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ATZ WORLDWIDE

10 October 2012 | Volume 114

FEM-AIDED Application of Strain Gauges

COST-EFFICIENT Hybrid Powertrain System with 48 V Network

DETECTION and Classification of Critical Incidents

/// INTERVIEW
Jun Li
FAW

DRIVE CONCEPTS FOR ELECTROMOBILITY

Springer Vieweg

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DRIVE CONCEPTS FOR ELECTROMOBILITY

4, 10, 14 | Individual mobility in the future will differ significantly from that of today. As far as electromobility is concerned, wheel hub motors will open up new opportunities regarding powertrain efficiency and package, as shown by Fraunhofer LBF in a research project. According to ika/fka, small range extender modules in a vehicle can be used as combined heat and power generators, thus offering the possibility not only to reduce CO_2 emissions for individual mobility but also to cut domestic energy requirements by connecting them to a property. In our interview, Dr. Jun Li, President of the Research and Development Centre of FAW Group, discusses whether China is ready for the commercialisation of electric vehicles.

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EXPLOITING POTENTIALS

Dead Reader,

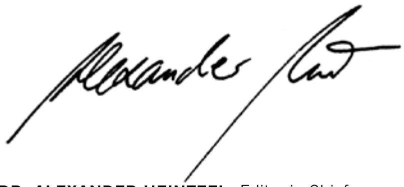
For some, it is the solution to all our problems, while for others it is the buzzword of the new millennium: electromobility. There is no denying that the climate targets for 2020 make good sense. It is also beyond dispute that the constructive potentials need to be consistently exploited. One can spend time arguing whether the German government's declared target for the number of electric cars on the road by 2020 is realistic. But the most important thing is that electric drive systems continue to be developed and tested and that efficient solutions find their way onto our roads.

Concepts for future electric vehicles will in some cases have to differ radically from current vehicle concepts. Wheel hub motors, in which the drive components are located directly at the wheels, offer benefits in vehicle design and construction, opening up great potentials not only in aerodynamics, space economy and vehicle dynamics but also in passive and active safety. This may result in enhanced user comfort, longer driving ranges and therefore a greater acceptance of electric vehicles by the customer – as long as the manufacturers are able to get the costs under control. The additional price of around 10 % forecast by the Fraunhofer LBF for a vehicle with a wheel hub drive system would only be accepted by the market if the prices of electric vehicles were brought down to a level affordable by the masses.

Combined heat and power (CHP) generation is also one of those magic words for an ecologically responsible future. Vaillant, for example, is producing systems for domestic installation. But in combination with mobility, such systems, for example Honda's Home Energy Station, have not yet progressed beyond the field trial stage. Their market launch is being hindered above all by the considerable costs involved. Much more promising, therefore, is an approach taken by fka and ika, in which small range extender modules in the vehicle not only help to reduce mobility-related CO_2 emissions but can also be connected to a property in order to cut the domestic heating bill. The car with its internal combustion engine therefore performs a secondary function as a (mobile) CHP unit. The advantages, especially for plug-in hybrids and range extender concepts, are obvious. The waste heat from the internal combustion engine can be used to heat the house, and the electricity generated can either be directly used to cover some of the electric power requirements or be stored in a traction battery.

All just a pipe dream? At the present time perhaps, but this technology may well make its breakthrough sooner than we think – as long as its potentials are consistently exploited.

Kind regards,



DR. ALEXANDER HEINTZEL, Editor in Chief
Wiesbaden, 6 September 2012

TECHNICAL POTENTIAL OF IN-WHEEL MOTORS FOR ELECTRIC VEHICLES

In the sector of electromobility, future concepts for automobiles will significantly differ from the current ones. In this context, in-wheel motors open a field of new possibilities. The Fraunhofer Institute for Structural Durability and System Reliability (LBF) made strong efforts with regard to the development of this new concept.

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MOTIVATION

Currently, the appearance of our cars is characterised decisively by the traditional drivetrain layout – such as engine, gearbox and power transmission. Those parts are placed in front of the passenger compartment as well as underneath, which limits the package available for passenger and payload significantly. Typically, the weight and the position of the engine create heavy front axle weight. That narrows the possibility for lightweight measures at the vehicle rear, because otherwise, the centre of gravity would be in an even more critical position. Large and extremely stiff parts such as engine and gearbox may also cause potential issues at front crash loads.

