versus physical architecture domains (© Volvo)
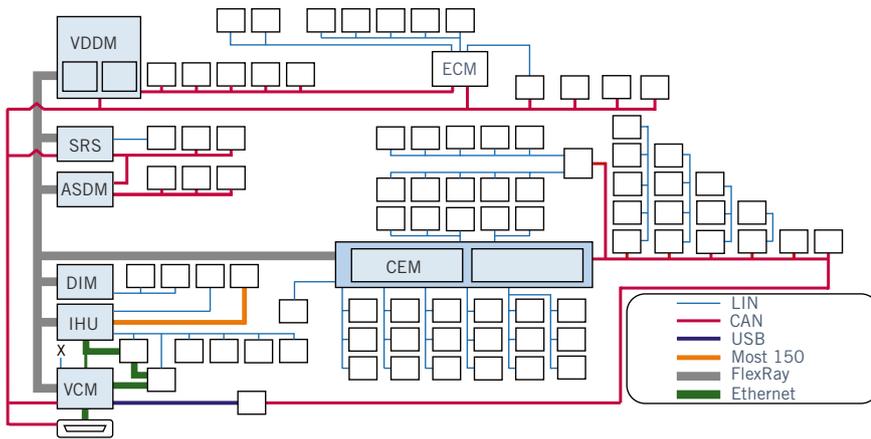
**FIGURE 5** SPA electrical system topology (© Volvo)
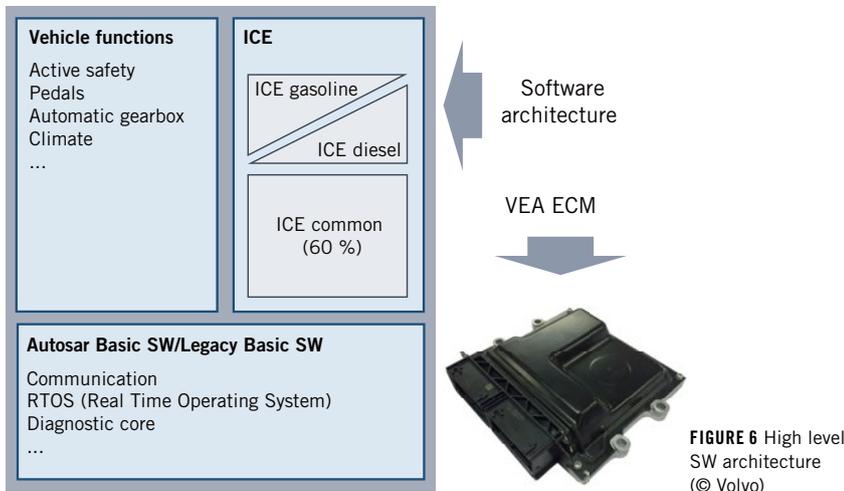
FIGURE 6 High level SW architecture (© Volvo)

Specific combustion control parts for diesel/gasoline are less than 40 % and the vehicle control features are common for all variants including e. g. transmission, hybrid propulsion, air conditioning compressor control, and cruise control, **FIGURE 6**.

OUTLOOK

The XC90, the first car on the SPA platform, is just the beginning of the SPA era. In 2019 the XC90 will be the oldest car in the entire Volvo product line-up. Coming products, which also includes the cars on the upcoming Compact Modular Architecture (CMA), will all be carriers of the same modular system and integration approach used on for example powertrains, infotainment, data network and safety systems, and will be further developed and refined over time.

REFERENCES
[1] Crabb, D.; Fleiss, M.; Larsson, J-E.; Somhorst, J.: New Modular Engine Platform from Volvo. In: MTZworldwide 74 (2013), No. 9, pp. 4-11
[2] Laurell, M.; Sjörs, J.; Wernlund, B.; Brück, R.: Commonised Diesel and Gasoline Catalyst Architecture. In: MTZworldwide 74 (2013), No. 11, pp. 30-35
[3] Fleiss, M.; Stiegler, L.; Eriksson, L.; Eriksson, R.; Lindersson, A.; Norén, B.; Persson, J.: The New Plug-In Hybrid Powertrain for the All-New Volvo XC90. 23rd Aachen Colloquium Automobile and Engine Technology, 6 to 8 October 2014
[4] Müller, T. M.: Volvo's all new EE architecture and development process. 17th International Automotive Electronics Conference, Ludwigsburg, 25 and 26 June 2013
[5] Müller, T. M.; Andersson M.: Driving electrically with Volvo. 24th Aachen Colloquium Automobile and Engine Technology, 5 to 7 October 2015

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"Cost-effective, low-emission cars that are fun to drive"

The CO_2 emissions legislation that will introduce a threshold of 95 g CO_2/km for new cars from 2020 onwards is presenting the industry with major challenges. In addition, these low-CO_2 vehicles must exert a certain fascination to ensure that customers buy them. In the ATZ interview, Dr. Peter Schöggl, Vice President Business Field Racing and Vehicle at AVL, explains how we can maintain our control over factors such as the fascination of cars and their development and product costs as the vehicles themselves become increasingly complex.

Dr. Peter Schöggl (born in 1962) took his degree in electrical and mechanical engineering at Graz University of Technology. He also completed his doctorate there. From 1992 to 1996, he was Research Assistant at the Institute for Internal Combustion Engines and Thermodynamics at Graz University of Technology. In 1996, Schöggl joined AVL List GmbH in Graz, Austria, where he worked as Product Manager, Technical Team Leader and Head of Department. Now he is the company's Vice President Business Field Racing and Vehicle and Head of Department and Managing Director of Österreichische Fahrzeug- und Motor-Akustik Forschungs- und Entwicklungs GmbH.

ATZ _ AVL is the largest engineering service provider in the world and is famous for specialising in engines and powertrains. A year ago, Professor Grebe made it clear in his guest comment column that AVL is entering the automotive engineering market. Why is this?
SCHÖGGL _ AVL has been working in some areas of automotive engineering for decades, for example acoustics, the objectification of driveability and vehicle simulation. The increasingly strict CO_2 limits are the decisive factor behind our current initiative, together with networking and driver assistance systems. We can only comply with these limits by working on both the powertrain and the car itself. Nowadays it is no longer enough for everyone to do a good job independently of everyone else. An interesting example of this is the variable radiator blind, where aerodynamics, cooling, engine emissions and the interior air conditioning system all have to be taken into consideration simultaneously. Only when we have end-to-end networking of our development processes can we achieve the best possible results.

The legislation on CO_2 emissions which will come into effect in 2020 and which involves a limit of 95 g CO_2/km for new cars from then on represents a major challenge for the automotive industry. Will the efforts to meet this new objective have an impact on cars' driving characteristics?
In order for the low-emission (below 95 g/km) cars to be included in large numbers in the calculations, they first have to be sold. Low-emission cars will not necessarily be cheaper, which means

that they need to appeal to drivers in other ways. They must exert a certain fascination to ensure that customers buy them. Therefore, manufacturers will have to add special new features to their low-emission cars. The fascination of these cars will lie in attributes such as dynamics, handling, sound, ride comfort and, of course, fuel consumption and emissions. These are the areas that we are looking at very closely.

"Nowadays it is no longer enough for everyone to do a good job independently of everyone else"

Customer expectations vary across the different markets in the world. Does AVL have the necessary knowledge of these markets?
Yes. For three years, we have been running a global vehicle benchmarking programme which analyses every important model that comes onto the market in terms of its functional driving characteristics and its attributes. On average, we evaluate between 100 and 150 vehicles each year. They are generally analysed locally, because AVL has offices in all the major countries including the USA, the United Kingdom, France, Germany, Italy, Russia, India, Korea, China and Japan. On the one hand, we provide our customers with the results from evaluations of these cars as benchmarking data

and, on the other hand, we have a technology scouting process in place to find out how much technology is being employed to achieve the objectives. These data are also used to identify the target requirements for future vehicles.

How does AVL configure a successful vehicle for a specific market on the basis of the wide variety of technical options available?
We established our attribute engineering programme for this purpose, which is a combination of high-performance simulation and objective evaluation. Working with the customer's marketing department, we use the benchmarking data to generate the most important driving-related objectives for the customer's product. These involve not only costs and CO_2, but also performance, dynamics, handling, ride comfort and emissions. Then we create thousands of virtual prototypes of the different variants. Many of our customers are still relying heavily on test vehicles to enhance the brand-specific character of their cars. The attribute engineering process allows us to move these activities into earlier, virtual phases, which means that we can identify very early in the development process whether the measures that are being taken are constructive or whether a specific variant will have an NVH problem, for example. The result is that OEM customers no longer need to build a large number of costly and complex prototypes. By taking a joint approach to all the target criteria, we also achieve better overall results, including driving pleasure and costs. This means that we can design cost-effective, low-emission vehicles that are fun to drive in the very early phases of the process.

Driving pleasure is a highly subjective concept. What approach should we take to this? How can an engineer turn an adjuster screw at later date?
We need to distinguish between customers and experts. Customers consciously give the car one of three ratings: I like it, I don't notice it or it annoys me. The subconscious rating scale is more detailed, because it identifies differences. Highly experienced test drivers differentiate much more precisely between the different categories and generally have a scale from one to ten with increments of 0.5. The experts use this to evaluate hundreds of criteria. The process begins with start-

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"The attribute engineering process allows us to move these activities into earlier, virtual phases", explains Schöggl in conversation with ATZ

ing the engine: How long does it take? What is the idling speed? How does the engine sound? What about the warm-up time? and so on. The simple process of starting the engine once can be broken down into a large number of individual elements. We have analysed the methods used by hundreds of experts like this and we have transformed what they say into computer programmes. The evaluation can now be used either together with a real vehicle, for example in the benchmarking programme, or with a simulation. This allows us to carry out an objective assessment of a simulated vehicle.

"Reducing costs by between 10 and 30 % means saving a lot of money"

You are putting the focus on virtual development. Is there a rough formula to indicate what computer simulations cost in comparison with testing on a test bench?
Each hardware prototype of a car costs between 50,000 and 1 million euros, depending on the development phase and whether it is a model upgrade or a completely new model. The cost of a virtual prototype is around one thousandth of that. Using the attribute engineering process, we can create 15,000 virtual prototypes and in 24 hours run virtual tests on them against all the emission cycles and driving cycles. If we use cloud computing, we can drive three million km in 24 h. The key factor is the virtual assessment with our objective procedure which reduces the work and the cost involved. But it is important not to see this in black and white. In other words, we cannot drive everything in the virtual world. We still need prototypes, but reducing costs by between 10 and 30 % means saving a lot of money.

You are a member of the advisory board for the ATZ driver assistance systems conference. Alongside CO_2 emissions, these systems represent one of the key topics in the automotive industry. What do you think their impact will be on world markets?
The largest proportion of development costs is currently being spent on reducing CO_2 emissions. But driver assistance

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"The fascination of low-emission cars will lie in attributes such as dynamics, handling, sound, ride comfort and, of course, fuel consumption and emissions", says Schöggl

systems are in second place. There will be a huge amount of growth in this area in the near future. For example, Mercedes-Benz has announced that there will be no more fatalities in its S-Class model from 2020. The pressure on the other premium manufacturers is growing. Everyone has to invest in this area, because it is all about safety. In addition, driver assistance systems are used to reduce emissions and make cars more fun to drive.

So your benchmarking tests also cover highly subjective topics such as driver assistance systems?
Yes, definitely. We evaluate these systems in every car that we benchmark, if they are installed. We look at how end customers see these systems and that brings us back to the three ratings: I like it, I don't notice it or it annoys me. The experts take a much more precise approach: Is the car snaking slightly? Does the distance between this car and the one in front vary? Do I ever reach the point where I feel unsafe as a passenger? These are the subjects that we are considering so that we can provide support for the development processes of our OEM customers and help improve cars' behaviour.

Another question that takes us back to the beginning: We said that AVL's history is in powertrain development. How are you able to make use of your huge amount of powertrain knowledge when you are working on a complete vehicle?
We have resolved this by creating a structure where we can bring together all our knowledge of powertrains and use it to reduce vehicle CO_2 emissions. We have experts from a wide variety of different areas working together in a team. They combine possible measures relating to the powertrain with possible measures relating to the chassis, aerodynamics, thermal management and air conditioning. All of these individual measures are linked together in an organisational structure which involves all the experts sitting together and working on joint projects.

Dr. Schöggl, thank you very much for talking to us.

INTERVIEW: Dr. Johannes Liebl and Michael Reichenbach

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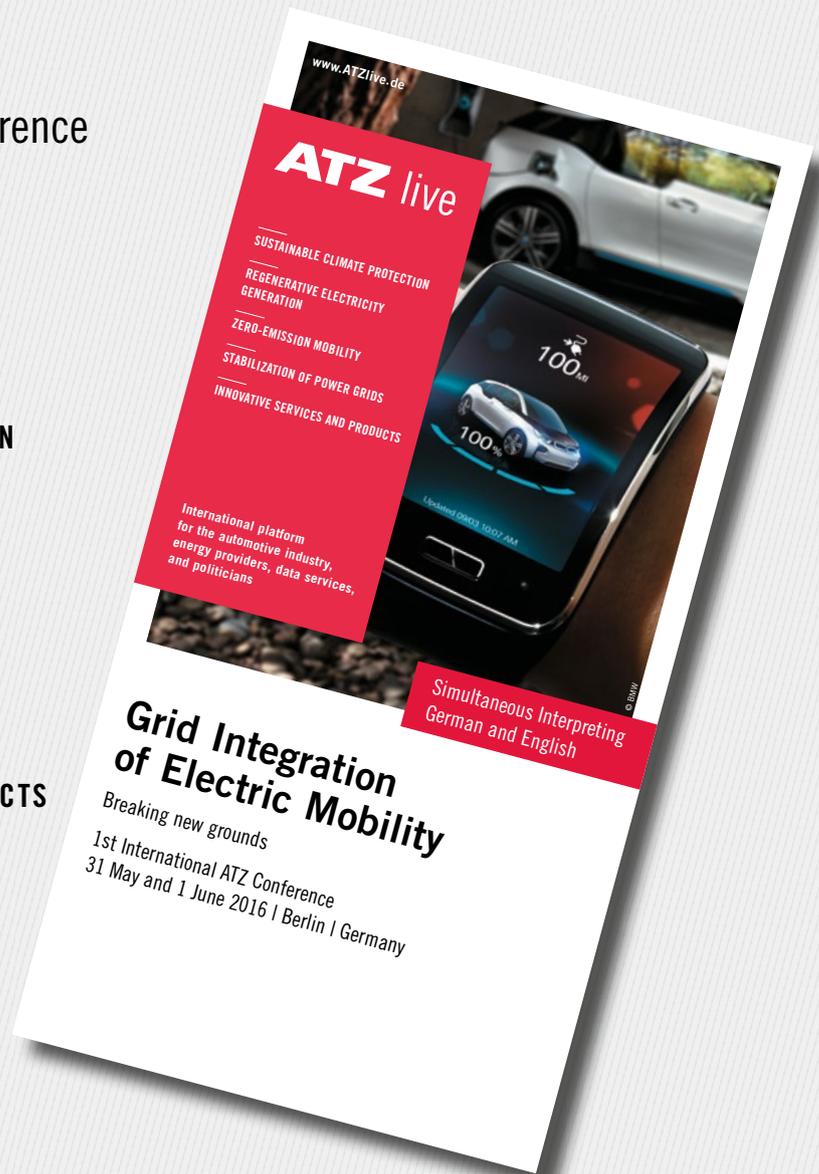
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NVH Aspects of Powertrain Mounting Systems Layout

The layout of a powertrain mounting system remains important, especially when taking into account current downsizing and cylinder de-activation technologies as well as alternative drive systems. FEV describes the process to design a powertrain mounting layout which achieves good NVH values.

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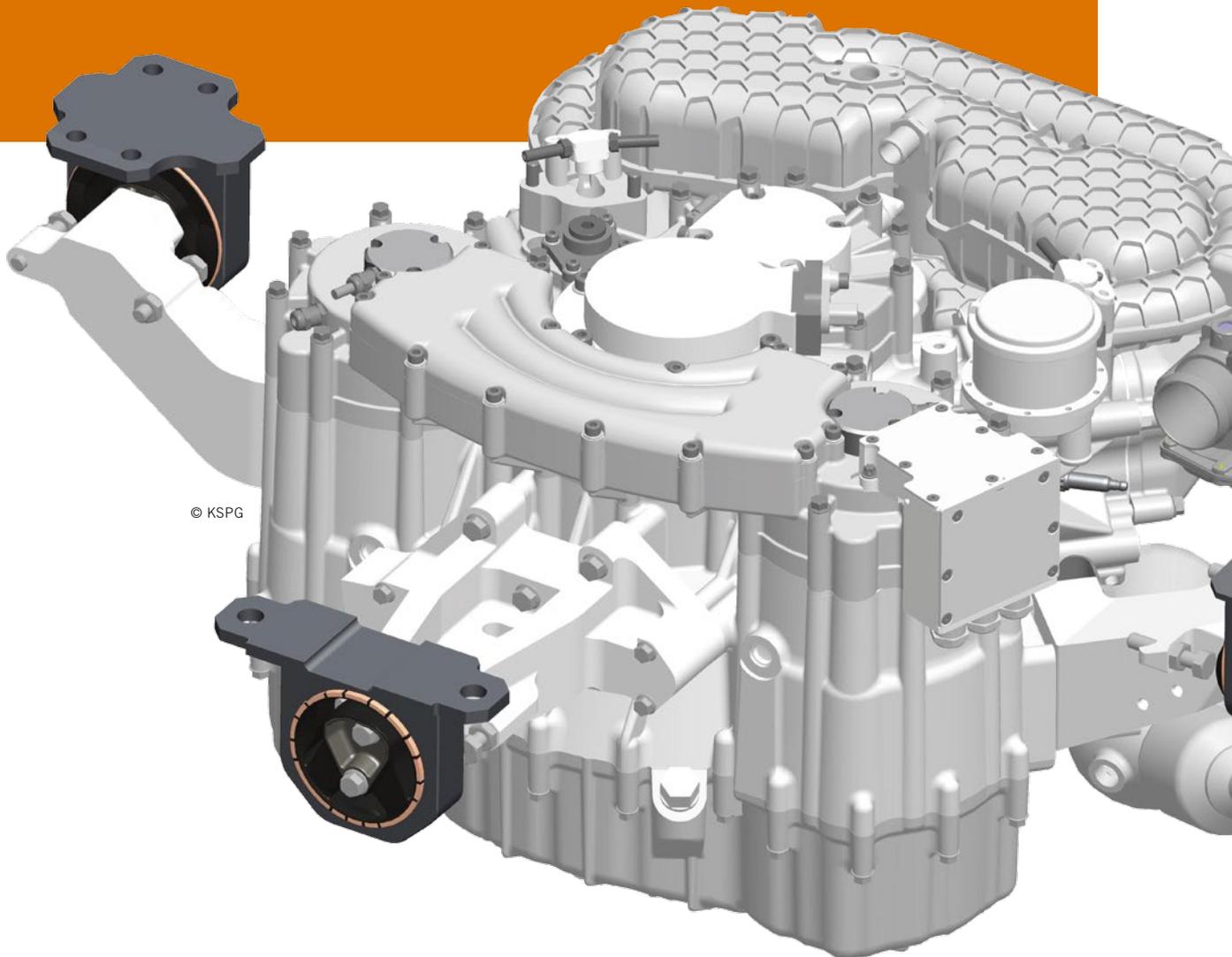
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IMPORTANCE OF EACH TOOL

The mounting of a powertrain in a passenger car is a discipline, which constitutes a compromise between many attributes like durability, drivability, packaging, weight optimisation, thermal constraints, cost reduction and desired NVH (Noise Vibration Harshness). The boundary conditions of this task become more complex because packaging need is increasing for alternative drive systems. This article describes the NVH development of powertrain mounting systems at FEV. The different phases during development and the dedicated tools for benchmarking, conceptual layout software, advanced simulation software, testing, and validation will be described in detail, and relevant examples will support the importance of each of these tools.

The different tasks which have to be fulfilled by a powertrain mounting system are contradictory and always lead to a compromise in the chosen mounting characteristics. Indeed, the tasks of a mounting system are the connection of the powertrain to the vehicle, support of static powertrain weight and quasi-static engine torque, isolation of high-frequency vibrations originating from the powertrain, motion limitation of the powertrain during standard and misuse load cases, good drivability, damping of road induced vibrations and crash performance.

On the one hand, due to packaging limitations (especially for alternative drives) and because of a desire for agile driving performance, one has a preference for stiff mounts. On the other hand, for good isolation one needs soft mounts. In addition, damping deteriorates the isolation.

FIGURE 1 shows that the NVH development process of powertrain mounts typically goes through several phases. At first phase the performance targets are defined. In the second phase the conceptual layout of the powertrain mounting system is realised. The output of this concept design is a list of characteristics for mounts, which are then manufactured by the mount supplier in the prototype phase. Finally these prototype mounts are validated and the production of serial parts is prepared. All these four phases
– definition phase
– concept phase
– prototype phase
– validation phase
will be discussed more in detail in the next chapters, and examples will support the description of the complete development process.

DEFINITION PHASE

At the beginning, the idea for a new driveline in a passenger car also necessitates the development of a proper powertrain mounting system. Through benchmarking a complete target book is generated, where the targets are predominantly based on global vehicle performance (for example permissible vibrations of the seat rail). These global targets then need
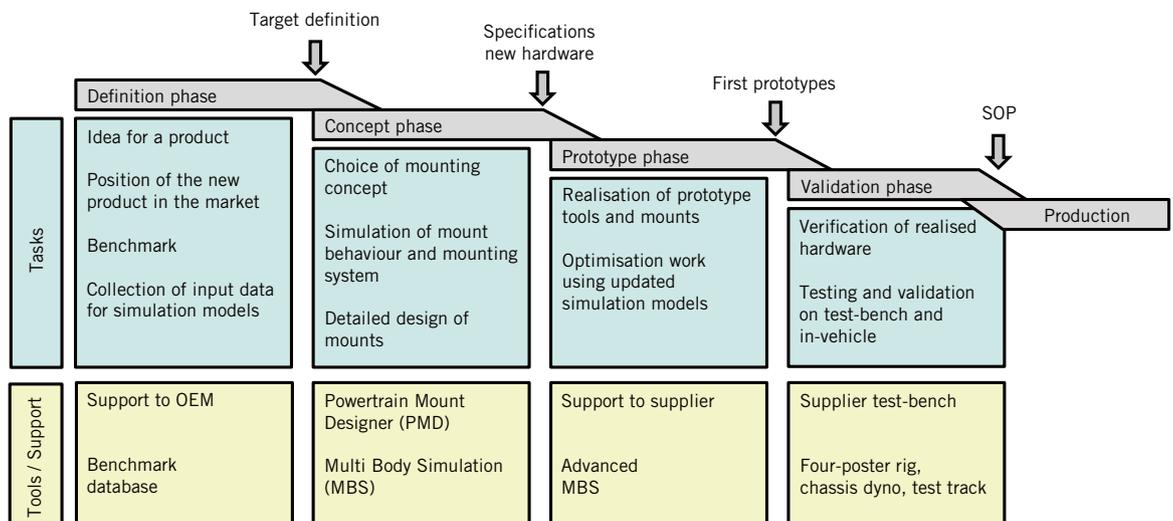
FIGURE 1 Engine mounting system development process in four phases (© FEV)
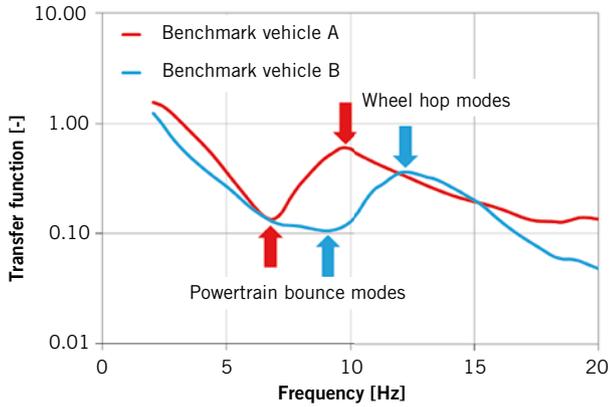
FIGURE 2 Benchmark database – ratio of seat rail vibration to wheel excitation (© FEV)

to be broken down to component targets, which are related to the individual mount characteristics.

As an example for benchmark data investigations, results of measurements on a hydraulic four-poster rig are described here. This rig enables the investigation of vehicle properties. In **FIGURE 2** the response of the passenger car body in the vertical direction for a sine sweep input at the front wheels is shown.

The results are shown in **FIGURE 2** as a transmissibility function for two front-wheel driven vehicles A and B with transversally mounted gasoline engines (three-point) and automatic transmissions. The transmissibility function is a ratio of two accelerations (vehicle body and vertical input), thus the unit of this function is dimensionless. The mid frequency area between 5 and 15 Hz clearly shows a different behaviour in both vehicles. It confirms that the interaction of the bounce mode and wheel hop modes can, when optimised, lead to a significant reduction of vibration levels (down to 25 % around 10 Hz for the vehicle B). This example clearly shows

the usefulness of information stored in the benchmark database, which enables the generation of component and vehicle targets for the projects under consideration.

CONCEPT PHASE

As mentioned before, at first a conceptual layout of the mounting of the powertrain needs to be defined, which includes the orientation of the powertrain in the vehicle (transversal, longitudinal) and the number of connection points fixing the powertrain in the vehicle. For this task at FEV their "Powertrain Mount Designer" simulation tool is used [1]. In addition standard analysis work can be carried out with this tool, for example the modes in the six degrees of freedom are determined, **FIGURE 3** (left). The horizontal diagram axis shows the mode frequency, the vertical axis shows the distribution of the kinetic energy of each mode on the translations and rotations along the axes of the vehicle coordinate system. This is relevant, because the main excitations from the gas and mass forces usually are also ori-

ented along these axes. The rigid body modes are considered as well separated, if at least 80 % of the kinetic energy is concentrated on the basic movements along the different axes.

In **FIGURE 3** (right) the results of an optimisation step are shown. By choosing an asymmetric mount layout for the engine mount, the stiffness in x- and y-direction can be adjusted separately, which leads here to a clear decoupling of the lateral and bounce mode around 7 Hz. When more details become available in the layout phase, a Multi Body Simulation (MBS) in the software FEV Virtual Engine is used. Typically a lot of MBS work is done in the next phase, the prototype phase.

PROTOTYPE PHASE

After the rough system parameters have been defined in the concept phase, the final specifications have to be decided in the prototype phase. These decisions require the highest possible simulation accuracy. To this end MBS simulation of the whole driveline in the FEV Virtual Engine software will be performed. In **FIGURE 4**, three Campbell diagrams for left engine mount acceleration of a rear wheel driven car with a longitudinally installed powertrain are shown. **FIGURE 4** (left) shows the results of simulation with nominal values. In **FIGURE 4** (right) the results of the measurement is presented.

The comparison of the three diagrams in **FIGURE 4** shows that the main orders are reproduced properly, but other orders are completely missing. A sensitivity analysis of the system points out that deviations from an idealised system behaviour cause this effect.

As an example, the imbalance of the converter causes the first order and the
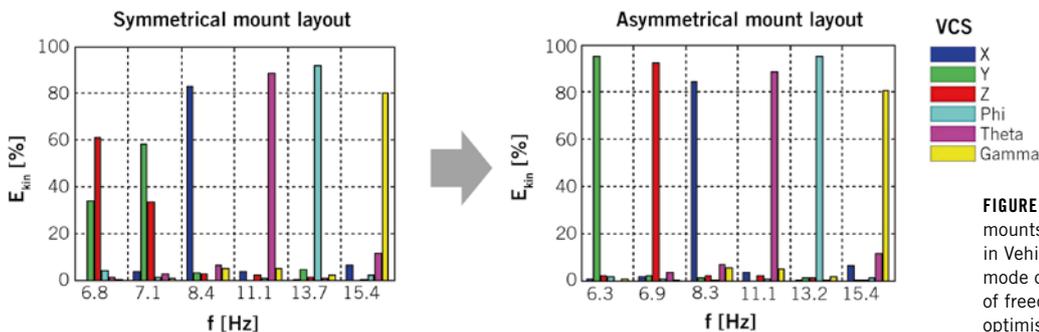
FIGURE 3 Optimisation of powertrain mounts for better mode decoupling in Vehicle Coordinate System (VCS) – mode determination in the six degrees of freedom (left) and results of an optimisation step (right) (© FEV)
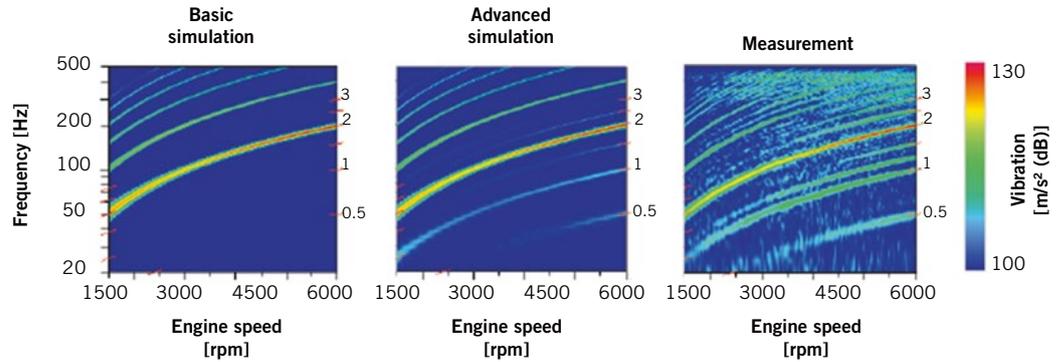
FIGURE 4 Comparison of engine mount vibrations: basic and advanced simulation and measurement in three Campbell diagrams (© FEV)

cyclic fluctuations of combustion can cause half order excitations. In the early stages of the prototype phase one can live with a lower accuracy. In later stages of this phase – when more information becomes available – an interior noise synthesis is typically performed by combining the body transfer functions with the simulated mount excitations. In this calculation step, the half engine order excitations play an important role as they mainly determine the sound quality making it sound more realistic and less synthetic.

The mount supplier takes the requirements obtained from simulation and builds them into prototype hardware, testing the prototypes to ensure they perform as specified. These prototypes are built into the test vehicles, and then NVH measurements are performed on a four-poster test rig, chassis dyno and test track. To support the development process further testing is carried out on component test rigs. On the four-poster test rig, the input data for the experimental modal analysis of the engine as a rigid body in its mounts is measured [2].

A comparison between modes typically obtained by CAE and measurement (on a four-poster test rig) is given in [1], showing that a very good correlation can be obtained between both disciplines and confirming the quality of results obtained via the "Powertrain Mount Designer".

After the four-poster testing, additional measurements are carried out on the chassis dyno and the test track. An example of this process step is the fine-tuning of the hydraulic function of a hydraulic mount. The bad road section (Belgian Blocks) of the test track is selected as the excitation input. Typically the mount supplier is asked to produce

several hydraulic mounts with different tuning as prototype parts. These prototypes are tested consecutively and the engine mount with the best performance is then recommended to become the serial part. In **FIGURE 5**, a comparison of hydraulic mount tuning (11 respectively 13 Hz maximum loss angle) clearly shows a mount optimised for reduced seat rail vibrations.

VALIDATION PHASE

The optimal mount system is tested on further properties such as durability, and then the production process parameters are checked before the mounts are finally approved for serial production. The transition from prototype parts to serial parts also needs to be guided with respect to NVH. The quality of mounts has to be guaranteed when switching from one-cavity prototype tools to multi-cavity serial tools. Additionally environmental variables such as the production location can cause differences in the

quality of rubber products. So, typically tests are repeated on dedicated samples taken from the serial production, to guarantee effective and consistent NVH performance.

For troubleshooting in the validation phase a transfer path analysis is used, which is called Vehicle Interior Noise Simulation (VINS) at FEV. This analysis delivers a detailed insight into the chain of powertrain excitation, dynamic stiffness of the rubber mounts, body stiffness and body noise transfer function. This chain leads to the noise coming from each individual structural path, in this case the connection points (in 3-D) of the powertrain to the vehicle. For further and a more detailed description of VINS, and its use as target setting for structure borne contributions of powertrain mounts, refer to the literature [3, 4].

FIGURE 6 shows the results of a VINS analysis, consisting of interior noise shares for all powertrain mounts as structure borne contributions. This analysis reveals that the transmission mount
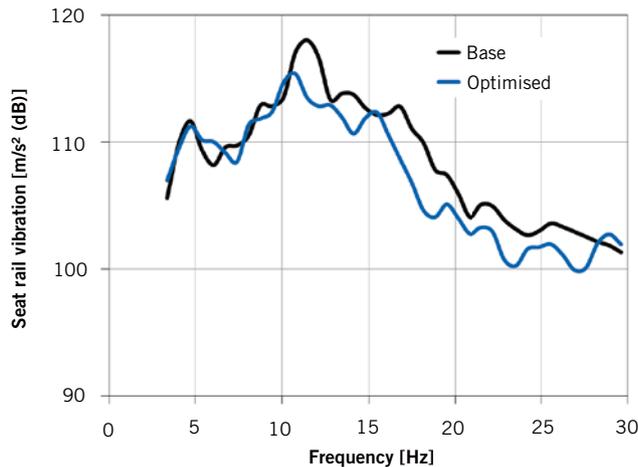

FIGURE 5 Vibration at the seat rail for basic and optimised hydraulic mount – hydraulic mount tuning on the test track (© FEV)
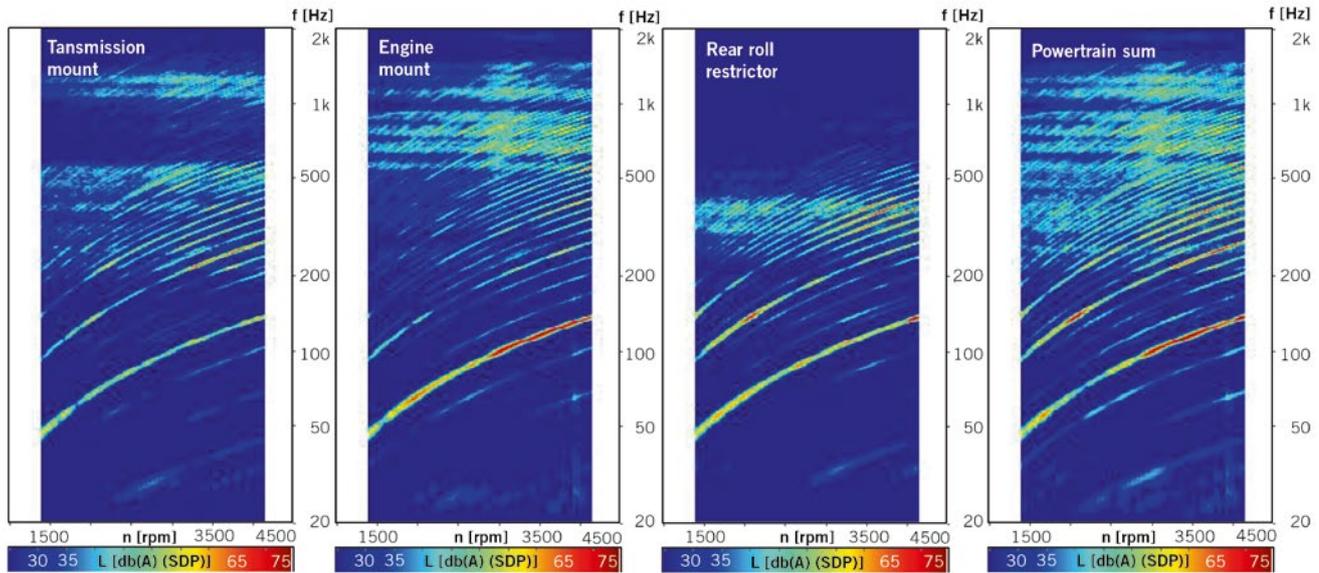
FIGURE 6 Structure-borne contributions of different components as Sound Pressure Level (SPL) to the interior noise sum (VINS) (© FEV)

has a very low contribution to interior noise in the main firing order. This allows the use of a stiffer variant for the transmission mount. It will simplify the search for a transmission mount, which can be better optimised for non-NVH disciplines (for example durability). This example again demonstrates the level of complexity in mounting design.

CONCLUSION

The layout of a mounting system for a combustion engine remains a very challenging discipline. From the initial benchmarking, conceptual design, prototype and validation phases up to the start of production, numerous examples demonstrate the complexity of powertrain mounting system development, and the necessity of intensive cooperation of OEM and mount supplier. FEV as an engineering service provider for the automotive industry is supporting this task with several software tools, testing and benchmark database, through all development phases.

REFERENCES
[1] Nussmann, C.; Van Keymeulen, J.; Eisele, G.; Steffens, C.; Seo, J. Y.; Kim, S. G.: Powertrain Mount Designer – Fast interactive tool for conceptual mount layout. Aachen Acoustic Colloquium, 2015
[2] Hansen, T.; Wang, X.; Han, Q.; Gretzbach, U.: NVH simulation of engine mounts verified in vehicle testing. In: ATZworldwide 113 (2011), No. 6, pp. 42-47
[3] Genender, P.; Wolff, K.; Pichot, F., Eisele, G.: Vehicle Interior Noise Simulation VINS as a production vehicle development tool. 16th Aachen Colloquium "Automobile and Engine Technology", 2007
[4] Eisele, G.; Angermaier, F.; Genender, P.; Wolff, K.: Systematic concept for definition of NVH targets for vehicle subsystems and components. Aachen Acoustic Colloquium, 2011

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Continental | **48-V Mild Hybrid with Connected Energy Management**

Continental showcased a 48-V mild hybrid with connected energy management for the first time at the 2016 Consumer Electronics Show (CES) in Las Vegas. Thanks to dynamic traffic data (electronic horizon), it makes more extensive use of coasting and recuperation phases for an improved energy management. Dynamic data on current traffic provide the digital input data for Continental's Connected Energy Management (CEM). Compared with the basic Golf VI model with a 1.2-l TSI engine and 12-V start-stop function, the Eco-Drive hybrid is claimed to save up to 21 % of fuel. CEM is said to contribute a further 3 to 4 % in fuel savings without any changes to vehicle architecture.

Volkswagen | **Fully Networked Budd-e Microbus Concept**

At the CES in Las Vegas, Volkswagen unveiled its fully networked Budd-e concept which is based on the MEB modular electric drive kit. The MEB produces a drive system architecture that is designed for the use of compact electric motors and high-performance batteries. The battery has an energy content of 92.4 kWh and is large and thin, which allows it to be mounted under almost the entire floor area of the Budd-e to save space. It supplies two electric motors that are used to drive each axle. The front motor produces 100 kW (200 Nm) and the rear motor 125 kW (290 Nm). The mechanical system output is 225 kW. When the battery is fully charged, the Budd-e has a total range of up to 533 km (Europe/NEDC). The battery can be charged from a mains socket or using a cordless inductive charging system. With a charging capacity of 150 kW (DC), the battery can be 80 % charged within around 30 min. The concept car with an all-wheel drive system has a top speed of 180 km/h. The zero emission vehicle can reach 60 mph (around 100 km/h) from a standing start in 6.9 s.

© Volkswagen

© BMW

BMW | Contactless Touchscreen Operation

BMW presented its vision of what a car interior and the user interface of the future might look like in the form of a concept car at the Consumer Electronics Show (CES) in Las Vegas, USA. One example of new technologies in seamlessly networked vehicles is the so-called AirTouch feature, with which entertainment, navigation and communications functions can be controlled with a simple hand movement. This feature claims to allow the car's display to be operated like a touchscreen while eliminating the need for any surface contact. Sensors register hand movements in the area between the centre console and the interior mirror, allowing the driver or front passenger to change the focus of the large panorama display. The desired menu item can be selected or a button activated through simple confirmation.

© GM

GM | Chevrolet Bolt EV

Almost a year ago, General Motors (GM) presented the Chevrolet Bolt EV concept, a small car with a pure electric drive. The production version of the Bolt EV has now had its premiere at the CES 2016. Manufacturing will begin at the end of 2016 and the new model will be available on the market in early 2017. The key features of the five-seater electric car can be summed up in two numbers: The range on a full charge will be more than 320 km and the purchase price after the deduction of US state tax credits will be 30,000 US dollars. When the battery is fully discharged, it can be 80 % recharged in less than 60 min using a fast charging system. The very flat battery packs from LG are stored in the under-floor of the car to save space.

© Daimler

Mercedes-Benz | E-Class with New Engines

At the Naias 2016, Mercedes-Benz unveiled the tenth generation of the E-Class. The highlights of this latest version of the business saloon include a new multi-chamber air suspension system and a newly developed four-cylinder diesel engine. This engine, together with a four-cylinder gasoline version, will be available from the market launch onwards. They will be followed later by the E 350 e, a plug-in hybrid which has a four-cylinder gasoline engine and a motor and a total system output of 210 kW. Mercedes-Benz will continue to offer a 190 kW six-cylinder engine with SCR exhaust technology and a six-cylinder gasoline engine producing 245 kW.


© ZF

ZF | Concept Cockpit for Automated Driving

ZF presented a range of communication options between driver and car for automated driving at the Consumer Electronics Show (CES). These included a steering wheel with touch sensors, camera-based facial recognition and assistance belts. Under the slogan "Shaping the next decade of automated driving", ZF demonstrated four approaches to the human-machine interface in a concept cockpit. The key features of the cockpit were a special steering wheel with hands on and hands off detection, a touch display, an innovative high-precision facial and emotion recognition system and active safety belts with communication functions.

Here | **Cloud-based Map for Automated Driving Functionality**
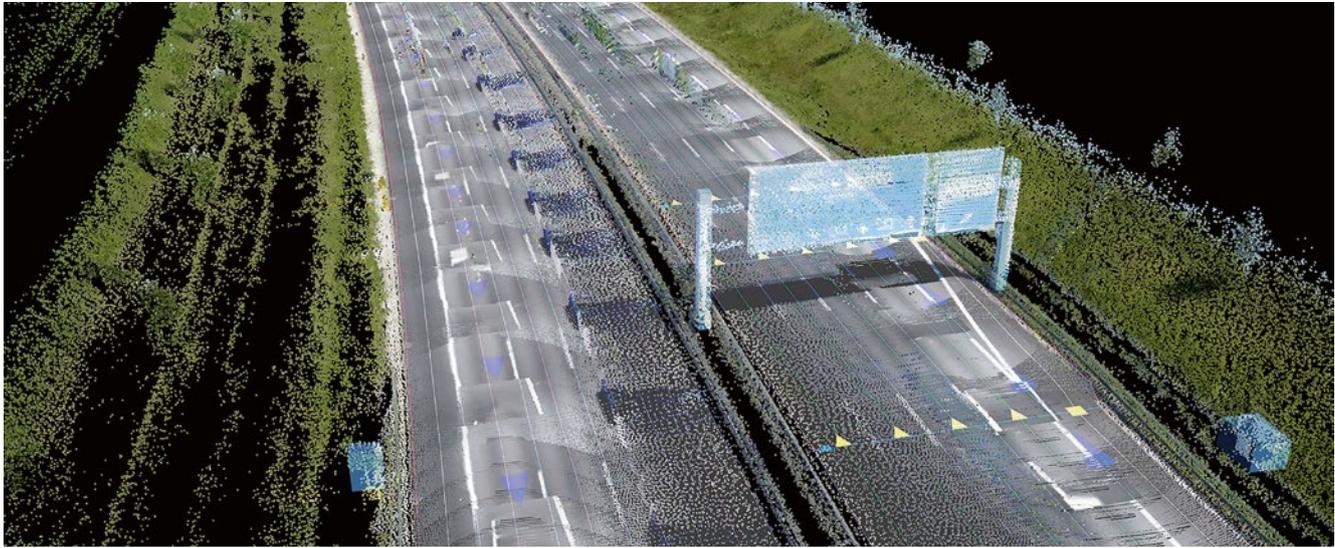
© Here

At the CES 2016 in Las Vegas, Here, a specialist in mapping technology, unveiled the HD Live Map, a cloud-based map which updates itself independently. It is ready for use in connected vehicles in North America and Western Europe and provides real-time information about the car's surroundings. This enables vehicles to effectively "see around corners" beyond the reach of their on-board sensors. According to Here, it is designed to enhance both driver assistance systems and automated driving functionality and therefore to make driving more enjoyable. The map consists of multiple layers of data provided in a map-tile format. The cloud-based map includes data of longer-term relevance, such as lane level information about the road network, data of short-term relevance, such as details of roadworks, traffic and accidents, and analysis data, including speed profile information.

© Fiat

Fiat | **Roadster with Soft Top**

The Fiat 124 Spider is making a comeback, nearly half a century after its debut. The new roadster was designed by Centro Stile in Turin, Italy, with a soft top reminiscent of the original 1966 Spider. Features like the upper hexagonal grill and grille pattern, power domes on the bonnet and striking horizontal rear lights evoke the historic Spider. The car is powered by a 1.4-l four-cylinder engine with turbo-charging, which delivers 103 kW. Maximum torque is 240 Nm. The two-seater comes with a six-speed manual transmission.
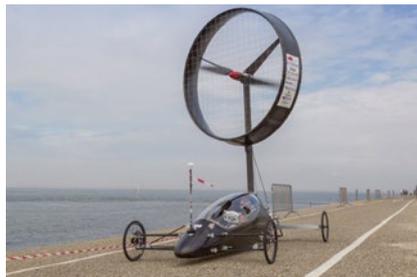
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University of Stuttgart | Ipetronik | **Ventomobile**

As part of the Inventus project, researchers at the University of Stuttgart are designing a car powered only by wind energy that can be driven upwind, which is known as the Ventomobile. According to the researchers, in the same way as a sailing boat, the car has no fuel tank or accumulator. Its only power source is a small wind turbine. As detailed measurement data are needed for the development and operation of the Ventomobile, the researchers are using a trace logger from Ipetronik, which is the key element of the measurement system. It is used for recording data and for passing it on to the driver and the team.

© Rinspeed

Rinspeed | **Etos with Drone**

Rinspeed presented its latest concept vehicle, Etos, at the CES in Las Vegas, with an auto-pilot and drone on board. Their 22nd concept car, which uses the BMW i8 as its technical base, was again designed by 4erC and realised technically by Esoro. A 1.5-l gasoline engine and an electric motor delivering 96 kW are used to power the plug-in hybrid study. Overall output is 266 kW and overall torque 570 Nm. Furthermore, the concept car is fitted with an on-board DJI drone, complete with a landing platform at the rear. The drone itself is intended to perform useful tasks like collecting a bouquet of flowers ordered online on the drive home, the developers explain.

© obs | Ford

Ford | Corning | **Break-proof Glass for the GT**

The windshield and the transparent rear engine cover of the new Ford GT super sports car will be manufactured from so-called gorilla glass, a scratch-resistant and break-proof special glas. The use of gorilla glass would be a first for a series production vehicle. This glass is a special ultra-thin, lightweight and yet very durable form of glass that the US supplier Corning launched in 2007; particularly for consumer electronics applications, for

example as a glass cover for displays on portable electronic touchscreen devices. While developing the new sports car, Ford engineers investigating the use of lightweight design materials soon came across the glass product. After thoroughly testing this glass technology for use in the Ford GT, Ford worked with Corning to develop the appropriate series product for the new super sports car.

BMW Motorrad | **Laser Light and Helmet with Head-up Display**

© BMW Motorrad

At the Consumer Electronics Show 2016, BMW Motorrad presented a concept bike with laser lighting and a helmet with a head-up display. The aim of the two solutions is to give a technical perspective on their potential use in future volume production models. The laser light on the K 1600 GTL concept bike exhibited at the show was derived from a design developed by the car division of the BMW Group. As part of its preliminary development work, BMW tested this type of headlight technology in production models. The technology is currently too expensive for use in motorcycles. However, according to BMW, the economies of scale that can be achieved as a result of volume production in the car industry are likely to result in a reduction in the component price, which would allow the technology to be introduced in motorbikes in the medium term.

© Human Solutions

Optimising Dynamic Operating Procedures in the Truck with Manikins

Digital manikins have been used for the ergonomic design of the driver's working place in trucks for quite some time. Their continuous advanced development means that they can be used for designing complex operating procedures. For the first time, the manikin simulations Ramsis and Dynamicus are being used in the Arvida project to implement and validate applications for the ergonomic design of dynamic operating procedures in commercial vehicles. This BMBF-funded project includes the collaboration of Daimler, Human Solutions and the Institut für Mechatronik.

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VEHICLE AND OPERATING ERGONOMICS THROUGH THE COURSE OF TIME

Ergonomics plays a crucial role in the development of a vehicle, because it establishes the link between the vehicle and its occupants. Anyone who enters, sits in or drives a vehicle experiences ergonomic design. In earlier times when the first motorised carriages were made, designers pondered about how the vehicle should be boarded, the design of the seats and the arrangement of the controls; seat templates sufficed for their designs and they created seating arrangement diagrams based on the templates.