So the conceptual benefits of in-wheel motors for electric vehicles are clearly visible: the complete drivetrain is positioned at the wheel directly. Consequently, the vehicle body can be reshaped according to the requirements for passenger compartment, aerodynamics as well as crash and pedestrian safety. Furthermore, the centre of gravity becomes lowered, and the introduction of all-wheel drives improves the axle-load distribution as well.

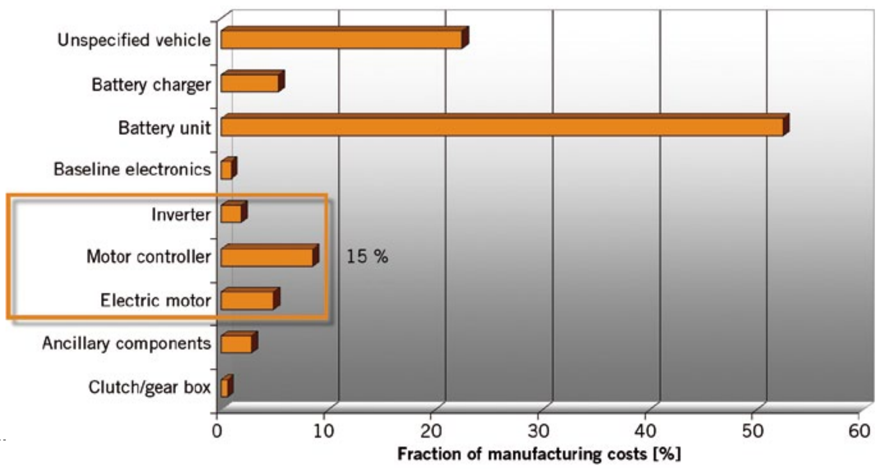
Hence, in-wheel motors are of special interest for future electric vehicles, but as a complete new technology they are challenging as well. That was the reason for extensive research activities on in-wheel motors within the framework of the Fraunhofer System Research Electromobility (FSEM) from 2009 to 2011, which was managed by the Fraunhofer Corporate Research Director directly.

THE TRADITIONAL DRIVETRAIN

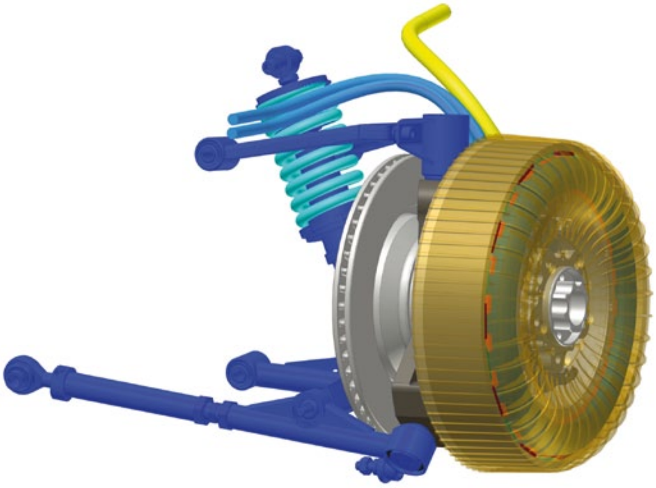
The complexity, the number of parts as well as the weight of combustion engines can be characterised as follows: spark ignition base engines with a performance of 120 kW or above weigh 100 to 150 kg without additional parts and it depends on swept volume, performance, and number of cylinders as well. A crankcase made of cast aluminium saves about 10 % compared to a cast iron part. Additional weight and package requirements are caused by coolant and oil pumps, fuel line parts, the radiator grill, as well as from supercharging and the exhaust system including the catalytic converter.

Present-day drivetrain topology – front engine and front wheel drive – leads to high front axle weight, which causes potential issues, especially for longitudinal vehicle dynamics. Because the gravity centre is located so much in the front of the vehicle, it is almost impossible to implement lightweight measures for the decklid or tailgate which then would move the centre of gravity even more to the front.