However, the methods have been continuously refined since then. In the 1980s, the German FAT, short for the Forschungsvereinigung Automobiltech-

nik (Research Association for Vehicle Technology) laid the foundation for today's software-based ergonomics design with its "Der Mensch als Fahrzeugführer" project (The human being as a vehicle driver) – and the development tool Ramsis is based on this project (Ramsis is the German abbreviation for "Computer-assisted Anthropometric-mathematical System for Vehicle Occupant Simulation") [1]. Today, Ramsis is the established simulation tool for designing vehicle ergonomics in CAD designs and is used to optimise seating design. It is offered by the Human Solutions GmbH. Visual and control reachability studies are performed and belt routes are examined, **FIGURE 1**.

However, ergonomic studies still exist today that can only be carried out in the "old" way, that is on a physical mock-up (a real model of the driver's cab). This method includes all dynamic motion sequences (motion flows), which are particularly relevant for the development of commercial vehicles (entering, exiting from, climbing up into and descending from the driver's cab).

DYNAMIC ERGONOMICS STUDIES OF THE FUTURE

Future dynamic ergonomics studies will take place in a Digital Mock-up (DMU). The advantages are obvious, because it means that the first conceptual planning for a modified vehicle will be carried out in the virtual world. This is where the digital mock-up is used for ergonomic motion studies. A motion flow such as "Entering a Driver's Cabin" is simulated with Ramsis. The virtual test person, a short woman or a tall man, is selected from a representative population. Various vehicle concepts with different entry options are tested digitally with just a

mouse click. Probably the biggest advantage here is in time savings, because conventional studies using physical mock-ups can take up to several months.

The necessary individual systems already exist today, but they are incompatible with one another. These specialist systems can only be combined into one stringent process through the research results of the BMBF project Arvida. The core purpose of the project is to ensure the interoperability of expert systems through web-based reference architecture [2].

SYSTEM ARCHITECTURE

Digital dynamic ergonomics studies are made possible in a 3-D simulation system that allows the designer to simulate and image the motions and interactions of any test subjects in 3-D models of vehicles, **FIGURE 2** (right). Here the simulation uses a database of real human motions that have been digitised, **FIGURE 2** (left).

The digitisation of real motions is carried out in two steps. A human being (the test subject) first performs typical activities on a physical model of the vehicle (for example entering the vehicle) and the flow of these motions is recorded with a tracking system. The motion data obtained is then processed and digitally segmented and modelled in terms of its individual dynamic structure. The three main components of the system, namely motion capture, modelling and simulation are described in more detail in the following.

MOTION CAPTURING

The recorded images of the motions are captured using a physical vehicle mock-up or a real vehicle with different test subjects. An optical motion capture

FIGURE 1 Optimising seating design in the commercial vehicle by means of the Ramsis manikin (© Human Solutions)

system is used as a measuring system; it is based on the highly accurate tracking of reflective markers by means of 18 infrared cameras, **FIGURE 3**.

Markers are attached to the relevant body points of the test subject to capture the motions made by all parts of the body. Markers are also placed on the driver's cab and on the lower steps. Each marker must be recorded by at least two cameras in order to determine its position in space. Measurement accuracy lies in the range below 1 mm.

One particular challenge for optical motion capture systems is the occurrence of concealment situations during recording. This can only be countered by comprehensive coverage of the measuring area (number of cameras and their positions, choice of focal lengths) and by reprocessing the data during the post-processing (intelligent deduction of the marker motion trajectories). The resulting marker trajectories are streamlined with a filter and passed to a motion modelling programme for further processing.

MOTION MODELLING

Up to this point, we only know the positions of the individual markers and the segments to which the markers belong. For further study, however, one must transmit the motion to a digital manikin – and the Dynamicus [3] from Institut für Mechatronik biomechanical manikin is used for this task.

The manikin is first calibrated for the individual test person that is the person's body measurements are determined from the position of the markers. The next step is the reconstruction of the motion using the inverse kinematics method [4]. For each time step, a manikin posture is calculated that optimally corresponds to the posture captured by the motion capture system markers. This results in the consistent motions of the digital manikin as motion trajectories of the pelvis and the joint angles between the segments, **FIGURE 4** (left).

Based on this data, the motion is then annotated, together with a functional model of the environment and a set of defined motion/interaction conditions. The functional model contains all the environmental components that are relevant for the interaction; these are, for
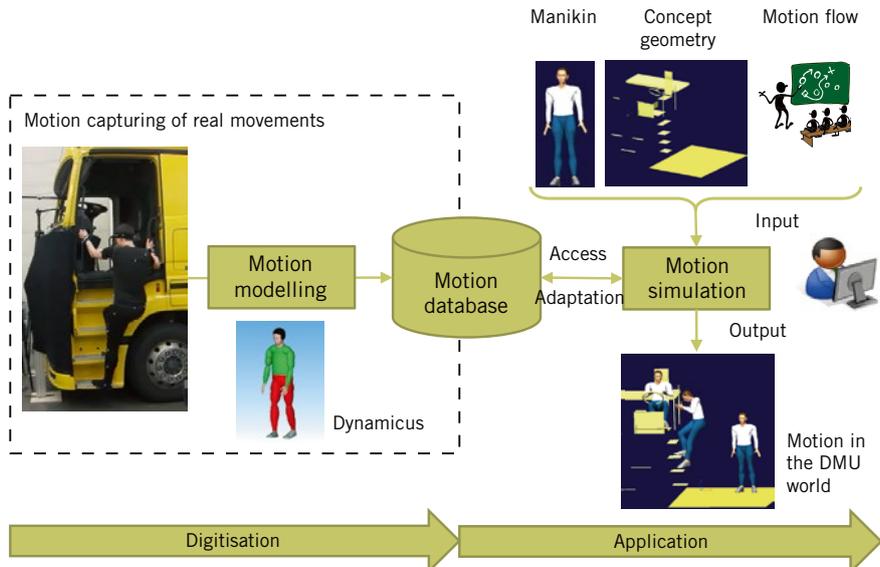
FIGURE 2 System architecture of digital dynamic ergonomics studies (© Human Solutions)

FIGURE 3 Motion capturing at the real vehicle with the optical motion capture system and the reflective markers on the test subject (© Daimler)
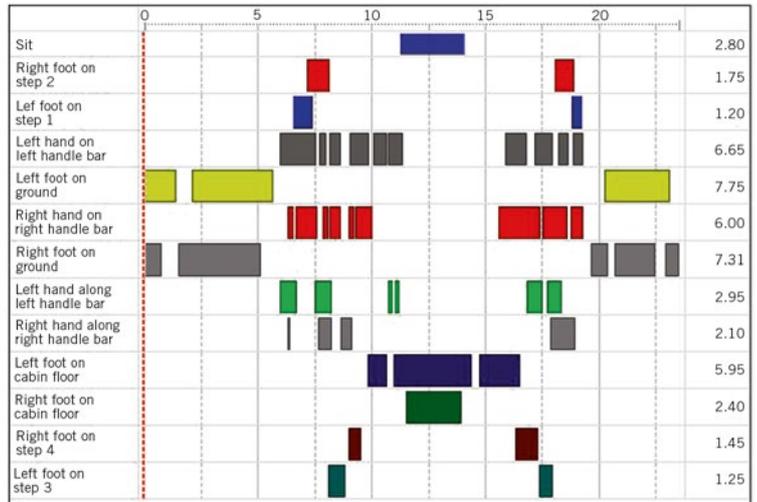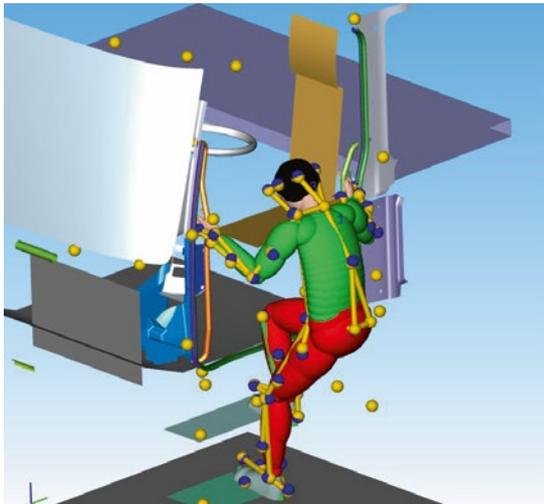
FIGURE 4 Modelling the motions with Dynamicus (left) and annotating them in a table (right) (© IfM)

	0	5	10	15	20	
Sit						2.80
Right foot on step 2						1.75
Lef foot on step 1						1.20
Left hand on left handle bar						6.65
Left foot on ground						7.75
Right hand on right handle bar						6.00
Right foot on ground						7.31
Left hand along left handle bar						2.95
Right hand along right handle bar						2.10
Left foot on cabin floor						5.95
Right foot on cabin floor						2.40
Right foot on step 4						1.45
Left foot on step 3						1.25

example, the floor of the cab, the cab steps and handrails, the steering wheel and the seat – the so-called 3-D function geometry.

As a result of this annotation process, additional information is made available for all the time points, for example left hand on left handrail or left foot on step 1, **FIGURE 4** (right). This information is then passed to the Ramsis manikin for further processing, together with the motion data.

MOTION SIMULATION

The modelled motions with Dynamicus are stored in a database, which is used for motion simulation with the Ramsis manikin [5]. The following process takes place in a 3-D CAD environment, **FIGURE 5**:

1. The user selects the type of motion/interaction (for example entering the vehicle).
2. Depending on the selected type of motion, the vehicle geometry is used to specify the components with which the vehicle occupant interacts during the motion (for example cabin steps, cabin floor, handrails). Here, various vehicle concepts can be addressed, such as the position of the steps and handrails, **FIGURE 5** (lower left).
3. The user defines the occupant according to gender, body dimensions (for example body length, corpulence) and age. A relevant 3-D manikin is then automatically produced in the digital environment (for example short woman or a tall man, **FIGURE 5** (top left).
4. The system automatically extracts a modelled motion from the database. Here a motion is selected that optimally corresponds to the user's input, for example vehicle model and occupant model (reference motion), **FIGURE 5** (centre).
5. The selected reference motion is automatically adjusted to match the specified vehicle model and the manikin. The key postures of the manikin are exactly calculated from the occupant's interaction points with the vehicle (for example steps, handrails). The dynamics of the reference motion are reproduced between the key postures, **FIGURE 5** (right).

The calculated motion is then transmitted to the Ramsis manikin, enabling it to be dynamically imaged in the environment.

VARIOUS MOTION BLOCKS

The current status of the progress being made shows that the process can indeed be carried out successfully. Various motion blocks have been created, such as entry into a cab and climbing up in front of the windshield. The data sets can be transferred to new vehicle geometries and modified later. The body dimensions of the virtual test persons can also be freely modified and the sim-

Manikin

Vehicle geometry

Most suitable motion from the database (reference motion)

Motion adapted for manikin and vehicle geometry

Process taking place
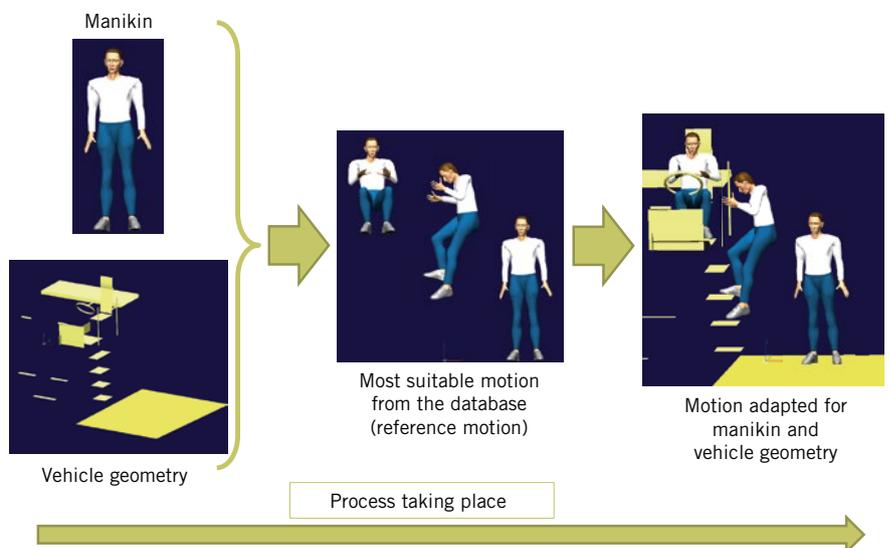
FIGURE 5 Automated simulation of motion flow (© Human Solutions)

FIGURE 6 Simulation of motions for various vehicle geometries and body dimensions – climbing up in front of the windshield (left) as well as entry into a cab for a tall man (centre) and a short woman (right) (© Human Solutions)

ulation results are biomechanically conclusive, **FIGURE 6**.

More motion blocks still have to be created. These include the climb up to the bunk in the cab and motion flows in the so-called living area of a cab. The aim is to store all truck-typical human motions in a database and make them available as generic components.

OUTLOOK

The process must be further developed under the premise of "artificial intelligence". Then specific adjustments will be recognised and independently executed by the system during the simulation, for example the automatic change of strategy in the case of imminent collisions. A collision due to geometry adjustments in the DMU world requires a biomechanically-correct evasive strategy (for example in the case of a half-open cab door).

The calculated simulation has to be evaluated to compare it with different variants and an ergonomic evaluation is ideal for this purpose. Established methods such as EAWS [6] and Rula [7] are already available in the field of production ergonomics. For product ergonomics, however – and especially for entry-level operations in commercial vehicles – these methods still have to be fully developed.

The development of the Arvida tool so far has provided valuable ergonomic statements during the early stage of development, when new vehicle concepts are still rudimentary approaches. Continuous advanced development would mean that one could completely dispense with physical mock-ups in future.

REFERENCES
[1] Van der Meulen, P.; Seidl, A.: Ramsis – The Leading Cad Tool for Ergonomic Analysis of Vehicles. In: Digital Human Modeling, Lecture Notes in Computer Science, Vol. 4561 (2007), pp. 1008-1017
[2] BMBF Research Project Arvida. Online: Project web page www.arvida.de
[3] Institute for Mechatronics: Dynamicus 8 – Referenz und Benutzerhandbuch. Chemnitz, 2014
[4] Härtel, T.; Hermsdorf, H.: Biomechanical Modelling and Simulation of Human Body by means of Dynamicus. In: Journal of Biomechanics, Vol. 39 (2006), Supplement 1, Abstracts, 5th World Congress of Biomechanics, Elsevier, p. 549
[5] Wirsching, H.-J.; Bichler, R.: Integrating Motion Capture Data into Knowledge Based Ingress Motion Simulation Tool. Proceedings, Digital Human Modeling Symposium, Ann Arbor, 2013
[6] Schaub, K.; Caragnano, G.; Britzke, B.; Bruder, R.: The European Assembly Worksheet. In: Theoretical Issues in Ergonomics Science, 2012, pp. 1-23
[7] McAttamney, L.; Corlett, N. E.: Rula: A Survey Method for the Investigation of Work-related Upper Limb Disorders. In: Appl. Ergon. 24 (2) (1993), pp. 91-99

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Cockpit Concept for Conditional Automated Driving

In the course of the increasing automation of the automobile, one question is receiving more and more attention: which non-driving-related activities drivers might choose to engage in while their vehicles drive themselves. Valeo is working on what an appropriate Human Machine Interface (HMI) should look like.

END-USERS' NEEDS AND EXPECTATIONS

For the development of a new HMI concept for conditional automated driving (SAE Level 3) [1], Valeo focused on end-users' needs and expectations. At this level of automation especially, interactions and communication between the driver and vehicle are extremely important. Drivers are able to hand the driving task over to the car and so address themselves to other activities, but they must also be able to resume driving as quickly as possible at all times.

In an international study conducted in 2012 in the US, China, Germany and France on the subject of Intuitive Driving Valeo elicited participants' expectations of an automated vehicle. The participants firmly endorsed automation for traffic jams [2]. In the light of this, and given increasing possibilities for delegating control to the vehicle in other circumstances, new expectations concerning communication and entertainment

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are emerging. At the time of that study already, participants put Smartphone use at the top of their wish-list for activities they could perform during automated driving, especially for emailing and messaging. Most of the respondents confessed that they already used their Smartphones when they drove, even without automated driving.

For the respondents the ideal place to read messages would be directly in front of them, in line with the road, on a head-up display for instance. But the information the driver needs during automated driving is not limited to communication or entertainment: displays and indicators are needed to build trust in the system. Valeo found this out in more than 60 in-depth interviews conducted in Germany, China and France in 2014. The driver wants a system of transparency of information about what the car is detecting, what it is going to do next and why. Predictive information is very important for trust building. People are not readily willing to hand responsibility for their safety over to a machine. To build trust the car needs a carefully thought-out HMI concept which can reassure the driver and permit them to concentrate on other tasks.

Many of the participants did however presume that they might need less information after an initial adaptation phase. As positive experiences boost trust, the need for information is progressively reduced. But it can at least said in general that drivers never want to be out of the driving loop. They always need to keep an eye on all information relevant to driving, like speed, GPS, traffic information, etc.

In addition to these opinions and attitudes, Valeo also gathered data on the driver's physical abilities and limitations which could play an important role for automated vehicles. Driving tests focused on topics like situational awareness and motion sickness in order to evaluate the effects of different HMI concepts. Since the tests focused on the relation to perception and well-being, the test subject was sitting as a passenger in a normal car driven by another driver.

Especially in automation Level 3 the presence of situational awareness plays an important role. Test drives simulating automated driving mode with 30 participants showed that situational awareness could be increased by 30 % during an automation phase by a higher positioning of the display on which the driver was reading an article. This adjustment enhanced the driver's perception of the environment by keeping his gaze closer to the road. Simultaneously, it has been found that the risk of motion sickness decreased by 50 %.

After a thorough analysis of the various data in the study, two particular challenges emerged:

ENHANCE SAFETY

In all markets Valeo found very safety-conscious end-users. Safety in the context of intuitive human machine interface means, firstly, that it is clear and easy to use and that the right information will be provided at the right time. This enables a request for take over from automated to manual driving to be executed in a correct and timely manner.

Secondly, the HMI must be used to promote trust and at the same time comfort or well-being in an automated car. The feeling of being out of control is both uncomfortable and not reassuring because it implies a lack of safety.

MORE VALUE FOR THE END-USER

An automated vehicle will only represent real added value for end-users when they can make good use of the time freed up during automation. Therefore a HMI concept is needed, that supports non-driving related tasks in a safe and comfortable way. This is another factor which will facilitate the acceptance of automation.

In automated mode any negative feelings experienced whilst performing non-driving activities will erase any added value. So for example since reading is one of the preferred activities, motion sickness is an important issue to deal with.

THE SOLUTION APPROACH VALEO MOBIUS

Valeo Mobius, **FIGURE 1**, is a response to these challenges [3]. The cockpit concept is composed of a 12.3 inch instrument cluster placed above the steering wheel as close as possible to the direct line of sight, enabling peripheral perception of traffic and frequent switching of glances between road and display. In automated mode the driver is able to connect mobile devices like a Smartphone or tablet via wired connection (e.g. HDMI) or even wireless. The complete content of the smart device will be mirrored in the instrument cluster display and can be controlled from the steering wheel. What the user usually sees directly on the phone is now in front of him, even if the smart device is located somewhere else in the car. This control is executed via a
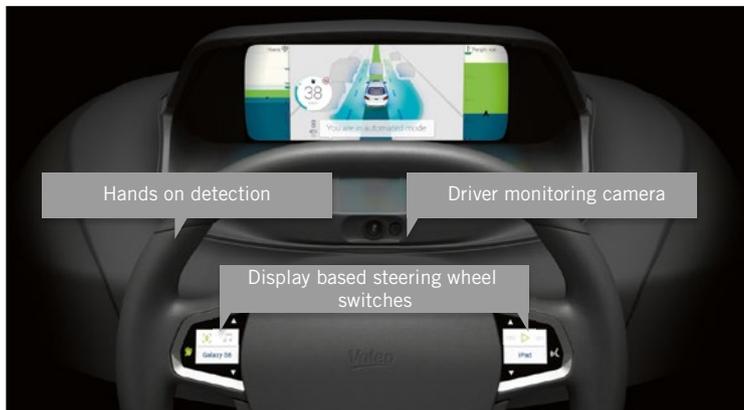
FIGURE 1 Key products of the Valeo Mobius concept and QR code leading to the movie (© Valeo)

wireless connection as well, in this case it is Bluetooth Smart and two innovative touch screen based steering wheel switches, **FIGURE 2**, one on each side of the steering wheel, which replace conventional steering wheel switches.

The core component of this input device is its integrated touch screen. It enables a complete, open, configurable HMI providing a high degree of contextualisation. For example function could be dependent on the driver or on the situation. Furthermore, software updates and upgrades of the user experience can be carried out easily. The switch offers

several input possibilities like simple pressing, touching, gestures and so on.

In order to avoid the activation of safety critical features, like for example the activation of the automated driving mode, dedicated safety measures can be taken, e.g. a long press on the switch surface which then activates a micro switch.

The full content of a mobile device will be displayed in the digital instrument cluster in order to allow peripheral perception of traffic and simple and quick glance switching between road and display without eye accommodation. Even if the driver is actively distracted by a

non-driving related task it allows him to quickly resume the driving task since their hands are already on the wheel and their eyes facing the road. This setup therefore combines a modern and intuitive user experience with a high depth of application and a low level of distraction.

In addition the driver can always keep an eye on the most relevant driving-related information, even in automated mode. A dedicated space on the instrument cluster provides the driver with real time information on the speed, surroundings, GPS information and so on. By pursuing the objective of keeping the driver in the driving loop and building trust into the system, situational awareness is increased and motion sickness reduced.

Valeo Mobius does not only innovate in the manner of control. It also contains a driver monitoring system which is crucial to the critical transition from automated back to manual driving. A camera monitors the driver to make sure they are looking at the road and dedicated sensors in the steering wheel detect if their hands are on the wheel. The driver will not be able to resume control until both eyes are on the road and hands on the wheel.

END-USER STUDIES WITH VALEO MOBIUS

The early involvement of the customer in the innovation process and evaluation is important to Valeo. Thus, Valeo Mobius was and is constantly tested and further developed by doing end-user studies. In early 2015 Valeo launched the first tests with a prototype to evaluate usability and acceptance. The study included small focus group interviews, moderated usability testing and in situ inter-

FIGURE 2 Exploded view of the display based steering wheel switch (© Valeo)

Distraction	SAE Level 2 Baseline	SAE Level 3 using Valeo Mobius	SAE Level 3 using Smartphone
Manual	–	–	✔
Visual	–	o	✔
Cognitive	–	✔	✔
Head position			
Hand position			

– Not distracted   o Partly distracted   ✔ Distracted

FIGURE 3 How the three test conditions differ in the level of distraction from driving task (© Valeo)

Comparison of the reaction time

FIGURE 4 Reaction times braking after surprise take over request (© Valeo)

tance was the combination of audible and visual warning and information elements. Many also perceived additional information or instructions delivered by voice as very positive.

What was striking in this study was that the majority of the study participants were not aware of the added value in safety this concept could offer. People mainly saw the added value in the use of communication and entertainment media in automated mode. Some participants questioned why they could not use profit from automated mode to take their smartphones in hand rather than operating via the Valeo Mobius controls. Only when Valeo installed the concept in a driving simulator for another study did the participants realize the potential danger of handheld usage and therefore expressed how Valeo Mobius enhanced their feelings of safety [4].

This second study was conducted in April 2015 in cooperation with the Fraunhofer Institute IAO in Stuttgart. In a driving simulator experiment with 42 test subjects two options were tested against a baseline condition, **FIGURE 3**. An automated driving phase was simulated in which the test subjects either looked at the street or read an article on a large smartphone or on the Valeo Mobius instrument cluster. Text scrolling was either performed via the Valeo Mobius press-touch-displays on the steering wheel or by swiping the screen of the phone. The automated drive was interrupted by an unexpected take-over request with a short time reserve. The Smartphone condition shows significantly slower reaction times compared to Mobius: 520 ms, **FIGURE 4**. This represents 8.4 m extra stopping distance at a speed of 60 km/h, **FIGURE 5**. Interestingly no significant difference between the Valeo Mobius condition and the baseline condition was identified [5].

After the simulator test drives the participants had to decide which of the two solutions they would use for reading an article during automated driving: Valeo Mobius or the smartphone. 93 % voted for the solution with Valeo Mobius. According to the test subjects the main advantage of the system is a greater feeling of safety and less stress during a sudden take-over.

This result was confirmed by additional interviews at the end of the simulator test in which the subjects were asked about the feelings they experienced during the

views where subjects were interviewed during testing.