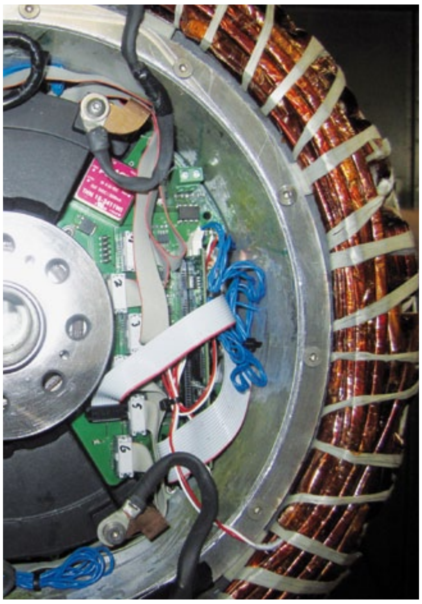
Engine and gearbox are large and stiff components directly positioned in front of the passenger compartment and may intrude into the structure. At moderate to strong injury levels (≤ 3 at Abbreviated Injury Scale, AIS) due to vehicle accidents, passengers are issued by skin related injuries as well as by tibia and femur fractures. In those cases, the injuries are caused by the bulkhead, the lower part of the dashboard, and the pedals. For occupant safety, size and stiffness of the engine are critical items as



❶ Major components contributing to the vehicle costs



❷ Study of package of in-wheel motor at rear suspension



❸ In-wheel motor with integrated inverter

well, especially for head impact on the engine hood. Therefore, some sophisticated measures such as airbags or actuated hoods were introduced.

Shaping the vehicle front according to the package requirements of engine and gearbox does not provide an optimum for aerodynamics. Additional aerodynamic losses are given by the under-hood flow and the uneven vehicle underbody because of the exhaust system. Aerodynamics is still an important part for the energy consumption: 26 % of the overall energy is related to aerodynamics for a vehicle with a weight of 1.5 t running at the New European Driving Cycle (NEDC).

THE ELECTRIC DRIVETRAIN FOR CONVERSION DESIGN

The facts mentioned above are valid for today's hybrid-electric vehicles (HEV) and battery-electric vehicles (BEV), too. Front engines as well as clutch, gearbox, and driveshaft are decisive for vehicle package and design. For electric vehicles, the weight of the vehicle also influences energy consumption and operational range significantly: the mass related proportion is about 36 % at the NEDC for a 1.5 t vehicle. Introducing brake energy recuperation helps slightly to reduce the energy consumption. But that effect is limited to approximately 10 % only, due to losses at the recuperation and storage processes as well as relevant longitudinal vehicle dynamics appearing at urban traffic primarily. As a result, lightweight becomes a dedicated product development target especially for BEV. It is a way to compensate the disadvantages of the relatively small energy density which is provided by electrochemical energy storage devices. Typically, the vehicle body structure as well as chassis and suspension components are chosen for vehicle weight reduction. That is often done by introducing new materials and features. As an example, carbon fibre reinforced plastics (CFRP) become increasingly interesting even for automotive application and will be used for body parts and panels of the new electric BMW i-vehicles which will be brought to the market in 2013.