End-users perceived the overall concept as very appealing and attractive. The control through the touch screen steering wheel switches was rated intuitive and innovative. The connection and control of the full mobile device content during automated driving was a real highlight. During the simulated transition phases drivers felt well guided and supported by the system. Of great impor-

FIGURE 5 Differences in stopping distance between the conditions in the surprising take over situation (© Valeo)

surprise take-over situation. The Valeo Mobius advocates expressed how in control and unstressed they felt during the test. This feedback suggests the positive impact Valeo Mobius could have in boosting trust in automated driving.

NEXT STEPS

Valeo is currently updating the prototype in line with the needs and expectations end-users expressed. This means, for example, to work on a way to simplify text entry on the steering wheel.

The next big step in Valeo's end-user centered approach to innovation will be the integration of the Valeo Mobius concept in an automated car. This will allow Valeo to evaluate how the concept handles real driving situations.

REFERENCES
[1] SAE: Automated Driving. Online: http://www.sae.org/misc/pdfs/automated_driving.pdf; last access: 5 October 2015
[2] Reilhac, P.; Millet, N.; Hottelart, K.: Thinking Intuitive Driving Automation. Tractatus Technologico-Humanicus. In: Meyer, G.; Beiker, S. (ed.): Road Vehicle Automation 2. Lecture Notes in Mobility. Springer International Publishing Switzerland, 2015
[3] Reilhac, P.: From human factors to user experience for level 3 car automation. The 2-in-1 Mobius cockpit concept. Online: Ertrac Annual Conference, Brussels, www.ertrac.org/uploads/documents_publications/2015%20Conference%20presentations/Valeo.pdf; last access: 5 October 2015
[4] Diederichs, F.; Bischoff, S.; Widlroither, H.; Reilhac, P.; Hottelart, K.; Moizard, J.: New HMI concept for an intuitive automated driving experience and enhanced transitions. Workshop proceedings, 7th Conference on Automotive User Interfaces and Interactive Vehicular Interactions, 2015
[5] Diederichs, F.; Bischoff, S.; Reilhac, P.: Welchen Einfluss hat das HMI auf automatisiertes Fahren? 11. Berliner Werkstatt Mensch-Maschine-Systeme, Berlin, 2015

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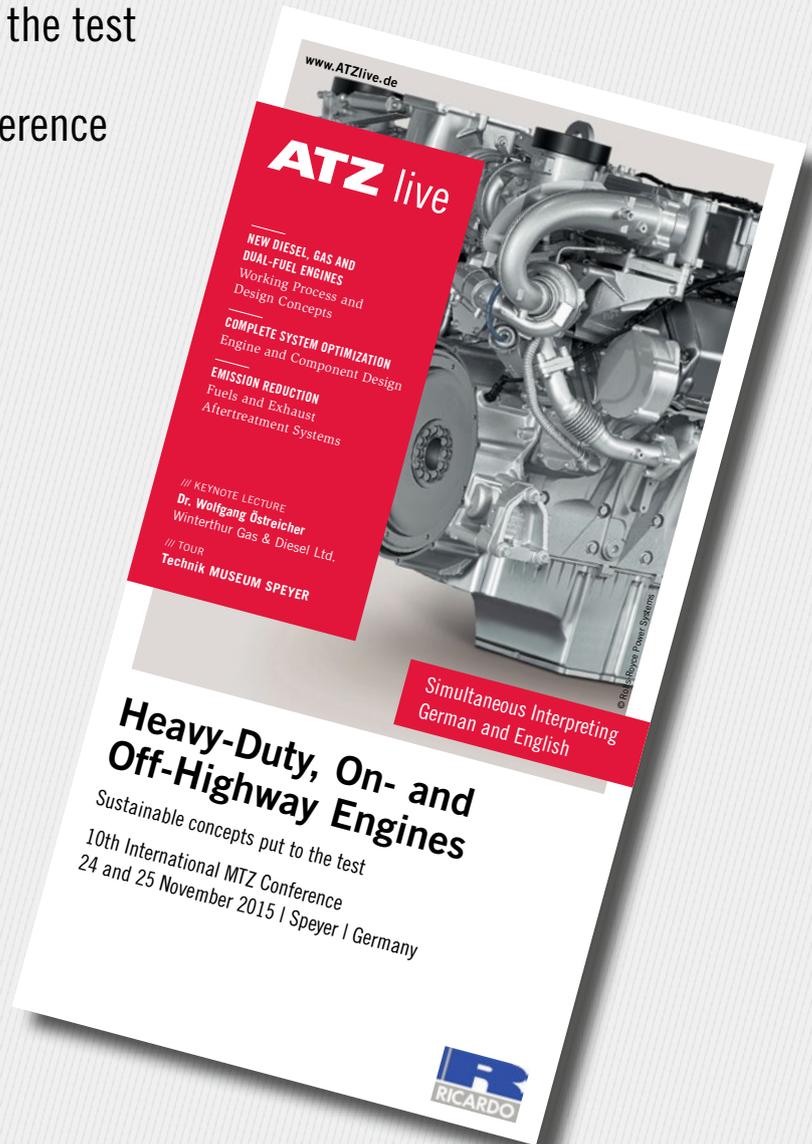
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Lightweight Forging Initiative
Phase II: Lightweight Design Potential for a Light Commercial Vehicle

For a medium-sized passenger car, forging allows a weight reduction of 42 kg in powertrain and chassis parts. How about a Light Commercial Vehicle with 2394 kg? The Lightweight Forging Initiative discusses this issue and shows in its investigations that weight savings of 99 kg can be identified on the basis of the lightweight design potential which may be achieved through forging, alternative steel materials or lightweight design concepts.

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FIRST PHASE FOR PASSENGER CAR

The Lightweight Forging Initiative was formed in 2013 by 15 forging and nine steelmaking companies under the auspices of the German Forging Association (IMU) and the Steel Institute VDEh. During the first phase, a medium-sized passenger car was analysed and a lightweight design potential of 42 kg was identified for components in the powertrain and chassis [1].

Based on the tremendous interest that the results received from customers and driven by the intensive cooperation within the two participating industries, a decision was made to launch Phase II in 2015 to focus on the lightweight design potential of forgings in a light commercial vehicle. Phase II of the Lightweight Forging Initiative brings together 17 forging companies, ten steelmakers and one engineering service supplier, **FIGURE 1**.

LIGHTWEIGHT DESIGN POTENTIAL IN A LIGHT COMMERCIAL VEHICLE

During the second phase of the initiative a Light Commercial Vehicle (light duty truck, LDV, following US american denomination) was analysed for the aim of getting lighter with forged components. In contrast to cars, the weight of LDVs still continues to increase from one generation to the next. However, the stipulations for decreasing CO_2 emissions in cars likewise apply to LDVs. It should also be noted that the total cost of ownership is more critical in commercial vehicles than in cars – weight reduction leading to the decrease of fuel consumption has a bigger impact on purchasing decisions [2]. Finally, lower vehicle weight allows for a higher payload to be transported, which can be another factor in the purchasing decision of the professional vehicle owner.

1.44 million light commercial vehicles (gross vehicle weight up to 3.5 t) were sold in the EU in 2013. Here, legislation requires a reduction in CO_2 emissions of 13 % to stand at a CO_2 value of 182 g/km by the year 2020. The vehicle chosen for this lightweight design potential analysis is very representative for this class. The vehicle has a 2.1-l four-cylinder diesel engine with 120 kW power, a manual six-speed transmission and rear wheel drive, thus representing the most widely sold configuration. The total mass balance for powertrain and chassis, but also body, interior and electronics as well as the spectrum of manufac-

turing processes applied are shown in **FIGURE 2**.

The same procedure was used for generating ideas for the lightweight design potential as in the first phase of the Lightweight Forging Initiative [1]. After finding a representative model for this application segment, the vehicle (ensuring it was the latest generation) was purchased second hand (age: 12 months, mileage: 23,000 km). The vehicle was then dismantled. Two hands-on workshops took place in which the members of the initiative analysed all 2536 parts and generated lightweight design potential ideas. The ideas were classified according to weight reduction potential, possible impact on manufacturing cost and finally according to the level of implementation difficulty.

THREE IDEA GROUPS FOR LIGHTWEIGHT DESIGN POTENTIAL

In total, 535 ideas for lightweight design potential were generated for parts made from rolled long material (forgings, bolts, nuts, tubes or springs). With the classification data attributed to each idea, an overview for a meaningful prioritisation of lightweight design suggestions can easily be generated. The ideas may be clustered into three groups in a portfolio chart, **FIGURE 3**. On the horizontal axis the ideas have been placed with cost impact versus realisation potential (with a weighting coefficient of 2:1). On the vertical axis, the level of the lightweight design potential is shown.

FIGURE 1 The Lightweight Forging Initiative – phases I and II as well as research project (status in winter 2015) (© Lightweight Forging Initiative)
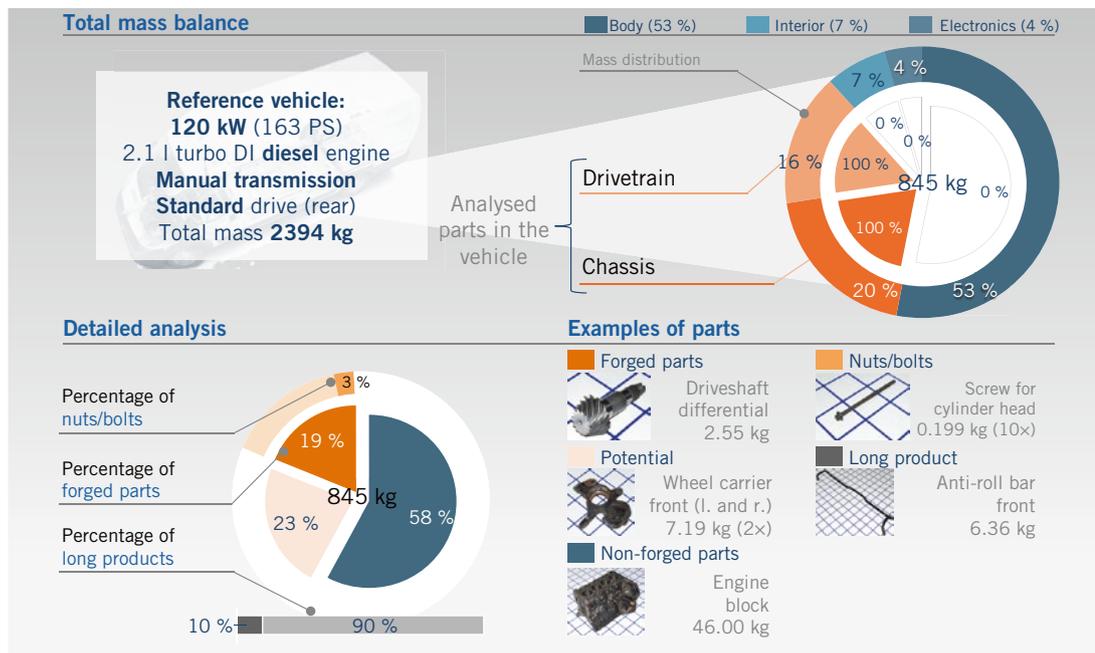
FIGURE 2 Total mass balance especially for the powertrain and chasiss domains as well as manufacturing processes for the analysed light commercial vehicle (© Lightweight Forging Initiative)

The first group of ideas A in **FIGURE 3** is that of the "Quick Wins". These ideas should be pursued fast and with high priority. They offer a decrease in weight with no or hardly any cost increase and pose no or only little implementation difficulty. The Lightweight Forging Initiative, however, clearly wants to state that this is not at all to be understood as criticism of any kind towards the designers at the manufacturer of the vehicle. These ideas are meant as suggestions in order to apply the current state of the art of forging and materials technology (especially modern steel solutions), in order to support the megatrend of "Lightweight Design".

The second group B in **FIGURE 3** encompasses those ideas with balanced lightweight potential. They offer weight reduction at increased cost and require greater implementation efforts. It should be noted that these efforts need to be compared thoroughly with other weight reduction options in a vehicle, which are currently dominating the headlines (CFRP, sheet-metal steels, plastics). Forging is a proven technology and can offer a better weight reduction cost per kilogram of weight saving than many other manufacturing methods – if given its appropriate attention (which is one of the primary goals of the Lightweight Forging Initiative).

The third group C in **FIGURE 3** is the class of "Tough Nuts". Here, cost and effort increase further for a lightweight design action.

IN TOTAL 99 KG SAVINGS POSSIBLE

For the whole vehicle, weight savings of 99 kg in total were identified on the basis of the lightweight design potential which may be achieved through forging, alternative materials or lightweight design concepts. The steel based lightweight design potential reaches 65 kg. As this vehicle exhibits a higher ratio of iron-based solutions (for example cast iron parts) than the passenger car analysed in Phase I [1], the lightweight potential by using non-ferrous metals could contribute another 34 kg.

Implementing all the best lightweight proposals would mean that the weight of the powertrain and chassis in this vehicle could be reduced by 11.7 %.

TAKING MATERIAL AWAY WHERE NOT NEEDED

Many lightweight design potential ideas have been detailed in CAD models, comparing the idea with the original component. This allows for a comparatively exact calculation of weight difference. Depending on the competence of the respective consortium member, the lightweight idea was even simulated in FEA

programmes in order to confirm its validity. Similar to phase I [1], weight reduction was primarily generated by taking material away where not needed, thus utilising the shaping possibilities of forging technology to a greater extend.

Secondly, steel materials with better performance allowed for lightweight design. For selected components, the use of aluminium alloys to replace cast iron or some steel sheet based components allowed for notable weight savings. The economic validity of these ideas, like in all cases, needs to be assessed thoroughly. Finally, some conceptual ideas were able to fulfil the given functional requirements on parts or subsystems with lower weight. The broad spectrum of the ideas can be accessed in the extensive overview presentation [3] provided by the Lightweight Forging Initiative.

STRONGER STEELS FOR LIGHTER TRANSMISSIONS

The call for lightweight design is increasing in the entire field of automotive technology. The Lightweight Forging Initiative thus considered it worthwhile to explore the relationship between the increased cost of higher performance steels and the possible weight reduction for transmissions resulting from this. In order to do so, a transmission design study was commissioned at the Institute

Lightweight design idea portfolio

Optimum

Group A "Quick wins" 55 ideas

Group B „Balanced lightweight potentials" 85 ideas

Group C "Tough nuts" 395 ideas

Lightweight potential — High (≥30 %) — Constant

Cost potential & realisation effort
Expensive — High / Cheap — Low

Portfolio evaluation

Mass [kg]

845 kg
45 ideas
Group A 23 kg
80 ideas
Group B 38 kg
204 ideas
Group C 38 kg
Drivetrain 381 kg
-11.7 % (-99 kg)
746 kg
Suspension 464 kg
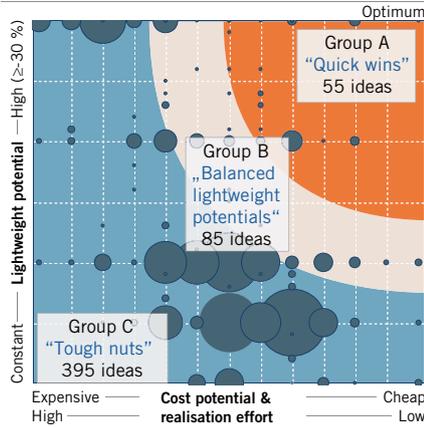
Start mass — Lightweight version
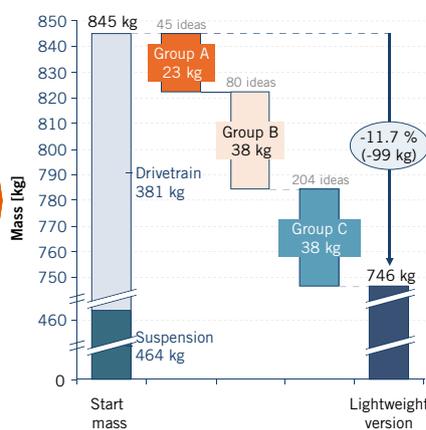
FIGURE 3 Portfolio chart: overview of the three groups of ideas A, B and C for lightweight design potential and their evaluation for weight reduction (© Lightweight Forging Initiative)

of Product Engineering (IPEK) at Karlsruhe Institute of Technology (KIT).

The data of the LCV manual transmission were modelled in an MS-Excel sheet, **FIGURE 4**. The Excel model takes into account tooth flank load, tooth root load, shrink fit torque transfer capacity and shaft fatigue of the medium alloyed carburising steel used in this transmission. Based on fixed input values (engine power, torque and vehicle speed) and on the transmission topology, it is now possible to vary "pitting resistance" and tooth root fatigue strength. Depending on the increase in these strength properties, the model can predict savings in system weight and size, **FIGURE 4**. The decrease in size of the gear wheels and shafts is directly taken into account. An

additional programme step calculates the secondary weight effects within the shrinking transmission housing.

In order to compare steel based weight reduction cost against possible weight loss now, strength parameters for a higher alloyed steel were then fed into the transmission model. This results in predicted weight savings of 2.45 kg. If the manual transmission were to be equipped with the high alloy steel, it would be necessary to switch approximately 21 kg of shafts and gear wheels to the higher alloyed steel. This steel exhibits an increased material price (base price plus largely the alloy surcharge). If it is now assumed that the input weight for the forged components drops by the same amount of 2.45 kg, the total cost

increase for the lightweight design transmission is only 2 euros.

It can thus be assumed, that a weight saving of 2.45 kg may be achieved at an increased cost of less than 1 euro per kg of weight saved. Saving weight by using higher performance steels in transmission applications is thus a very cost-effective lightweight measure. This not only applies to the transmission itself, but to all systems where gears mesh (differentials, transfer boxes, etc.). Additionally, the transmission model predicts, that further weight reduction could be expected with even higher strength values.

ECONOMICAL WEIGHT REDUCTION SOLUTIONS

The Lightweight Forging Initiative has demonstrated on two different vehicles (passenger car and light commercial vehicle) that modern forging technology and forging materials, especially high-strength-steels, can significantly contribute to economical weight reduction solutions in the automotive industry. In its second phase, the importance and effectiveness of high quality steel in transmission applications has been more intensively highlighted.

The federally funded research project "Lightweight Forging" will yield even more lightweight design potential in the future. One key insight will always remain true: Only by good communication the optimum combination of component design, materials and manufacturing technology is reached in order to
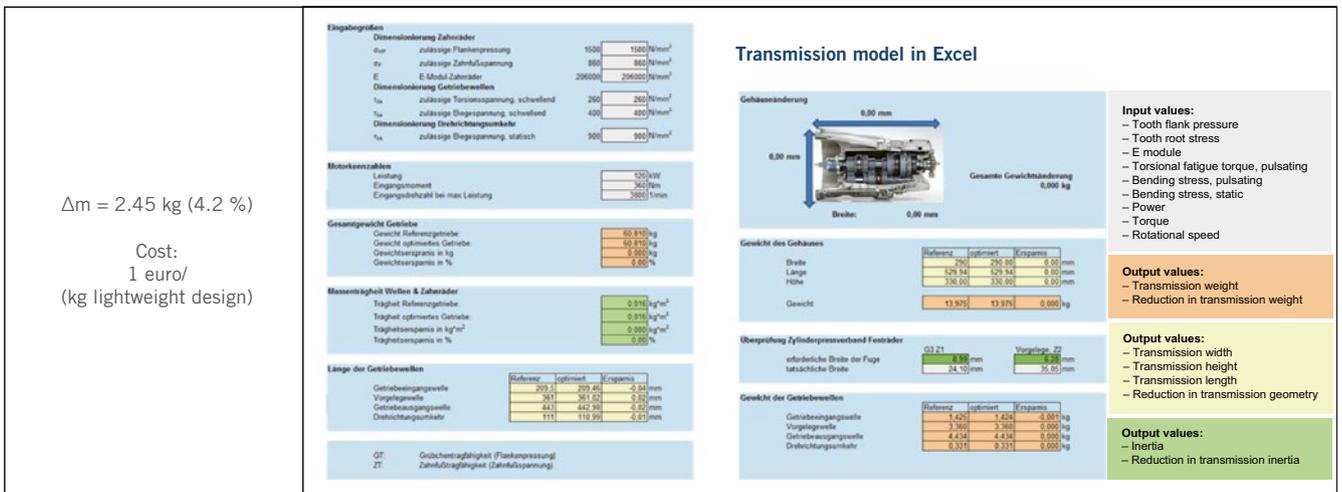
FIGURE 4 Transmission design model, takes into account secondary weight effects within the shrinking transmission housing besides weight optimisation of the gear set (© Lightweight Forging Initiative)

ensure the development of a high quality lightweight solution in mass production at a competitive lightweight design cost.

SUMMARY

The Lightweight Forging Initiative has, during phase I, demonstrated a lightweight design potential of 42 kg in the powertrain and chassis of a mid-size passenger car. This successful undertaking was being continued in a Phase II in the light commercial vehicle segment. A vehicle has been dismantled at fka and all the components have been documented. In hands-on-workshops, material, forging and conceptual lightweight design ideas were generated. Additionally, in a transmission design study the cost of weight reduction by using stronger transmission steels has been quantified.

REFERENCES
[1] Raedt, H.-W.; Wilke, F.; Ernst, C.-S.: The Lightweight Forging Initiative – Automotive Lightweight Design Potential with Forging. In: ATZworldwide 116 (2014), No. 3, pp. 58-64
[2] Ernst, C.-S.; Busse, A.; Göbbels, R.: Massiver Leichtbau 2.0: Leichtbaupotenziale massivumgeformter Komponenten im leichten Nutzfahrzeug (LNF). fka, Lightweight Forging Initiative, internal presentation, Aachen, 19 March 2015
[3] Industrieverband Massivumformung e. V. (ed.): Two industries – one goal. Online: www.lightweight-forging.com. Last access 18 December 2015

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Development of an Innovative Repair Concept for CFRP Parts in Cars

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The Institute of Plastics Processing (IKV) and six other research institutes (ika, ISF, IBF, WZL, MMI, FIR) at RWTH Aachen University currently develop a new repair strategy for vehicles with CFRP design. Based on the challenges to repair future vehicles, a variety of approaches are designed, evaluated and validated. The objective of the project is an integrated repair strategy, including essential infra-structure for workshops. The project is executed in close cooperation with approximately 60 industry partners.

DETECTION OF DAMAGES OF CFRP

Legal requirements limit the corporate average CO_2 emission of car manufacturers. In combination with the customers' preferences towards environmentally friendly cars, this leads to an increasing demand for electro mobility [1]. With the battery technology available today, an acceptable range and vehicle dynamics can only be achieved through designing light weight structures, utilising materials of high rigidity such as carbon fibre reinforced plastics (CFRP). The main advantages, a reduction in energy consumption and an extended range of the car [2], are opposed by new challenges for the repair procedure of these vehicles.

In contrast to metal parts, structures made from CFRP tend to display a wider range of possible damages [3]. In addition, the detection of damages requires greater effort and is not always possible. Damages that cannot be recognised from the outside pose the most critical problem. Typical examples for such complications in the inhomogeneous material-structure of fibre-reinforced plastics are delaminations, voids and broken fibres, which can lead to the spontaneous failure of a part. This makes a reliable detection, individual analysis and expertly executed repair a core element of future automotive concepts.

ESTABLISHED CONCEPTS

There are established concepts for current vehicles with a substantial amount of CFRP parts. Lamborghini deploys their so-called Flying Doctors to repair CFRP structures at the customer's location [4]. In case of an incident, these technicians are flown to the customer. They are trained specifically to detect, assess and repair damages on certain car models, **FIGURE 1**.

BMW takes a different approach in their i-model range. Only selected workshops are certified to conduct a repair on the i-vehicles. Depending on the model, predefined segments of CFRP parts can be removed in case of damage and are then substituted by identical part segments.

Aside from these approaches a different strategy is used for attaching CFRP components. A replacement as a whole is usually most efficient, but also costly. All these concepts are not applicable for large integral structures like CFRP chassis in a mass produced electrical vehicle. In order to lower costs and effort to an acceptable level, the development of new repair concepts is necessary.

REPAIR STRATEGY

In contrast to the prevailing method of replacing large segments or whole CFRP parts, the capability to repair small areas on a damaged part is the aim of a new repair strategy under development by the IKV and partners. An industry 4.0 approach leads to the desired outcome. Each step in the repair process, **FIGURE 2**, is designed to be versatile and connected to an IT network. This also allows equipping small and medium sized workshops for the repair tasks of the future.

First, the damaged part is examined with a sensor-based, non-destructive procedure, **FIGURE 2** (1). The accuracy of the generated data is high enough to evaluate the remaining load-bearing capacity of the parts and to decide to which extend a repair is necessary (2, 3). Depending on the damaged part and the severity of the damage, central specialised production facilities manufacture individualised patches at high cost efficiency. In this context Individualised patches are damage-, stress- and geometrically-suiting patches. They are designed to restore the mechanical, load-bearing and geometrical properties of the original part. Different concepts to manufacture these patches are evaluated. These range from stocked standard designs, which can be milled to fit the geometry, to individually produced parts (quantity ~1). The damaged area is prepared for repair and recorded by sensors. The data (3) is used to produce a geometrically matching patch at the central production facility (4). The individually to the vehicle and the repair-preparation shaped and centrally manufactured repair patch is sent to the workshop (5) where it is utilised to conduct the actual repair (6). To guarantee the quality, stability and function of the repaired part, sensor-based devices are applied for final quality assurance (7, 8).

INDIVIDUALISED MANUFACTURING OF REPAIR PATCHES

A core theme of the project is to develop production methods for the automated manufacture of highly individualised

FIGURE 1 Lamborghini deploys their so-called Flying Doctors to repair CFRP structures at the customer's location (© Lamborghini)

Damage detection

Repair

Quality control

① Damage recognition

② Damage analysis

③ Data processing

④ Data for manufacturing patch

Patch-making

⑤ Patch delivery

⑥ Repair process

⑦ Quality control by technician

⑧ Measurement of part

⑨ Final result of quality control
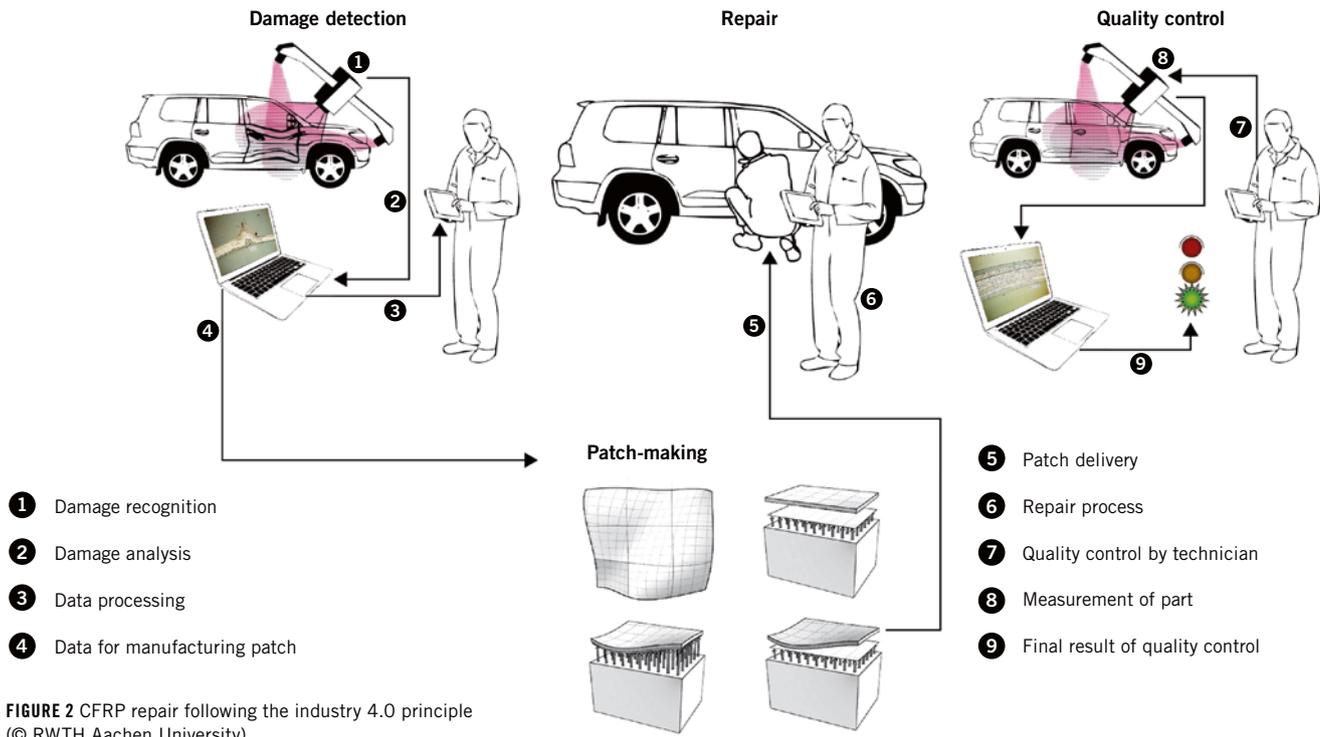
FIGURE 2 CFRP repair following the industry 4.0 principle
(© RWTH Aachen University)

repair patches. The main challenge is the high geometrical complexity and large variety of structural parts in modern cars. Depending on the damaged area, different radii, openings, onserts and inserts have to be taken into account, **FIGURE 3**.

TOOL CONCEPTS FOR THE INDIVIDUALISED MANUFACTURE OF REPAIR PATCHES

The choice of the tool to produce individualised repair patches depends on the process, the matrix materials (thermoset,

thermoplastic), the different geometries and the production quantity [5]. There are one-sided tools, in which the forming process is carried out by using pressurised air or punches. Usually, semi-finished products such as thermoplastic organic sheet or thermoset prepregs are processed in these tools. One version of such a thermoplastic process is the high-temperature diaphragm forming, developed at IKV [6]. In contrast to one-sided tools, two sided tools form all areas of a part with solid mould sides (cavity) in an injection process. A typical example for the application of such tools is the Resin Transfer Moulding (RTM) process, currently used by for example BMW to manufacture its CFRP parts. Both, one sided and two sided tools can be fitted with a "customisable" cavity by use of modular inserts or adaptive areas to manufacture different parts at maximum cost efficiency with only one basic tool. The variety of different tools is shown schematically in **FIGURE 4**.

The use of modular inserts leads to highly versatile cavities by changing small areas in the tool. This way only small areas in the tool cavity have to be manufactured when geometries are adapted (for example different sized cut-outs) or different component variation (for example with and without process integrated fastening elements) are produced. This

Onserts

Openings

Various radii

Inserts
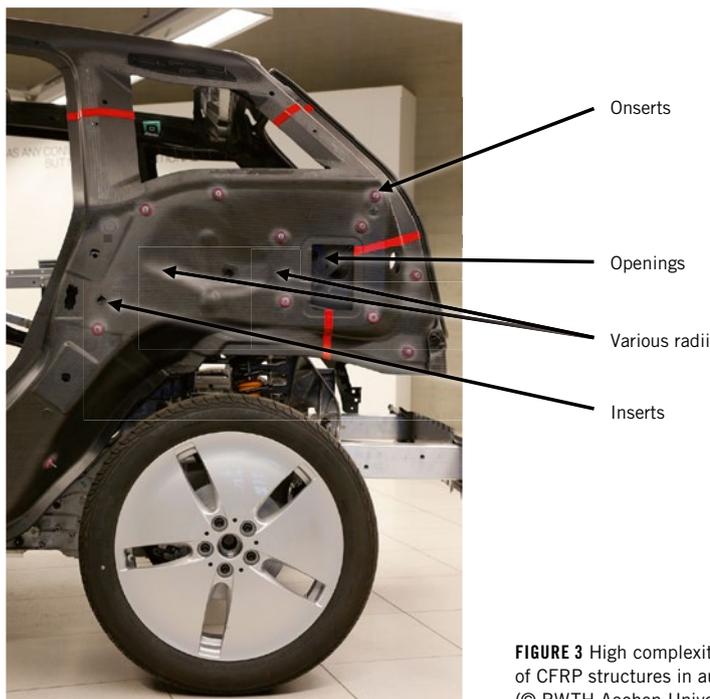
FIGURE 3 High complexity of CFRP structures in automobiles (© RWTH Aachen University)
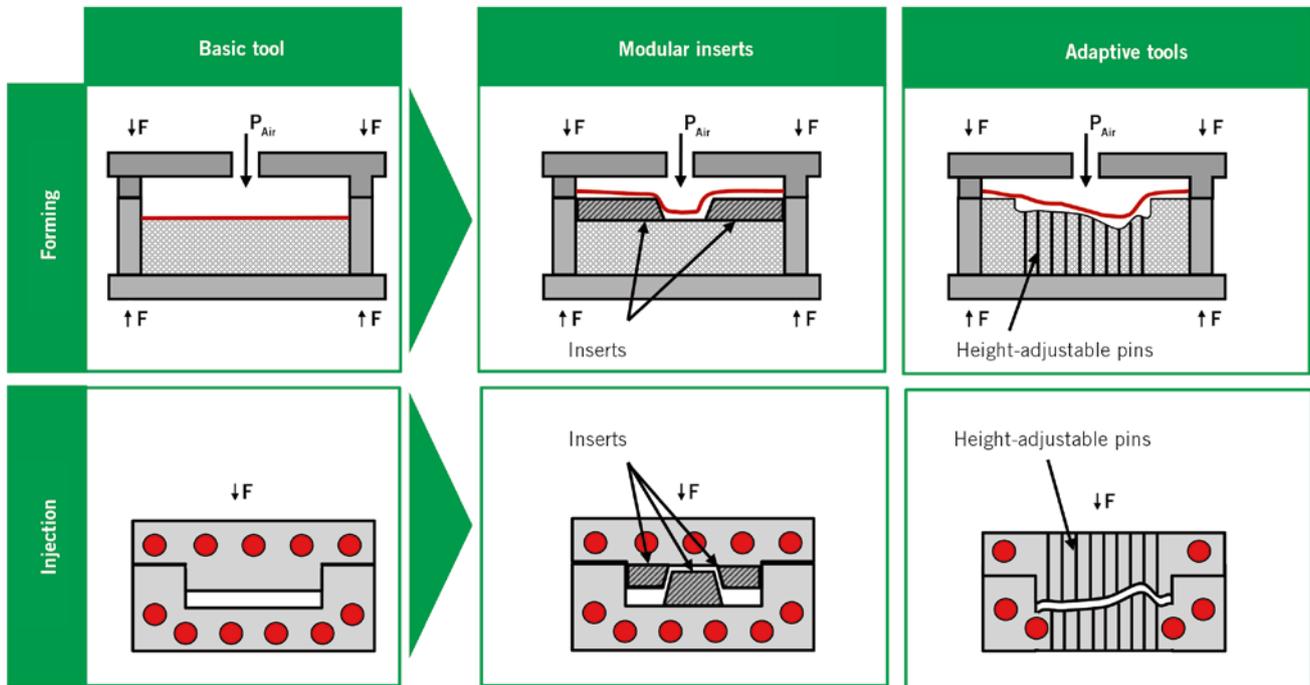
FIGURE 4 Possible modular and adaptive tool concepts (© RWTH Aachen University)

decreases the investment costs for tooling in contrast to making individual tools for each different part-geometry. Adaptive tools can be realised by a variety of means, for example by height-adjustable pins in combination with a flexible diaphragm. This eliminates the need to exchange components of the tool in order to manufacture different parts. A disadvantage of adaptive tools is a limitation for part-geometries. For example, it is not possible to manufacture parts with sharp corners or very small radii.

In the scope of this project, innovative adaptive forming tools with modular inserts will be developed, designed and manufactured. The high flexibility of adaptive tools will be used in rather planar areas of parts, while the combination with modular inserts enables the manufacture of more complex areas like sudden thickness changes, sharp corners or the integration of load-bearing fastening elements. For example, repair patches for car roofs can be manufactured in this manner, since those are mostly planar components with tight radii and steep edges in the outer regions of the part.

HOLISTIC APPROACH

The continuing trend towards more efficient car concepts and electro mobility causes many OEM to expand their usage of CFRP in high volume models. As a result, new repair strategies suitable for mass application have to be established. Hence, a current object of research is the development of an innovative repair strategy for vehicles with CFRP design. The approach currently developed at IKV and its partners is an integrated decentralised repair strategy that takes the already present infrastructure of workshops into account.

Within the project at the Institute of Plastics Processing (IKV) at RWTH Aachen University a central material and information flow network is established. All steps in the repair process are interconnected, starting with a sensor-based damage detection, the database-driven damage analysis, the individualised manufacturing of CFRP patches and last but not least the actual repair process. This will enhance the economic feasibility and efficiency of repair methods for future CFRP vehicle concepts.

REFERENCES
[1] N. N.: Megatrends. In: Thoughts, issue July 2012, Roland Berger School of Strategy and Economics (Ed.), Munich, 2012
[2] Ferkel, H.; Kurz, H.; Becke, J.-W.: Faserverbundwerkstoffe als wirtschaftliche Option für die Großserie. Calking of the CCeV Automotive Forum. Neckarsulm, 2010
[3] Hyonny, K.: Impact Damage Formation on Composite Aircraft Structures. Federal Aviation Administration, JAMS 2014, Technical Review Meeting, 14 March 2008
[4] Nothdurfter, S. K.; Oto, L. de: Lightweight Construction in Automotive: The Lamporghini Aventador. 15th European Conference on Composite Materials, Venice, Italy, 2012
[5] Neitzel, M.; Mitschang, P.; Breuer, U.: Handbuch Verbundwerkstoffe. Werkstoffe, Verarbeitung, Anwendung. München, Wien: Carl-Hanser-Verlag, 2014
[6] Schöldgen, R. A.: Inline-Imprägnieren und Hochtemperatur-Diaphragma-Umformen endlosfaserverstärkter Thermoplaste. Dissertation, RWTH Aachen University, 2013

Silent Brakes with Magnetic Material Damping

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Disagreeable noise of disc brakes comes from vibrations that are generated due to the friction between brake disc and brake pad. Rassini developed a new process as Magneto-mechanical Damping (MMD) that will supply an end goal of noise-free brakes to the driver.

DISPLEASING NOISE OCCURRENCES

One of the highest warranty concerns for all automobile manufacturers is noise in the form of a brake squeal for the customer. This noise comes from vibrating frequencies that are generated due to the friction between brake disc and brake pad. It is exacerbated by the resonance of other components like the calliper, the rotor, and steering knuckles. Typical squeal frequencies range from 1 to 20 kHz, and noise amplitudes over 70 dB are unacceptable in most cases. Increase in damping or modification of resonant frequencies of the brake components are some of the most feasible options among

a myriad of solutions to mitigate or eliminate displeasing noise occurrences. Damping attenuates the vibration resulting in an amplitude drop, which can be achieved either by active system damping or passive material damping. Illustrated for the latter in **FIGURE 1**, higher damped metals will have the vibration amplitude drop to zero in a shorter time compared to materials with lower damping.

MAGNETO-MECHANICAL DAMPING

Material damping involves internal friction generated in response to a vibratory stress. Magneto-mechanical Damping (MMD) [1] is one of several material

damping mechanisms that helps generate internal friction – in fact by movement of so-called magnetic domains. Not all materials have such domains, but ferromagnetic materials do, such as iron, cobalt and nickel, and paramagnetic materials, like aluminum, and titanium. When the magnetic domain structure and alignment are changed in response to a magnetic field or a vibratory stress, the domain walls move and generate internal friction that causes MMD. MMD is typically caused through three mechanisms:

– macro eddy currents, which are produced due to the bulk response of the material to changing magnetic field under the influence of stress
– micro eddy currents, which are produced due to local changes of magnetisation due to stress induced domain wall movement (both reversible and irreversible)
– magnetic hysteresis, which is the energy lost under cyclic stress and is caused by irreversible domain wall movements.

Though the MMD is very applicable for the ferromagnetic grey iron rotors in brakes, there have been limited efforts over the years to study and apply this towards decreasing brake noise. In 2012, Rassini, a Mexican supplier engaged in design and manufacturing of suspension- and brake components for the automotive industry, and the University of Windsor in Ontario, Canada, saw this missing research as an opportunity: They partner together and developed methods that increase and optimise the contributions of MMD in brake discs through electrical and magnetic processing. The main hypothesis of the study [2] was that the damping is improved due to a better magnetic domain structure obtained from the electrical or magnetic processing that facilitates higher losses from eddy current and hysteresis damping. It is also possible that the processing can result in stress relief due to domain wall movements.

Several processes were used and benchmarked including the processes with Electrical Discharge Machines (EDM) or magnetic coils as well as passing current directly through the part using clamps. Each process is different in terms of the field produced around the part. EDM is a machining process where the workpiece (for example the rotor)

and the electrode (typically made of graphite) are placed in a dielectric fluid, and they are both connected in a circuit to a power supply. The power supply supplies pulses of direct current and then the voltage difference between the rotor (cathode) and the electrode (anode) generates a spark in the gap between each other which machine the part.

Magnetic coils are used typically for Magnaflux equipment, and a strong magnetic field is typically produced in the centre of the coils. The part could be placed in the magnetic field or even in a

demagnetiser to produce a change in the damping properties of the rotor.

The rotor could also be electrically processed by passing direct or alternating current through it and having the rotor in the circuit. The magnetic field in Magnaflux machines and the signal characteristics during the EDM process and direct clamping process were measured using a Gauss meter (measurement unit Gauss [G]) and a Rogowski coil respectively. The benchmarking data and a measurement plot are shown in **FIGURE 2**.
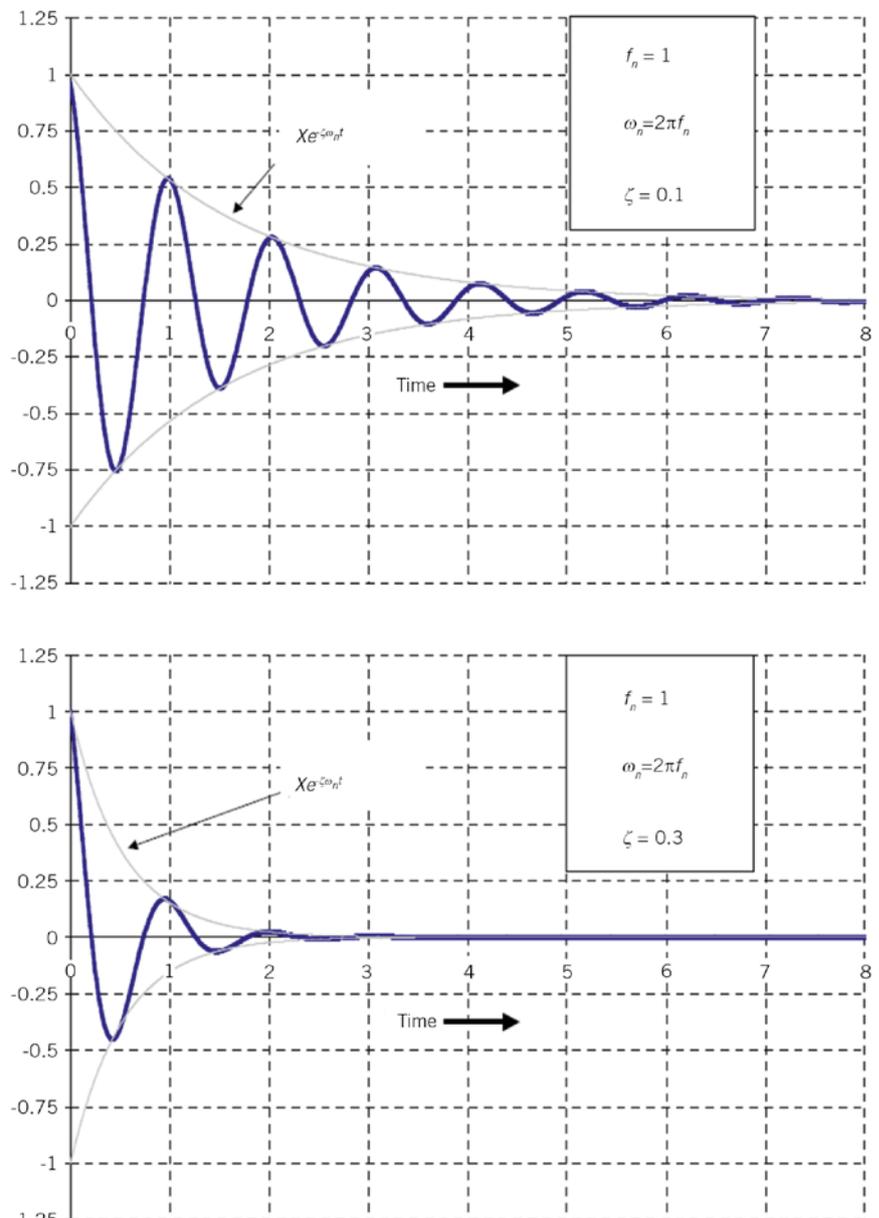
FIGURE 1 Vibration attenuation with different damping factors ζ in the time domain; higher damped metals (bottom) show amplitude drop to zero in a shorter time, in comparison to lower damped metals (top) (© Rassini)
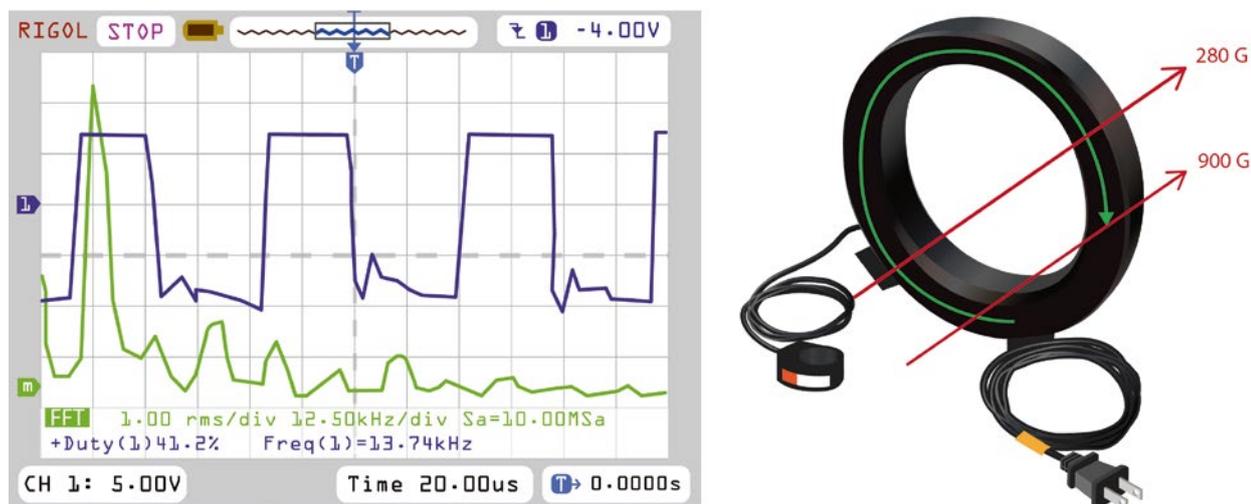
FIGURE 2 Benchmarking data and measurement plot of the Gauss meter (left) and setting of the Rogowski coil (right) (© Rassini)

EDM PROCESSING

Processed parts were analysed by comparing damping of the part before and after EDM processing. Damping was measured on a modal analysis test equipment from Leuven Measurement Systems (LMS) using a hammer and a microphone. The Q factor (measure of damping) was calculated based on the 3 dB drop from the frequency response plot at the 2 ND mode, **FIGURE 3**. The Q factor is related to the damping factor ζ as shown:

$$Q = \frac{1}{2\zeta}$$

Q factor improvements of up to 45 % were observed on the rotors processed by EDM and up to 35 % seen with the other processes. This significant improvement in damping helped to eliminate or reduce the noise occurrences during brake dynamometer testing as shown in **FIGURE 4**.

Baseline and EDM processed rotor were tested using the SAE J2521 noise test procedure, and the results show many noise occurrences at approximately 9 and 13 kHz on the baseline rotor and a significant reduction in the noise occurrences of the EDM rotor. Multiple noise tests show a significant improvement in noise performance, especially at noise frequencies that relate to the compressional/tangential modes. It should also be noted that other performance characteristics like wear or crack resistance are not affected by this processing. Negligible changes are seen in

the bulk chemistry, microstructure and in the natural frequency of these parts due to the electrical or magnetic processing. It was also observed that after noise or thermal tests, the Q factor of these processed rotors did not change. However, continuous exposure to temperatures over the Curie temperature (T_C = ≈700 °C or for iron at 768 °C) will result in a loss of the damping improvements.

Based on these benchmarking data, more feasible prototypes were manufactured with a special production equipment in 2014 to create and simulate the signal characteristics found to generate the maximum improvements in damping. The new equipment eliminated handling issues and complexity, and created an easier process to generate the damping improvements needed.

Process development is underway to provide a simple method to create a

magnetic field around the rotor, in a production environment. The intent is to be able to process the rotor in line, either as a casting or a machined part, in less than a minute. Successful manufacturing of the prototype machine has provided a simple and feasible way to further implement this technology for production. The prototype equipment to generate the optimal magnetic signal is still undergoing extensive research and tests in the lab. Once all the process parameters are optimised and perfected, it will be production feasible in late 2016.