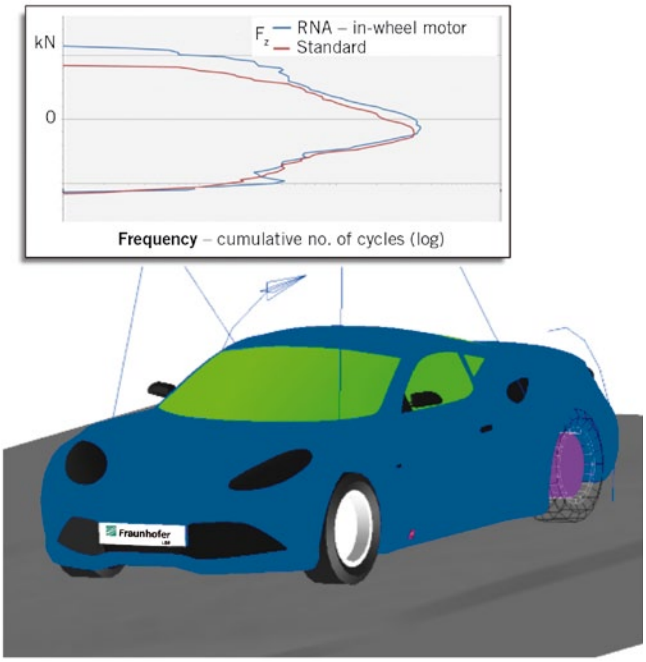
Although such materials and features are quite expensive, the overall cost break-down for BEV is dominated by the battery. Together with the battery charger, this system comes up to almost 60 % of the total production costs, while the electric motor together with its controller and the inverter is about 15 % only, ❶.

THE ELECTRIC DRIVETRAIN FOR PURPOSE DESIGN

The traditional drivetrain topology puts major constraints to the passenger and luggage compartment as well as to vehicle aerodynamics and safety. In other words: a maximum of flexibility and design freedom would be possible, if there is a way to integrate drivetrain components into other sub-systems which are already available and mandatory – such as suspension links and struts or the wheel/hub assy, ❷.

This can be realised by using electric synchronous-torque-engines, which are mounted together with the wheel/hub assy directly and help to eliminate other power transmission components such as gearbox, differential gear or driveshaft. Those in-wheel motors – sometimes called hub-motors – are practically wear-resistant and do not have any backlash or hysteresis. The basic layout is pretty

❹ Conceptual advantages of vehicles having in-wheel motors



❺ Multi-body analyses of complete vehicle structure

simple: an arrangement of magnets has a rotational degree of freedom – called rotor – and is aligned coaxially to an iron core with field winding on the stator frame. That can be arranged as an external or an internal rotor motor. The mechanical force is created at the gap between rotor and stator by the interaction of the magnetic and the electric current field. The engine torque is proportional to the number of pole pairs, the magnetic field as well as to the diameter of the gap between rotor and stator. Hence, external rotor direct torque drives are of special interest for in-wheel motor application.

Within the framework of the Fraunhofer Systems Research Electricmobility, researchers from the Institut für Fertigungstechnik und Angewandte Materialforschung (IFAM), the Institut für Integrierte Systeme und Bauelementetechnologie (IISB), the Institut für Werkstoffmechanik (IWM), and the LBF developed together a new external rotor synchronous-torque engine which was completed by an integrated inverter, ❸. The Fraunhofer IFAM in Bremen managed the production [1] as well as the vehicle integration.

The in-wheel motor itself is a 6-phase synchronous engine with bonded magnets and a number of pole pairs of 11. High torque (700 Nm and peak at 900 Nm) and performance (55 kW) are combined with relatively low weight (44.2 kg) that shows the comparatively good torque density. The inverter, developed at the Fraunhofer IISB and completely integrated into the engine package, ensures short wiring and good electromagnetic interference safety level. Combined water cooling was designed for both, inductors and inverter to limit the maximum temperature of the winding at 100 °C even at nominal torque. The rotor itself is stiffened by ribs and it is feasible to get it mounted to a 15'' wheel by its outer diameter of 364 mm only. The cast aluminium rotor is connected to the ring with the neodymium magnets by force-fitting. The wall thickness of the rotor is designed to ensure a proper force locking at a wide temperature range (-40 °C to 100 °C), although those materials have a significant different temperature expansion behaviour. Additional challenges were faced to limit the mechanical stresses of the rotor which are introduced by the force-fit.

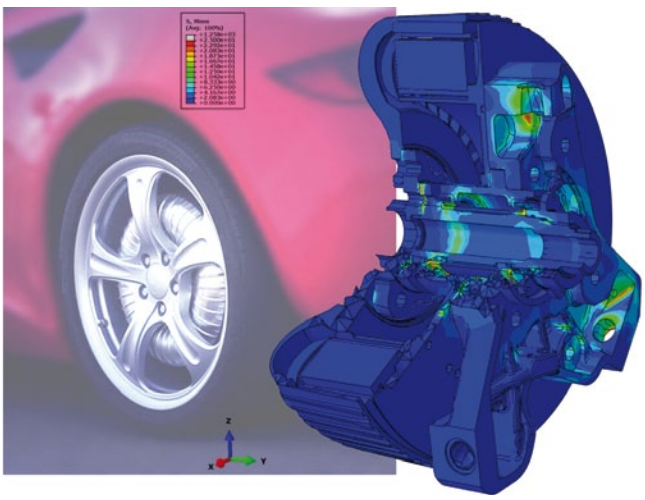
By using in-wheel motors, complete new vehicle concepts can be realised which are beyond current constraints, ❹.

Such concept features are:

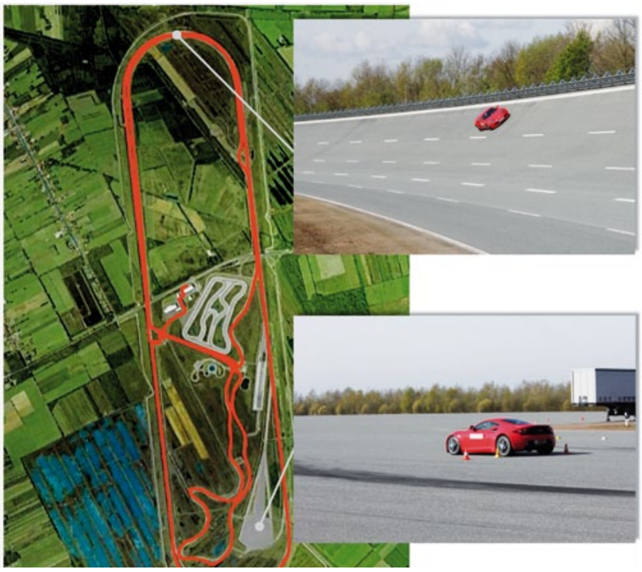
: highly flexible package design with regard to passenger and luggage requirements
: short vehicle front end with optimised deformation and intrusion behaviour at front crash
: significant potential to improve vehicle aerodynamics by minimising underhood flow, smooth lower underbody structure as well as aero-shaped front and rear design
: improved location of centre of gravity (COG) – especially for all-wheel drive configuration
: torque-vectoring, that means an optimised distribution of speed and torque to the individual wheels
: because rolling resistance becomes lowered for large wheels and narrow tyres, especially external rotor engines may use the in-wheel package of those tyre/wheel combination perfectly.