CHOICE OF MATERIAL

Damping improvements from electrical and magnetic processing were also found to be highly dependent on the rotor material. Traditionally, damping is

$$Q = \frac{f_3}{(f_1 - f_2)}$$
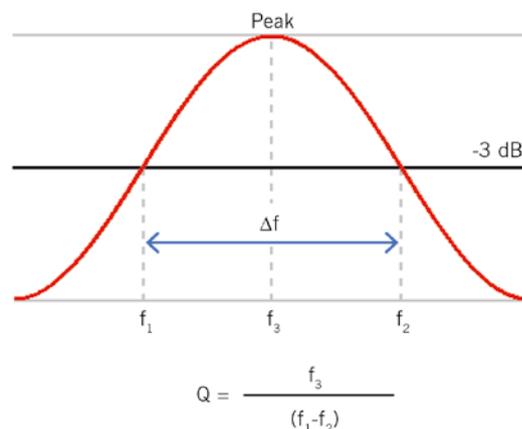
FIGURE 3 Measurement of the Q factor at 2 ND mode (© Rassini)

Baseline part

Test number 2264-1
baseline rotor
duralast semi-metalic brake pad (lining #1)

Noise events below 2 k Hz
were manually evaluated

• Warm section   ▪ Cold section

Post processed part

Test number 2264-2
EDM rotor on neck
duralast semi-metalic brake pad (Lining #1)

Noise events below 2 k Hz
were manually evaluated

• Warm section   ▪ Cold section
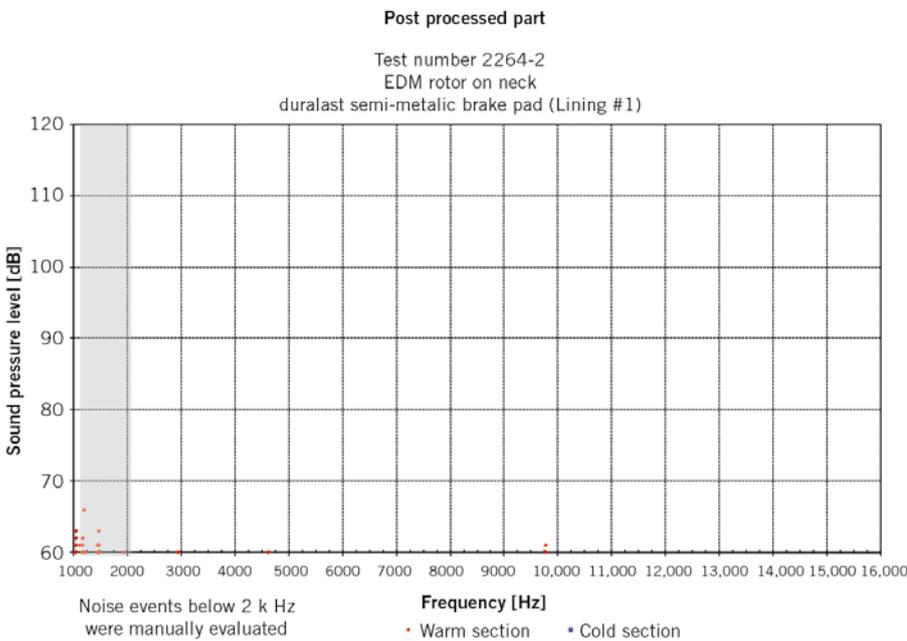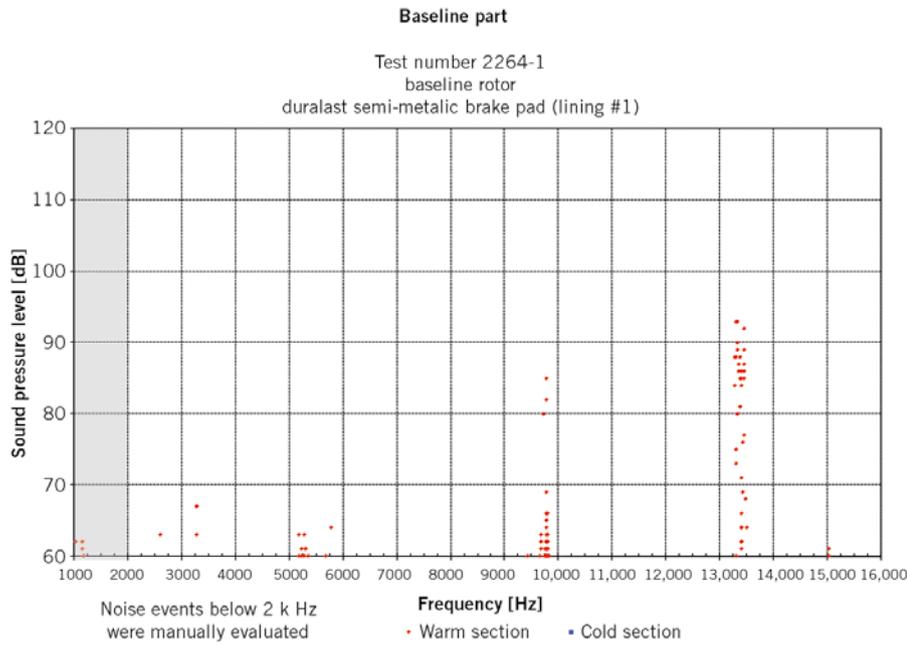
FIGURE 4 Comparison of sound pressure levels for a basic rotor (top) and the EMD rotor (bottom) (© Rassini)

dependent on the material chemistry and microstructure –higher carbon equivalent metals have a better damping than lower carbon metals. A very linear relationship was observed between the EDM pre-process Q factor and the post-process Q factor, **FIGURE 5**, which insinuates that a part with high Q factor (low damping) will show very little improvements in damping from processing and vice versa.

However, considerable variation was noticed in the improvements obtained.

Material microstructure was shown to have a significant effect, with the parts having larger graphite flakes and a low Q factor showing the highest improvements, as shown in **FIGURE 5**. Other variables like the pearlite distribution and the eutectic cell size were also studied, but no statistical differences were seen

between the parts with large (35 %) and no (0 %) improvement. Chemistry and mechanical properties did not demonstrate any difference.

Further studies are underway to understand the inter-lamellar spacing in the pearlite and their effects on the MMD, as well as a better analysis of the graphite under a scanning electron microscope. Residual stress measurements on processed parts with large and no damping improvements also show differences, insinuating that the parts with a higher residual stress respond poorly to treatment than ones with lower surface residual stress.

OUTLOOK

More studies to Magneto-mechanical Damping (MMD) are underway to completely understand all the material and process variables. The process can be utilised not only to produce a very highly damped rotor material (Q factor < 200) but also to generate significant damping improvements on any rotor material, thus providing a better product for noise performance.

While significant steps had been made toward noise solutions for disc brakes, brake noise will remain a key initiative for automotive OEMs and suppliers alike.

A crucial next step will be the industry's commitment to developing and improving new and existing technologies that will only further advance these efforts until an end goal of supplying noise-free brakes to customers is reached.

REFERENCES
[1] Gonzalez, M.: Bremsen ohne Quietschen. In: Automobil-Konstruktion, 3 September 2015. Online: www.autokon.de/home/-/article/33673047/41187047/
[2] Mitchick, J. P.; Karthik, R.; Gonzalez, M.; Sokolowski, J. H.: Magnetic and electrical processing of metals, metal alloys, metal matrix composite parts and components. European Patent Application EP2580361, publication date 17 April 2013

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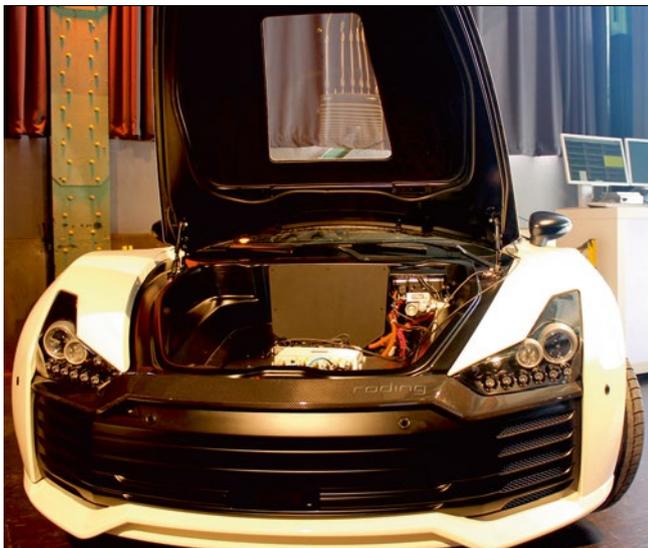
Fraunhofer ESK I
SafeAdapt Enters the Testing Phase

The construction of a test vehicle and a driving simulator by mid 2016 represents the start of the testing phase for the EU SafeAdapt project. The objective of the project partners around Fraunhofer ESK is to develop a new adaptive electric/electronic (E/E) software architecture for electric vehicles which will independently correct faults while the vehicle is being driven, in order to increase its safety, reliability and cost-effectiveness. This means that in the event of a fault the function or the control unit in question must continue to work until the vehicle has been made safe. The technologies developed by the SafeAdapt partners will be installed in a **RODING SPORTS CAR** that Siemens has equipped with the Race E/E architecture. In addition, the concepts will be complying with the Autosar standard.

TU Braunschweig I
Recycling Li-ion Batteries

At the Braunschweig University of Technology (TU), a demonstration plant for recycling lithium-ion batteries was recently brought into operation. It will be used to dismantle, discharge and recycle the batteries from electric cars. A newly developed procedure which is patent pending allows for **RECYCLING RATES OF OVER 75 %** per battery system. State-of-the-art existing processes have rates below 60 %. The residual energy in the end-of-life batteries will first be discharged into the university's electricity grid and returned to the value added process. The scientists involved in the project have investigated all the processes in the recycling chain from the deactivation of the batteries and cells and the partially automated disassembly of the batteries through to crushing and sorting the different material fractions. In order to achieve a high recovery rate, procedures for recycling the electrolyte (conducting salts and solvents) and the anode coatings (graphite) were also tested.

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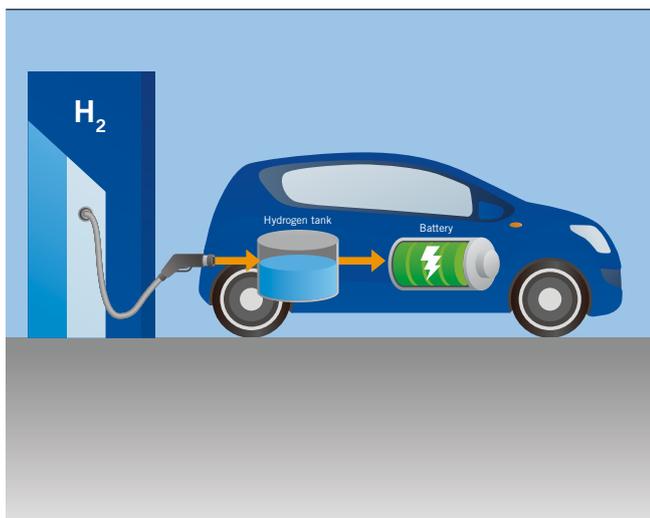
University of Hamburg I
Porous Hydrogen Storage

Hydrogen is the lightest chemical element and, under normal conditions, has a very large volume. When it is used as a fuel, it has until now only been possible to store it under high pressure in heavy bottles or at -253 °C in liquid form in tanks. Both methods have limited uses in mobile applications, because they are extremely costly. A research group is aiming to develop a new hydrogen store made from **NANOPOROUS MATERIAL** which can store the hydrogen and release it in a controlled manner, in a similar way to sponge soaked in water. The nanoparticulate light metal hydrides used for the purpose, which are compounds of light metals such as lithium or magnesium and hydrogen, can absorb hydrogen (tank storage) and release it again (for example, while the vehicle is travelling).

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In 2008, the peer review process utilised by ATZ and MTZ was presented by the WKM (Wissenschaftliche Gesellschaft für Kraftfahrzeug- und Motorentechnik e. V./ German Professional Association for Automotive and Motor Engineering) to the DFG (Deutsche Forschungsgemeinschaft/German Research Foundation) for official recognition. ATZelektronik participates in the Peer Review since 2011.

THE SEAL OF APPROVAL FOR SCIENTIFIC ARTICLES IN ATZ.

ATZ PEER REVIEW

REVIEWED BY EXPERTS FROM RESEARCH AND INDUSTRY.

Modelling Joint Damping in Engines

In order to be able to judge expected vibration amplitudes during the design phase of an engine, it is essential to include damping in the dynamic Finite Element analysis. Thereby, material and joint damping are the most important aspects. For metallic structures, joint damping causes most of the overall energy dissipation. However, there is no standard approach to model this effect. At the University of Stuttgart a process was developed in a FVV/DFG project, which, based on experiments on an isolated lap joint facilitates the consideration of joint damping for the simulation of complex structures such as engines.

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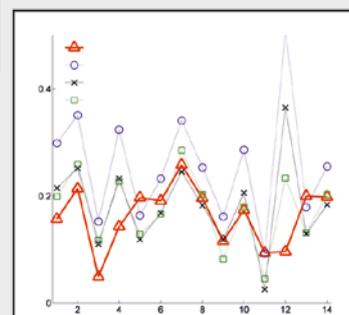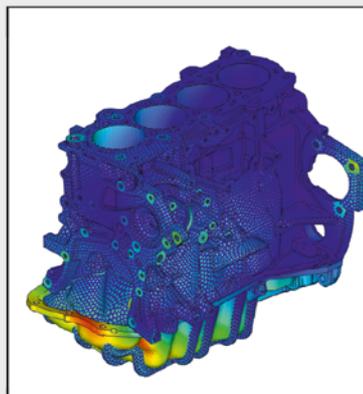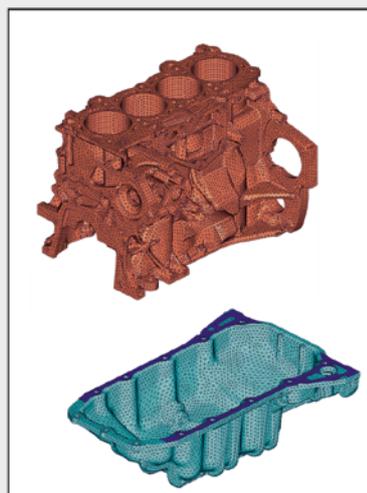
1 MOTIVATION

In-depth knowledge of the structural behaviour of engines before a physical prototype exists is essential for optimisation with regard to comfort and acoustic performance. While mode-shapes and eigenfrequencies can be predicted reliably and accurately with the Finite Element Method (FEM), there is no standard approach to predict the damping behaviour. For a reliable damping prediction, material and joint damping have to be considered [1]. While modelling material damping poses few challenges, the consideration of joint damping is more complex. Joint damping occurs only locally on joint interfaces and typically causes much higher energy dissipation than material damping in metallic structures. Therefore, an accurate model for joint damping is fundamental for a reliable damping prediction. Consequently, the objective of this work supported by the FVV and DFG is the experimental identification and numerical consideration of joint damping in engines in order to generate damping predictions without a physical prototype. A quantitatively and spa-

tially accurate representation of joint damping is achieved via the model of constant hysteretic damping [2] in combination with so called thin-layer elements (TLEs) [3]. As this approach is linear, it is only applicable for microslip [4]. The joint parameters are identified experimentally on an isolated lap joint.

2 EXPERIMENT

In order to determine the joint damping without taking measurements on the target assembly, an isolated generic lap joint in a resonator setup is examined, **FIGURE 1**. The joint is subject to harmonic excitation while the accelerations $\ddot{u}_1$ and $\ddot{u}_2$ on both sides of the joint are recorded as well as the normal force F_N in the joint. The joint is designed to be very stiff so that the resulting contact pressure σ_N is approximately constant over the joint area. Plotting the transmitted tangential force

Eq. 1	$F_T = M_2 \cdot \ddot{u}_2$

over the relative displacement

Eq. 2	$\Delta u = u_2 - u_1$

in a force-displacement diagram, one obtains the hysteresis curve, **FIGURE 2**. This yields the dissipated energy W_D and the maximum stored Energy U_{max}. Finally, the loss factor η, which will be used for the FE-simulation, can be computed according to Eq. 3:

Eq. 3	$\eta = \dfrac{W_D}{2\pi U_{max}}$

In order to extract valid parameters for the simulation, the generic joint configuration must match the joint configuration in the target application as accurately as possible in terms of material, surface finish, and normal force. Subsequently, measurements at increasing excitation levels are taken. An example for the resulting data from a steel-steel joint sample is shown in **FIGURE 3**. Only measurements in the microslip regime are shown. A detailed account on the separation of micro- and macroslip can be found in [5].
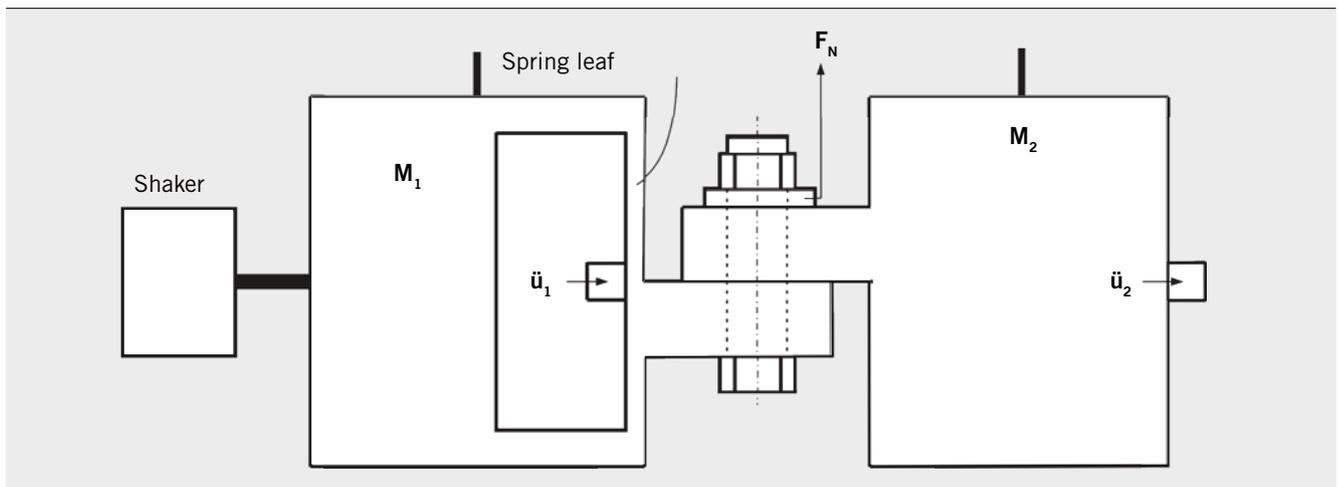
FIGURE 1 Resonator setup for the experimental investigation of an isolated joint (© University of Stuttgart)
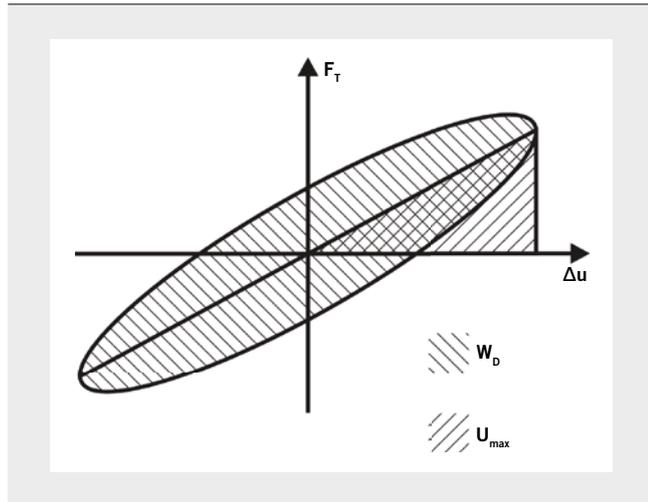
FIGURE 2 Hysteresis curve in a force-displacement diagram
(© University of Stuttgart)

3 SIMULATION

3.1 JOINT MODELLING

The chosen modelling approach is based on [6]. Thereby, thin-layer elements [7] are placed on all joint interfaces. **FIGURE 4** shows the FE model of a structure consisting of an engine block and an oil pan. Between these two components, the TLEs are situated. A lin-

ear, orthogonal material behaviour, with stiffness and loss factor parameters stemming from the generic experiment, is implemented in the TLEs. Both, material and joint damping are approximately frequency independent [8]. Therefore, the model of constant hysteretic damping is employed. Implementing this model, the undamped equation of motion, with the real-valued system matrices M and K, is transformed to the damped equation of motion.

Eq. 4	$M\ddot{u} + Ku = 0$

Thereby, the real-valued stiffness matrix K is replaced with a complex-valued stiffness matrix K* according to:

Eq. 5	$K^* = K + i \sum_{k=1}^{K} \eta_k^{Material} K_k^{Material} + i \sum_{n=1}^{N} \eta_n^{Joint} K_n^{Joint}$

Here, $\eta_k^{Material}$ is the material loss factor of the k-th component with the corresponding stiffness matrix $K_k^{Material}$ Accordingly, η_n^{Joint} represents the joint loss factor of the n-th TLE and K_n^{Joint} the corresponding stiffness matrix. The damped equation of motion yields a complex-valued eigenvalue problem Eq. 6 with eigenvalues λ_r and eigenvectors φ_r.

Eq. 6	$(\lambda_r^2 M + K^*) \varphi_r = 0$

This eigenvalue problem must be solved repeatedly for varying η_n^{Joint} in the following simulations. Therefore, an eigensensitivity analysis is performed which results in a reduced model. This approach is described in detail in [5]. The resulting reduced model consists of a single, linear equation for each eigenvalue.
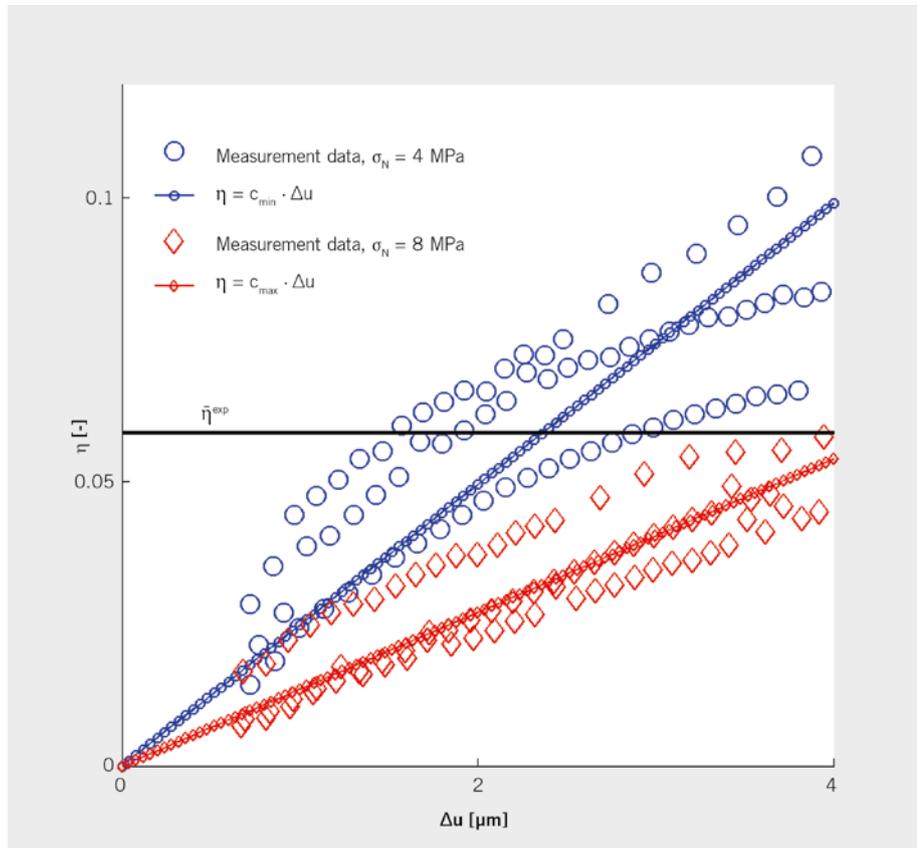
FIGURE 3 Experimentally determined loss factor for different normal and tangential loads (© University of Stuttgart)
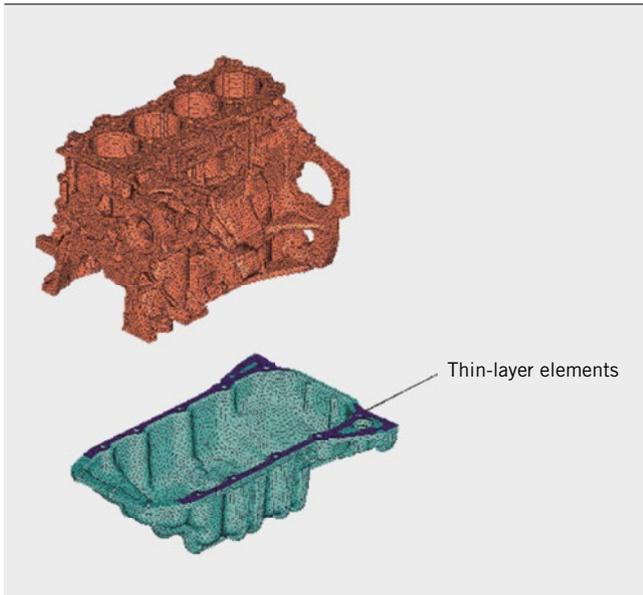
FIGURE 4 Example structure consisting of an engine block and an oil pan as well as thin-layer elements on the interface (© University of Stuttgart)

factor parameters for a more accurate final simulation, **FIGURE 5**. A linear regression with the slope $c_n(\sigma_N)$ is chosen for the empirical model [9]:

Eq. 7	$\eta_n^{Joint} = c_n(\sigma_N) \cdot \Delta u_n$

In **FIGURE 3**, two linear regression curves corresponding to the two different normal loads are shown. The slope of these curves is used to determine $c_n(\sigma_N)$. This linear approach is feasible despite nonlinear joint behaviour because unavoidable error sources e.g. limited measurement precision and model simplifications void any advantages a more complex empirical model would provide. As a next step, the TLEs are parameterised homogeneously with $\eta_n^{Joint} = \bar{\eta}^{exp}$, where $\bar{\eta}^{exp}$ is the mean value of the experimentally identified loss factor parameters. This model is used for a numerical modal analysis to approximate Δu_n, and a static analysis to determine the pre-load σ_N. These results are then used to determine load-dependent loss factor parameters according to Eq. 7. Before the final simulations are conducted, the loss factors are normalised so that the mean loss factor of all TLEs is equal $\bar{\eta}^{exp}$, **FIGURE 3**. The load-dependent parameterisation leads to mode-specific models. Therefore, each mode requires a separate simulation. By means of the aforementioned model reduction, the additional computational cost is negligible.

3.2 LOAD-DEPENDENT PARAMETERISATION

For accurate simulations, the load dependency of the energy dissipation in joints identified in **FIGURE 3** must be considered. To that end, an experimentally motivated, empirical model for the loss factor $\eta_n(\sigma_N, \Delta u_n)$ depending on the normal pressure σ_N and the relative displacement Δu_n is derived. It is then applied to preliminary simulation results in order to derive a set of improved loss

3.3 MODEL UPDATING

Besides improving the prediction quality, it is also possible to device an efficient model updating approach using the proposed joint model if a physical prototype exists. The model reduction facilitates an optimisation with a very large number of design variables. Thus, the optimal loss factor can be found for each TLE individually in order to reproduce experimental data (modal
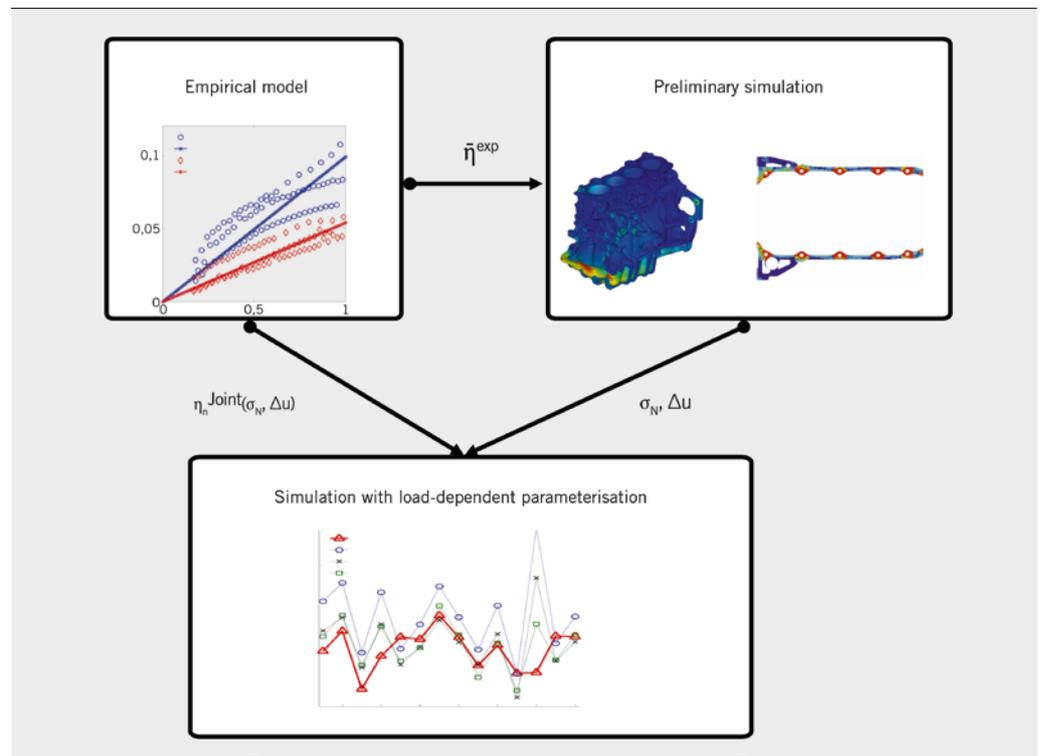
FIGURE 5 Workflow for the load-dependent parameterisation (© University of Stuttgart)
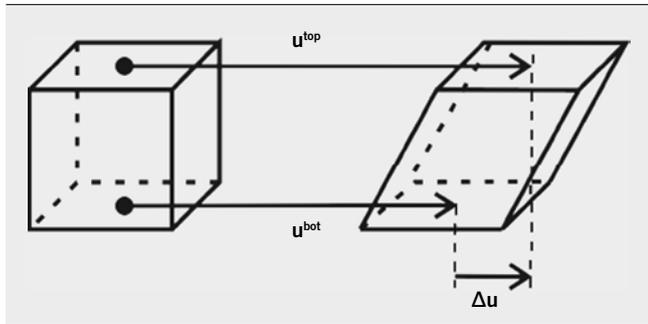
FIGURE 6 Schematic for the determination of the relative displacement in a thin-layer element (© University of Stuttgart)

damping) in an optimal, least squares sense. This means that, in contrast to the load-dependent parameterisation approach, the model updating results in a single model, valid for all considered modes. Because of the large number of design variables, multiple solutions for the optimisation problem exist. Therefore, boundary conditions have to be found which restrict the solution space to physically reasonable solutions. This is achieved by defining the admissible interval bounds for each element loss factor in relation to the relative displacement of that element:

Eq.8	$c_{min} \cdot \Delta u_n < \eta_n^{Joint} < c_{max} \cdot \Delta u_n$

The constants c_{min} and c_{max} can be identified from experimental data, **FIGURE 3**. Additionally, the maximum difference between the loss factors of two neighbouring elements is limited.

4 RESULTS

The presented modelling approach is applied to an engine block with an oil pan, **FIGURE 4**. Measurements on the isolated lap joint yield the factors $c_{min} = 0.00125$ [1/μm] and $c_{max} = 0.025$ [1/μm] for the empirical model. The mean value of the experimentally

identified loss factors is $\overline{\eta}^{exp} = 0.06$. **FIGURE 7** shows the results of the contact pressure analysis. Only small areas around the bolts feature high contact pressures ($\sigma_N > 6$ MPa, red areas in **FIGURE 7**). For these areas c_{min} is used. For the remaining areas c_{max} is used. Next, the load-dependent parameterisation according to section 3.2 is performed and the modal damping values are computed. In **FIGURE 8**, these results are compared to data from an experimental modal analysis. As baseline for the simulation, the results of a simulation with homogenous TLE parameters are shown, too. Here, the loss factor is $\eta_n^{Joint} = \overline{\eta}^{exp} = 0.06$ for all TLEs. It is evident that the load-dependent parameterisation approach leads to an accurate damping prediction. Only for few modes, such as Mode 5 and Mode 12, significant discrepancies between prediction and experimental data exist. Possible reasons for these deviations could be neglected damping mechanisms for example at pressed-in valve bearings. Comparing results from the simulations with load-dependent and homogeneous parameterisation shows that the homogeneous approach delivers less accurate results. **FIGURE 8** additionally contains the results of an optimised model. Hereby, optimal loss factors for all 1042 TLEs are found according to section 3.3. The optimisation in Matlab converges after 3790 iterations in 286 s. At approximately 40 min per full model evaluation and several hundred model evaluations per iteration, the cost reduction provided by the reduced model is evident. In this case, the experimental reference values cannot be reproduced significantly more accurate by means of the model updating. This indicates once more that the aforementioned discrepancies between prediction and experiment are due to neglected damping effects. For a smaller range of modes, the modal updating can achieve very high precision [10].

5 SUMMARY AND OUTLOOK

In this work, a modelling approach for joint damping in large, assembled structures is proposed. It facilitates the prediction of the damping behaviour of complex structures based on measurements on an isolated lap joint. The approach employs thin-layer elements in combination with the model of constant hysteretic
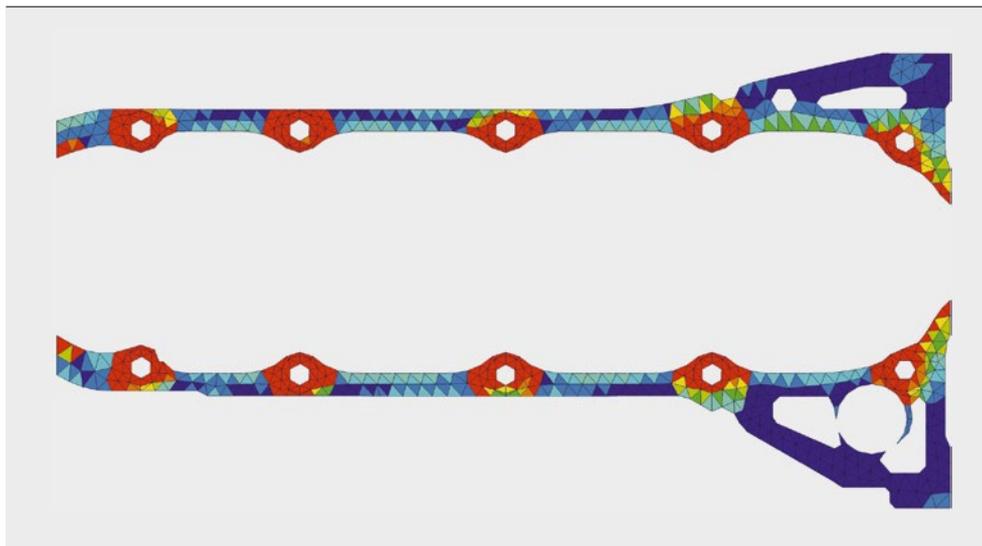
FIGURE 7 Contact pressure distribution on the interface of the example structure (© University of Stuttgart)
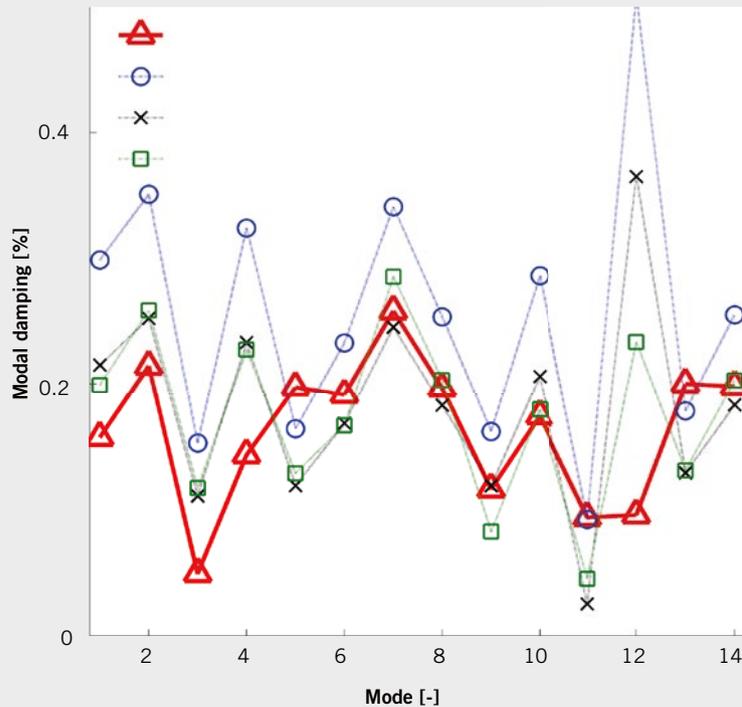
FIGURE 8 Modal damping of the example structure determined by simulations with homogenous, load-dependent and optimal TLE parameterisation compared to experimentally determined reference values (© University of Stuttgart)

damping. Experimental measurements show a significant dependence of the loss factor on the normal- and tangential loads on the joint. This is considered in the simulation by means of a load-dependent assignment of damping parameters. For that purpose, a linear empirical model is derived from experimental measurements on the isolated lap joint and implemented for the FE simulation. The approach is applied to an engine-block with an oil pan. An improvement of the damping prediction is achieved by employing the load-dependent parameterisation compared to a homogeneous parameterisation of the joint interface. Further, a model updating approach is presented, in which the optimal loss factor for each individual thin-layer element is identified. Thus it is possible to reproduce experimental measurements in a limited range of modes very accurately. Remaining discrepancies between simulation and experiment indicate the existence of neglected damping mechanisms in other areas of the examined structure. This will be the topic of future work.

REFERENCES
[1] Ottl, D.: Damping of Materials and Members. VDI-Guideline 3830, 2004
[2] Lazan, B. J.: Damping of materials and members in structural mechanics. Oxford: Pergamon Press, 1968
[3] Bograd, S.; Reuss, P.; Schmidt, A.; Gaul, L.; Mayer, M.: Modeling the dynamics of mechanical joints. In: Mechanical Systems and Signal Processing 25 (2011), No. 8, pp. 2801-2826
[4] Groper, M.: Microslip and macroslip in bolted joints. In: Experimental Mechanics 25 (1985), No. 2, pp. 171-174
[5] Ehrlich, C.; Schmidt, A; Gaul, L: Microslip joint damping prediction using thin-layer elements. In: Dynamics of Coupled Structures (2014), No. 1, pp. 239-244
[6] Bograd, S.; Schmidt, A.; Gaul, L.: Joint Damping Prediction by Thin Layer Elements. In: Proceedings of IMAC XXVI, Orlando, Florida, 2008
[7] Desai, C. S.; Zaman, M. M.; Lightner, J. G.; Siriwardane, H. J.: Thin-layer element for interfaces of joints. In: International Journal for Numerical and Analytical Methods in Geomechanics 8 (1984), No. 1, pp. 19-43
[8] Ewins, D. J.: Modal testing: theory and practice. Letchworth: Research studies press, 1995
[9] Clappier, M.; Ehrlich, C.; Gaul, L: Linearized Joint Damping Model for Assembled Structures With Inhomogeneous Contact Pressure Using Thin-Layer Elements. In: Proceedings of ICSV22, Florence, Italy, 2015
[10] Ehrlich, C.; Schmidt, A.; Gaul, L.: Reduced thin-layer element for joint damping. In: Proceedings of ICOEV 2015, Ljubljana, SO, 2015

THANKS

Lightweight Design of Automotive Transmissions through Online and Real-time Lifetime Monitoring

Reduction of the emissions and costs, shorter development time, design appropriated to the loads and lightweight design are now more than ever essential cornerstones of the development goals in the automotive industry. In this context, an input module for the introduction of new approaches to cost-efficient lightweight design in transmission engineering has been developed at the Institute for Mechatronic Systems in Mechanical Engineering of the TU Darmstadt.

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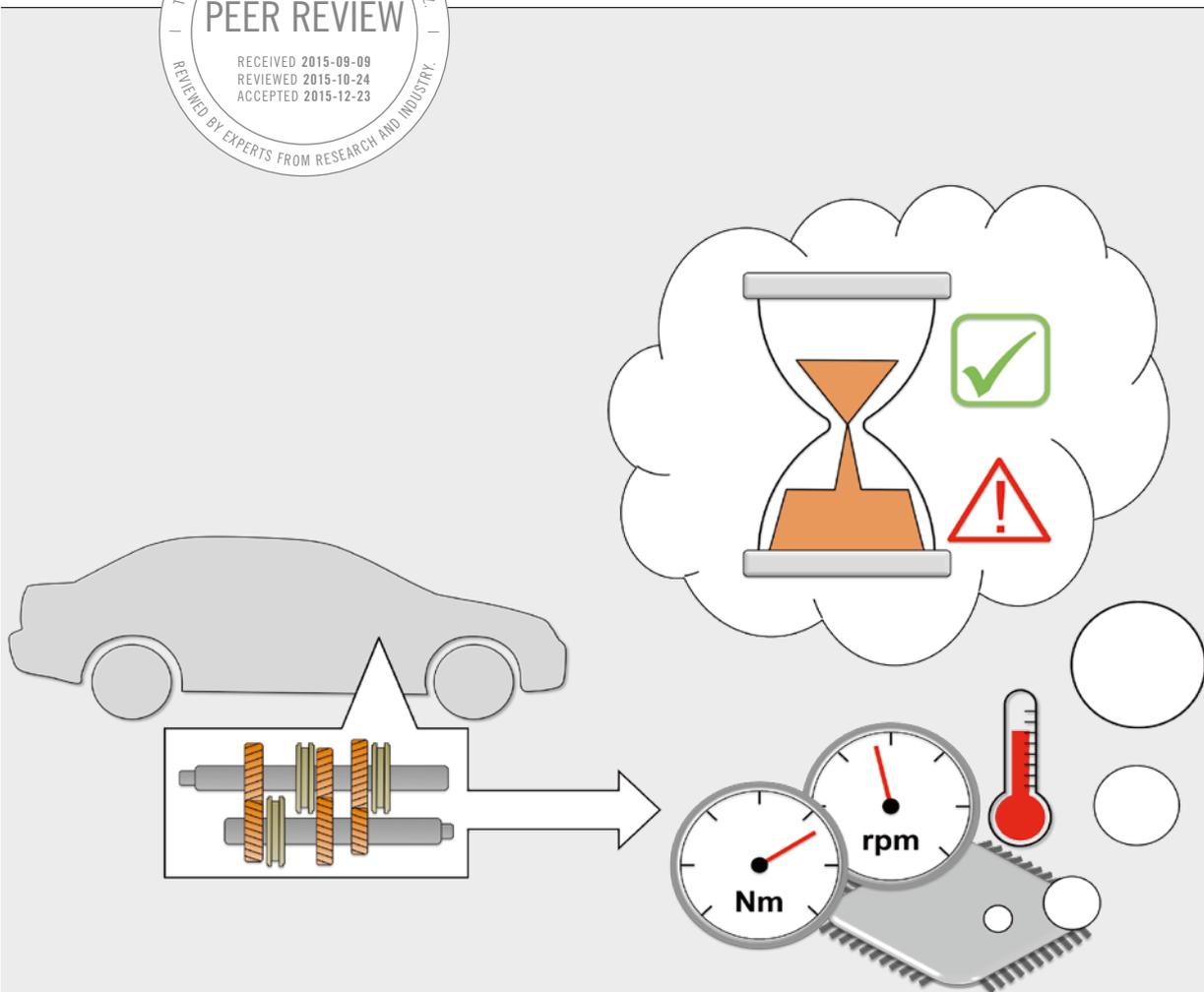
1 MOTIVATION

Due to the ever increasing stringent emission standards and the necessity for automotive manufacturers and suppliers to remain competitive, the aspects costs, development times and lightweight design are today highly focused. In this context, however, the current state of the art does not achieve its full potential in the development of mechanical vehicle components. Indeed, a conservative approach is generally adopted in order to guarantee a high degree of reliability and avoid operating failures as much as possible. This is mainly due to the limited knowledge about the actual customer profiles under real operating conditions. Particularly concerning transmission design, the 99.9 %-driver is usually taken as a reference, which covers theoretically 99.9 % of the driver profiles. This one is mainly determined by simulations and less and less field tests. Thus very demanding driving situations are taken into account, which do not necessarily represent the behaviour of the end users, and often overestimate it. As a direct result, the transmissions developed with standard industry procedures are overdesigned for the majority of the drivers. This leads to superfluous weight, which in turn implies higher material costs and emissions.

An additional aspect is that the load spectra of transmission components and the resulting service lifetimes are only considered during the development phase. In concrete terms, this means that, also after the introduction on the market, no data relating to the real driver profiles are generated. This brings three disadvantages. First, the future generations of components cannot be improved with regard to the real driver and damage behav-

iour. Second, the cause of a field failure can only be identified with a lot of effort, because the load history of the respective components is not available. Third, the transmission cannot be operated under consideration of the component damage levels because the required inputs are missing. A damage-oriented operating strategy could be advantageous to enhance the transmission service life for each individual driver during operation.

2 OBJECTIVES

The aim of the research project was to develop a lifetime monitoring system that enables the acquisition of the load collectives and an estimation of the remaining service life of transmission components in real-time and during vehicle operation [1]. The core idea is to predict the remaining life of the transmission from the first day of the vehicle use. In this sense, it is not supposed that a failure has already occurred or is progressing, but a continuous comparison between design (load capacity) and operation (load) is achieved (so-called DO-4-Life calculation for Design versus Operation Forecasts Lifetime). This is a significant distinction from Condition Monitoring methods. Thus, an innovative approach to improve today's design and operating procedures is given. Clear goals were defined in order to propose an application-oriented, easily adaptable and reliable system. The developed system does not require any additional hardware and is based on already available vehicle sensors and signals running on the Controller Area Network (CAN), **FIGURE 1**.

Nevertheless, the generated data provide a high quality and validity. In this regard, the system relates to standard industry procedures for load spectrum and damage calculation. As well, the loads generated by the engine and initiated from the tires are recorded and taken into account. In addition, the characteristics of standard Electronic Control Units (ECU) are accounted for. In particular, the lifetime monitoring system works in discrete time. Furthermore, the limited computing power and storage capacity are considered, so that the system can be implemented in all vehicles without any special expense. The amount of generated data is also kept low, so that, for example, the outputs of the monitoring system can be transmitted wirelessly or read during service inspections in order to generate databases.
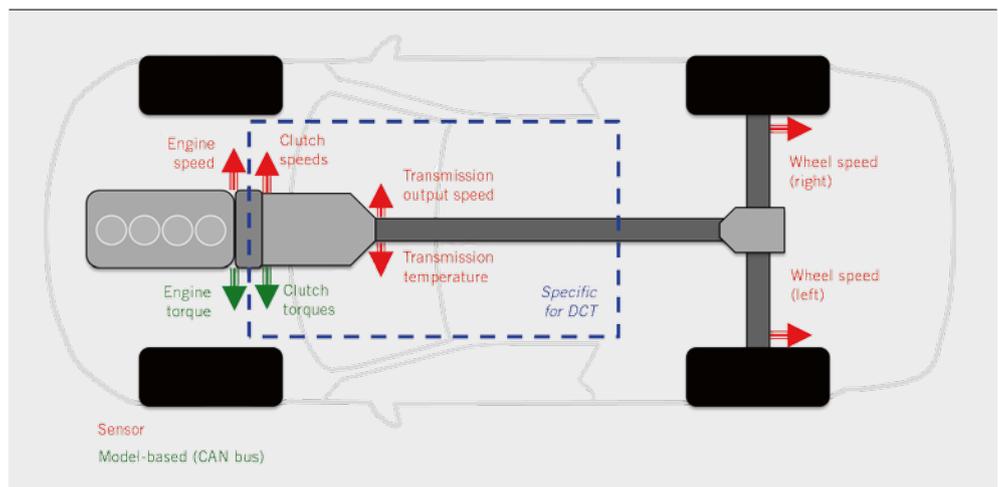
FIGURE 1 Available standard sensors and signals in a series production car (© TU Darmstadt)
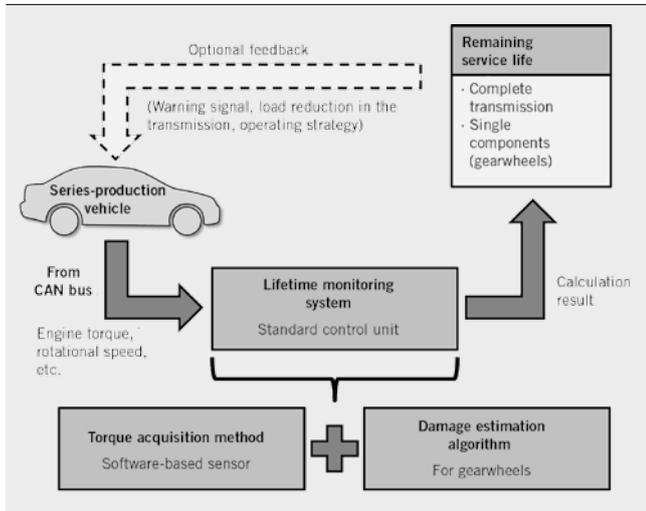
FIGURE 2 General structure of the lifetime monitoring system (© TU Darmstadt)

3 DEVELOPMENT OF THE LIFETIME MONITORING SYSTEM

Two real application cases have been investigated for rear-wheel drive vehicles, namely a manual and a dual-clutch transmission (DCT) of Getrag. In this article, the DCT is presented in more detail [2]. The implementation of the lifetime monitoring system for a manual transmission can be found in [3]. In both cases, the monitoring system is purely software-based, **FIGURE 2**. A torque observer is used for the reconstruction of the dynamic drivetrain torques [4, 5]. In parallel, an algorithm calculates the load spectra and damage levels of transmission components. As representative components for the service life status of the transmission, only the gearwheels are monitored [1]. For this purpose, the nom-

inal stress concept is adopted, coupled with a Revolutions-At-Level counting method and a linear damage accumulation according to Miner-Haibach [6, 7]. The developed algorithm for damage prediction refers to the initial specifications of the transmission manufacturer. This enables a direct comparison between the design procedure and the real operating conditions. For this, the Wöhler curves assumed during the development of the components and the underlying damage targets and strength limits are taken as a reference basis for assessing the real-time damage levels. The speed and load dependent variables are factored in the conversion of torque into stress with the same hypotheses as in the design procedure. The dynamic effects in the drivetrain are reproduced by the torque observer.