IN-WHEEL MOTORS AND FUTURE VEHICLE CONCEPTS

By having additional, concentrated masses mounted to the wheel/hub assy,



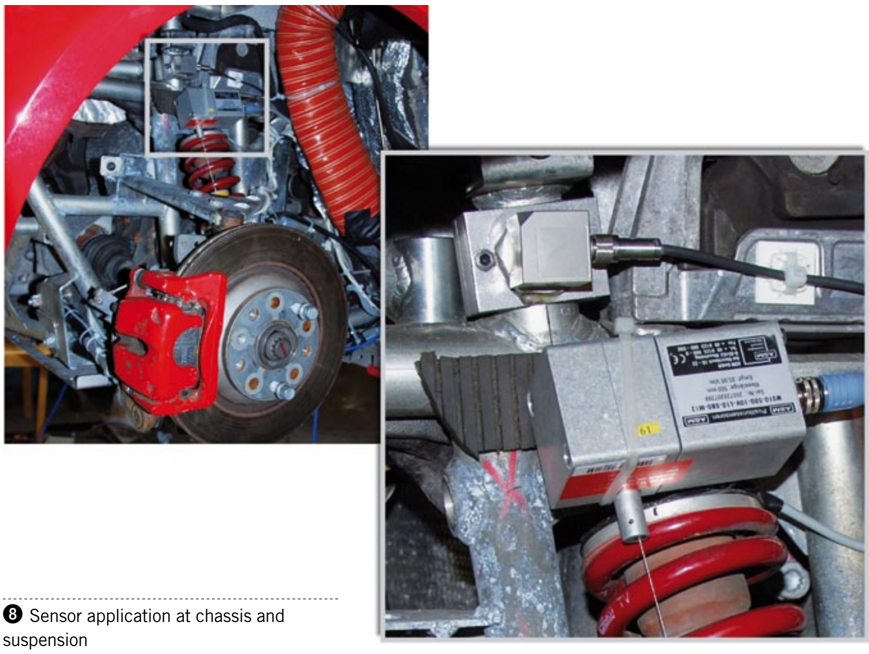
❻ FEA analysis of complete assy



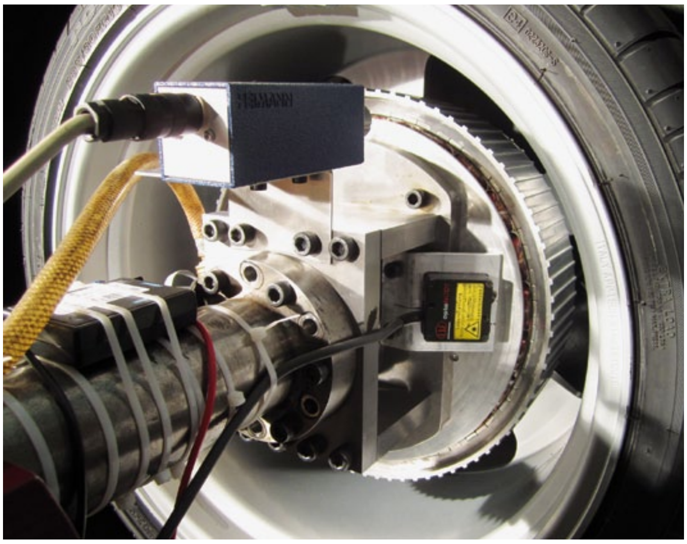
❼ Vehicle tests on proving ground

those components are highly loaded by forces and acceleration especially at rough roads. Both, traction forces as well as external loads have to be considered for design and dimensioning of in-wheel motors. The additional weight of these components increases the unsprung mass significantly. Extremely low weight wheels made from CFRP may help to slightly reduce those effects [2]. Therefore, full vehicle multi-body-dynamics (MBD) simulation, ❺, was performed by the Fraunhofer LBF, to examine loads and vehicle dynamics for rough road condition as well as for lateral dynamics by manoeuvres such as lane change. The wheel forces introduced by curb and pothole roads were used as boundary condition for math modelling by Finite Element Analysis (FEA) to evaluate the gap deformation between rotor and stator. This gap becomes changed dynamically by the loads from the road and the forces created by the interaction of the electric current and the magnetic field. Consequently, the rotor has to be designed for high stiffness, and by using computational results, it was possible to more than double the relevant eigenfrequency. The complex math models were considering all elastic bodies including a non-linear model for the ball bearing, ❻, for which the individual rotating elements were approximated by non-linear spring characteristics.

Since an in-wheel motor is both, functional part (related to its powertrain capabilities) as well as safety relevant component (related to the wheel/hub assy) there are demanding requirements with regard to functional safety and structural durability. Consequently, the development team had to look at analyses regarding the Automotive Safety Integrity Level (ASIL). That was prepared and managed by Fraunhofer LBF and different research teams were involved to examine issues which may be caused by unwanted differences in torque of the in-wheel motors at an axle, or even wheels rotating in opposed directions unintentionally. Another topic was to evaluate the impact of the unsprung mass on the loads to the vehicle as well as with regard to vehicle dynamics and ride comfort. Therefore, a baseline test vehicle was equipped with Wheel Force Transducers (WFT) and translational as well as rotational masses were added to the wheel/hub assy to simulate an increased unsprung mass in various different steps up to a mass which was equivalent to the in-wheel motor. At the proving ground tests, ❼, there were rough road sections to introduce oscillations at a frequency beyond the first wheel eigenfrequency, as well as there were ride and handling tracks. To get the most complete data for vehicle evaluation, the mule was prepared for Road Load Data (RLD) acquisition by strain gauges at body and chassis, 3-axis accelerometer for the acceleration of suspension and vehicle COG as well as string pots for spring travel measurement, ❽. Because of the large additional masses, similar to an in-wheel motor, the acceleration of the wheel carrier was reduced by 30 %, while the body mount area was almost unchanged. Based on the WFT data, the vertical forces were used to create load spectra for a pseudo-damage accumulation. The force peak was 20 % higher than without additional masses and the cumulative damage content increased by a factor of 2.6. Both, loads as well as ride and handling seemed to be manageable from vehicle develop-