Besides, an implementation of the system does not bring any additional uncertainties in comparison with today's calculation schemes, for example with regard to the dispersion of strength limits [8, 9], **FIGURE 3**. The purpose is not to realise a better prediction than provided during the design procedure, but to allow a comparison between the calculated damage state resulting from the design load collectives and the calculated damage state caused by the real loads. In addition, the influence of the transmission temperature can be accounted for. The temperature is measured with a sensor or calculated using a model.

Even if the considered theoretical bases are generally known, such an approach had never been implemented for real-time application under real operating conditions. Therefore, the following questions are raised:
– Which load cases influence the damage behaviour in a significant way and must be considered? Which ones can be neglected?
– Which torque signals are representative for the transmission loading conditions and must be reconstructed with the observer?
– Which standard vehicle signals can be used accordingly, in order to compute a good estimation of the load spectra and damage levels?

In this context, a comprehensive drivetrain model was developed for simulation of the longitudinal vehicle dynamics, including all
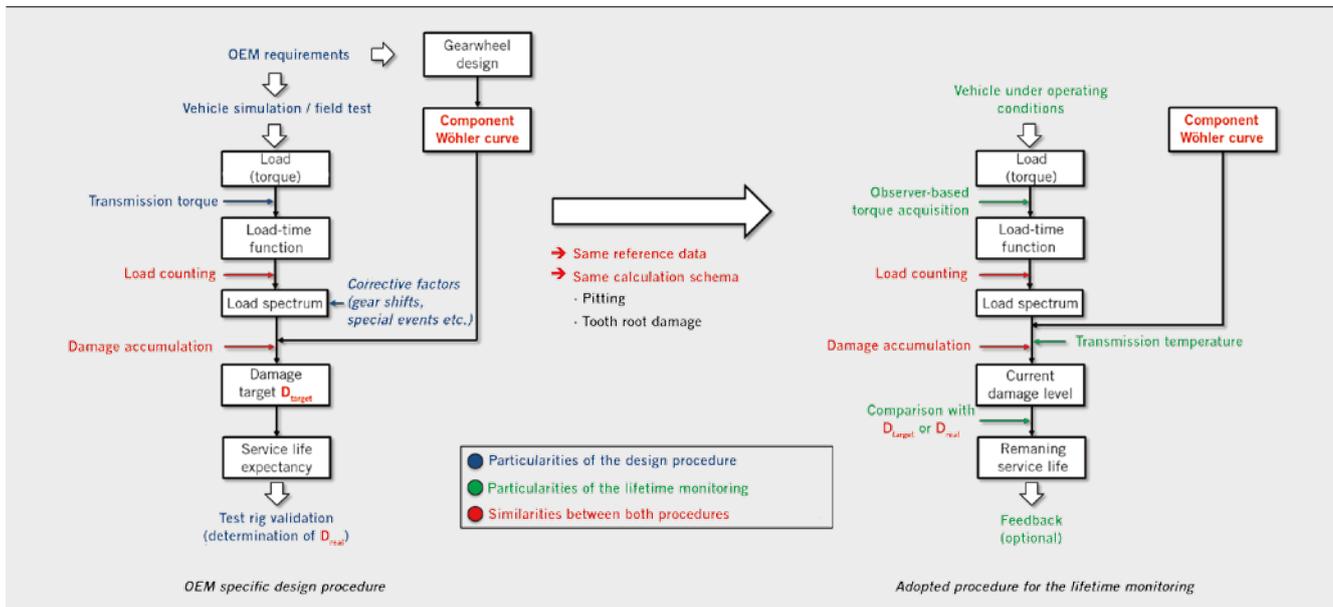
FIGURE 3 OEM-specific design procedure versus procedure for the lifetime monitoring system (© TU Darmstadt)
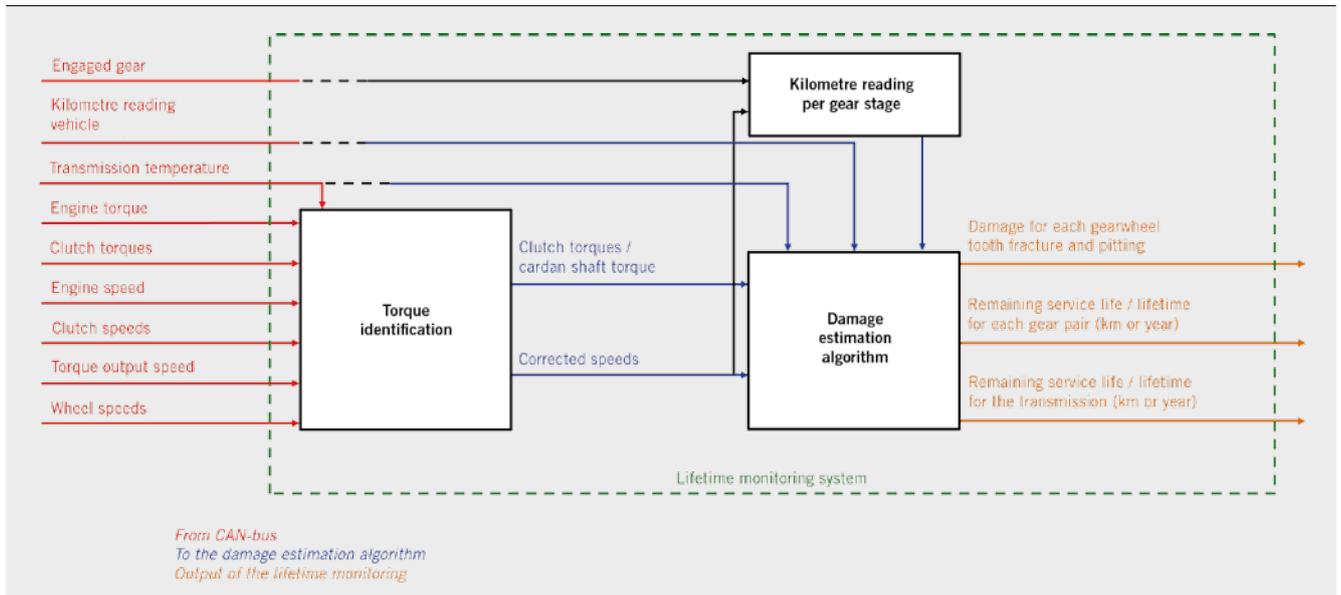
FIGURE 4 Structure of the lifetime monitoring system for a DCT (© TU Darmstadt)

relevant driving situations and the transmission dynamics (gearshifts, meshing stiffnesses) [10]. With this model, validated through driving tests, a parametric study was carried out to perform a requirement analysis for the lifetime monitoring system [1, 3]. The results show that the gearshifts and clutch actuations, as well as special events such as tire grip loss / re-adhesion, have most influence. On the other hand, the negative torques generated during coasting or downshifts can be neglected. Moreover, only the first natural frequency of the drivetrain (jerking) is relevant. For its part, the tooth engagement dynamics can be neglected, if a parametric excitation of the natural frequency of the meshing can be excluded. With this assumption, either the transmission input or output torque – under consideration of the transmission losses – can be used as a representative loading condition. However, a sampling rate of 200 Hz is recommended to ensure the accuracy of the calculations in discrete time.

4 LIFETIME MONITORING SYSTEM EXAMPLE FOR A DCT

For the DCT, the signals and sensors shown in **FIGURE 1** are used. An overview of the lifetime monitoring system is shown in **FIGURE 4**. The torque observer is based on the model depicted in **FIGURE 5** [1, 3]. Such a simplified model is sufficient to represent the jerking behaviour of the drivetrain. The engine torque, calculated on the engine control unit, is used as an input and is corrected with efficiency maps in order to take the transmission losses into account.

According to the requirement analysis, the torque observer reconstructs the transmission input and output torques. The clutch torques calculated on the transmission control unit are only selectively used. The reason is that they are computed as a function of the clutch pressures and provide exclusively usable information during clutch slip phases. During clutch stick phases, the provided clutch pressure is increased in order to assure the clutch adhesion. Since there is no correlation between clutch pressure and transmitted torque in such situations, an overrated clutch torque is calculated. In addition, the sign of the transmitted torque is not taken into account, and thus the clutch torque calculated on the transmission control unit remains always positive. However, this is considered by the torque observer, as shown in **FIGURE 6**. As only the side shaft torque could be measured in the test vehicle, the observer was adjusted accordingly in order to allow comparison. The speed signals supplied from vehicle sensors are also smoothed by the filter effect of the observer in order to increase the signal quality. This allows for a more accurate calculation of the number of load cycles.

Compared to a calculation with measured signals, the lifetime monitoring system presents a maximum deviation of the estimated damage levels amounting to 8.5 % in the worst-case scenario. This is mainly due to the engine torque signal used as an input in the observer, which provides inaccuracies in some cases. However, the deviations remain within 5 % on average [1]. Nevertheless, these deviations are accounted for in the algorithm, thus the damage assessment remains on the safe side.

5 ECONOMIC AND ECOLOGIC POTENTIALS

Visionary applications of the lifetime monitoring system are presented here as a basis for a business case in the context of lightweight design measures for sports car transmissions. Assuming that the transmissions are not developed anymore for the usual 99.9-% driver and that the most demanding drivers are no longer accounted for: The DCT considered in the research project could be designed for about 100 Nm less transmission input torque, leading to a comparable situation which occurs if the engine torque is increased by an independent tuning company, fairly commonly for this vehicle segment. According to Naunheimer in [11], this represents potential for a reduction of the transmission weight by 10 % and a cost reduction of individual aggregate by 8.5 %. The lower weight leads to a potential reduction of the CO_2 emissions of the vehicle by 0.19 % [12].
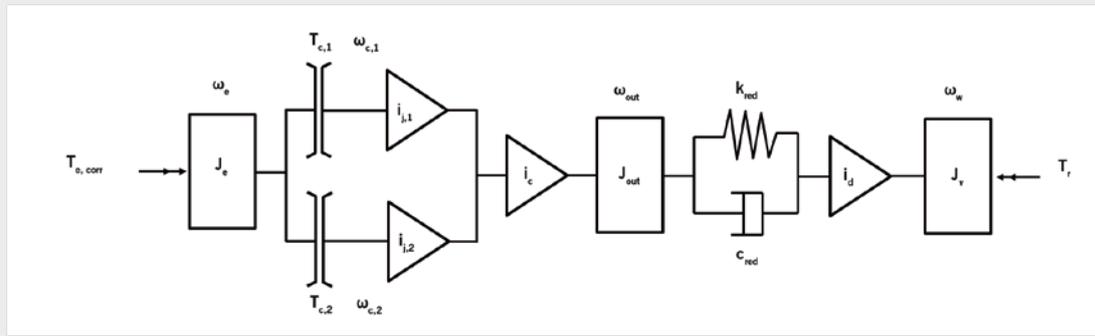
ω_e	: Engine speed (sensor, CAN-bus)		$i_{j,1/2}$	: Gear ratio in sub-transmission 1 resp. 2
$\omega_{c,1/2}$	: Clutch speed of sub-transmission 1 resp. 2 (sensor, CAN-bus)		i_c	: Gear ratio of the constant stage
ω_{out}	: Transmission output speed (sensor, CAN-bus)		i_d	: Gear ratio of the differential transmission
ω_w	: Average rear wheel speed (sensor, CAN-bus)			
			J_e	: Moment of inertia of the engine
			J_{out}	: Reduced moment of inertia of the transmission
			J_v	: Reduced moment of inertia of the vehicle
$T_{e,corr}$	: Engine torque (model based, CAN-bus), corrected with transmission losses			
$T_{c,1/2}$	: Clutch torque of transmission 1 resp. 2 (reconstructed, observer)		c_{red}	: Reduced damping coefficient of the drivetrain
T_r	: Driving resistance (reconstructed, observer)		k_{red}	: Reduced stiffness of the drivetrain

FIGURE 5 Simplified drivetrain model for the development of the torque observer (© TU Darmstadt)

On basis of the lifetime monitoring system, a safe operation could still be ensured for each driver and the transmission could be replaced for the drivers coming to lifetime limit. The remaining service life could be displayed as service information and, additionally, an engine torque limitation could be generated in critical cases as a safety measure. Since early detection of criti-

cal cases is always given, no increased risk of operation failure in field is expected. This would ensure that a safe operation is guaranteed for all drivers, even if the transmissions are lighter designed and no longer cover all driver profiles. Although the transmissions for the non-covered driver profiles have to be replaced, the on-cost can be compensated or even over-compen-
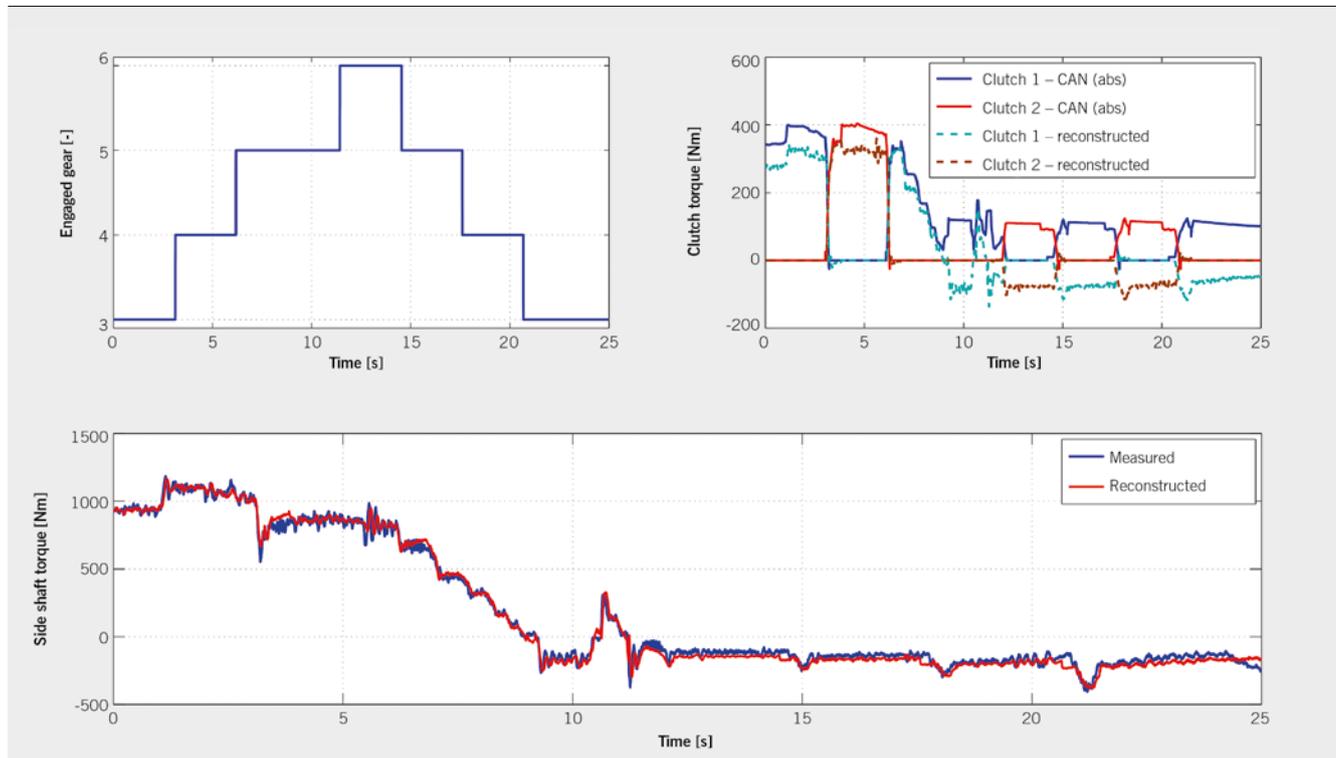
FIGURE 6 Reconstructed (observer) vs. measured side shaft torque for a succession of up- and downshifts (© TU Darmstadt)

sated depending on the real usage profiles and the chosen design. All drivers profit from lightweight and the related reduction of CO_2 emission.

Furthermore, on basis of the damage levels estimated with the lifetime monitoring system, intelligent safety functions can be developed and the operating strategy of automated transmissions can be enhanced, or the gearshift recommendation displayed on the dashboard in case of a manual transmission can be adapted. At IMS, this application of the lifetime monitoring system is called eLife (electronic Lifetime Improvement based on Fatigue Estimation). This offers the possibility to influence the service life of the transmission during operation and for each individual driver. As a result, the economic and ecologic potential can even be further increased.

Besides the potentials for the development of new transmissions, the approach could be applied for the torque capacity increase of already available transmissions. In addition to the benefits explained for new transmissions, significant advantages with respect to development cost and time would occur. These considerations should serve as an inspiration for paradigm change in transmission design, but nevertheless represents realistic applications of the lifetime monitoring system in the medium term.

6 SUMMARY AND OUTLOOK

The software-based lifetime monitoring system developed at IMS can be considered as suitable for series production and can be introduced in production vehicles in the near future. A first implementation on a development microcontroller has been already performed and projects with OEMs are going to start. The system opens up new perspectives to design transmissions more appropriately, more cost-effective and lighter, and can serve as a basis for paradigm change in transmission design. In this regard, high-motorised vehicles are predestined applications because their full driving potential can only scarcely be used on public roads. In addition, hybrid vehicles also represent a highly interesting field of application, since the today's design methods for determining reference load collectives still present strong development needs [13]. In principle, the system allows for a better understanding of real customer profiles and damage behaviour in field, in order to adjust the transmission design to the actual customer usage with more precision and potentially consider a transmission replacement for extreme driver profiles without generating additional risk and worsening the business case.

The involvement of the damage levels in the operating strategy of the transmissions or in intelligent safety functions also represents a highly interesting application of the lifetime monitoring system in the context of the eLife concept. Active research is currently conducted on this topic.

REFERENCES
[1] Foulard, S.: Online and Real-Time Load Monitoring for Remaining Service Life Prediction of Automotive Transmissions. Darmstadt, Technische Universität, dissertation, 2015
[2] Rinderknecht, S.: Getrag Powershift 7DCI600 – Dual Clutch Transmission for high Efficiency and Dynamics in Inline Powertrains. Innovative Automotive Transmissions, 6th International CTI Symposium, 2007
[3] Foulard, S.; Ichchou, M.; Rinderknecht, S; Perret-Liaudet, J.: Online and real-time monitoring system for remaining service life estimation of automotive transmissions – Application to a manual transmission. In: Mechatronics, 2015
[4] Turner, M.C.; Bates, D.G.: Mathematical Methods for Robust and Nonlinear Control. Berlin Heidelberg New York: Springer, 2007
[5] Wang, W.; Gao, Z.: A comparison study of advanced state observer design techniques. In: Proceedings of the American Control Conference, Denver, Colorado, 2003, Vol. 6, pp. 4754-4759
[6] Köhler, M.: Zählverfahren und Lastannahme in der Betriebsfestigkeit. Springer, 2012
[7] Haibach, E.: Betriebsfestigkeit: Verfahren und Daten zur Bauteilberechnung. VDI-Verlag, 2002
[8] DIN 3990 – Tragfähigkeitsberechnung von Stirnrädern. Deutsches Institut für Normung, 1987
[9] Kurtzke, A.; Hierlwimmer, P.: CAE-basierte Abstimmung bezüglich des Fahrzeug-Leistungsverhaltens und der Getriebelebensdauer. In: Systemanalyse in der Kfz-Antriebstechnik V, 2009, pp. 126-141
[10] Foulard, S.; Rinderknecht, S.; Ichchou, M.; Perret-Liaudet, J.: Automotive drivetrain model for transmission damage prediction. In: Mechatronics, 2015
[11] Naunheimer, H.: Automotive Transmissions: Fundamentals, Selection, Design and Application. Berlin Heidelberg: Springer, 2007
[12] Fontaras, G.; Samaras, Z.: On the way to 130g CO_2/km – estimating the future characteristics of the average european passenger car. In: Energy Policy, 2010, No. 38, pp. 1826-1833
[13] Lavall, T.: Der Hybrid-Effekt: Einfluss der Hybridisierung auf die Lebensdauer von Automatikgetrieben. In: Proceedings, Internationaler VDI-Kongress Getriebe in Fahrzeugen, 2009, No. 2071, pp. 661-672

THANKS

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COVER STORY

Driver Assistance Systems –
En Route to Automated Driving

Bertrandt's article in the next ATZ describes how driver adaptation will in future help to increase the acceptance of driver assistance systems and make automated driving a permanent part of our everyday lives. Assistance systems and intelligent networks of sensors that can identify imminent problems on the roads will also play an important role in reducing fuel consumption. BMW's EfficientDynamics strategy brings together a wide range of technologies which will be effective in particular in real-life situations.

Volvo has ambitious objectives in the field of road safety. The company's aim is that no one should die or be seriously injured in a new Volvo from 2020 onwards in the event of an accident. In an interview, Dr. Peter Mertens, Senior Vice President Research & Development, Volvo Car Group, explains how the Swedish car manufacturer intends to implement its strategy using driver assistance systems.

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Future Engineers

The Bologna Declaration, which was signed by 29 European ministers of education in 1999 with the aim of harmonising academic courses and degrees, resulted in a wide-scale conversion to Bachelor and Master degree programmes in Germany. As a result, the German academic title "Diplom-Ingenieur" (Graduate Diploma in Engineering) has gradually been replaced by "Bachelor/Master of Science/Engineering". Except for a few individual cases, German universities will therefore soon no longer award the title "Dipl.-Ing.".

Some federal states have taken this development as a reason to tighten the so-called "engineer laws" in order to comply with EU Directive 2013/55. These laws are regulated by the federal states and, since the 1970s, have specified the conditions under which the professional title "Ingenieur" (Engineer) may be used and how qualifications obtained in other countries are recognised. Until now, a German degree programme in engineering has had to fulfil only basic requirements: the degree programme must have a technical or scientific specialisation and have a duration of at least six semesters. Some federal states now want to make far-reaching changes to this. For example, they plan to prescribe by law a minimum proportion of 80 % MINT subjects (mathematics, information science, natural science, technology). The Chambers of Engineers are to be granted the fundamental right to examine and authorise the use of the professional title

"Engineer". They will prescribe professional duties and typical activities. And engineers with a foreign professional qualification will be required to enrol in a register kept by the Chamber of Engineers.

Such proposals are neither conducive to protecting the good reputation of the engineering profession nor constructive with regard to streamlining and simplifying the regulations, as was the intention of the EU directive, in order to recognise professional qualifications. Instead, they create additional bureaucracy, weaken the autonomy of universities, impede the national and international mobility of engineers and reduce the possibilities of engineering courses to adapt to new technical and social developments.

To ensure that we can continue to educate excellent engineers in the future, the certification of the quality of engineering degree courses must remain within the university and academic domain. Detailed legislation is unnecessary. We require a simple and transparent process for recognising equivalent credits and qualifications gained abroad. Participation by the Chambers of Engineers should be possible, but not necessary. And the degree certificates of all German engineering courses should grant the right to use the professional title "Engineer", thus making sure that "Engineer" still remains a recognised and transparent trademark in the future.

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