❽ Sensor application at chassis and suspension



❾ Laboratory measurement and testing of in-wheel motor

ment point of view. This was confirmed by individual driver assessment as well.

Prior to any full vehicle tests of the in-wheel motors, those were extensively examined by laboratory testing. The evaluation of deformation characteristics and structural strength were done by using unique test rig hardware at Fraunhofer LBF. The Wheel Accelerated Life Test Machine (W/ALT) has an inner drum to simulate the road at different vehicle speeds as well as a hexapod actuation system to load tyre, wheel, and in-wheel motor realistically. So the dynamic wheel forces from the proving ground test were reproduced as well as the traction forces of the motor. While the laboratory test drive was performed, the temperature of the neodymium magnets as well as the load dependent gap between rotor and stator were measured, ❾. Hence, the deformation characteristics of the rotor were examined to ensure a basic level of reliability even in case of peak loads at the proving ground.

CONCLUSION

In-wheel motors are an enabling technology for unrivalled flexibility in vehicle package and design and may help BEV to enter the market more successfully. Fraunhofer LBF provided relevant product development support for functional safety, verification and validation testing by its core competencies.

Although in-wheel motors have some basic disadvantages, such as the increased unsprung mass or issues with regard to an efficient type of sealing especially for external rotor engines, there is a huge potential for new and improved features like spacious passenger compartment, vehicle dynamics as well as crashworthiness and aerodynamics by reshaping the vehicle body. Currently, in-wheel motors are still relatively expensive, so an all-wheel driven BEV may introduce a market barrier by its price. But it is expected that mid term the motor controller will be more cost efficient. Hence, in 2020 a BEV with in-wheel motors at an axle may come up with a cost penalty of about 8 to 12 %.

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"WE ARE READY FOR LARGE-SCALE COMMERCIALISATION FOR ELECTRIC VEHICLES"

China is the most interesting and flourishing car sales market in the world. This may be one of the reasons why the Fisita members recently elected President Dr. Jun Li of FAW Group Corporation R&D Centre as their president. ATZ seized the occasion to talk to Dr. Li about the current state of the Chinese motor market and its global alignment. Topics included the commercialisation of electric vehicles as well as the marketability of hybrids.

DR. JUN LI, 55, received his doctoral degree in 1989 from the Jilin University in Changchun, China, where he had majored in internal combustion engines (ICE). Starting as an engineer, he joined FAW immediately afterwards. Twenty years and several posts later, he eventually became Vice Chief Engineer of FAW and President and Professor Level Senior Engineer of the FAW Group Corporation R&D Centre in 2009. Apart from other honorary and social posts, he is also Standing Director of SAE China and professor and doctor tutor at the Jilin University. Dr. Li was Chinese Scientist of the Year in 2008 and holds many patents in automotive development. For many years, he has been engaged in the research and development of automotive engines, hybrid vehicles as well as automotive electronics.

ATZ _ Today, China is the most important automotive market. Do you expect the strong growth rates we have seen in the past for the midterm, too?

LI _ China has seen a boom in its automotive industry over the past decade. In 2011, China ranked first in terms of world auto volume with a total market volume of 18.5 million, 14.5 million for passenger cars. However, this fast growth has been experiencing a substantial slowdown compared to the past few years. I think that the Chinese automotive market will enter into an era of stable growth and its market structure is going to be continuously optimised.

In the past, Chinese OEMs copied western car concepts or manufactured derivates like the VW Jetta under license. Will that substantially change in future?

The Chinese auto industry has been evolving for half a century and cultivated its own development capacity. The Chinese auto market is an international one and any player who wants to survive on this market must have his own development capacity, core technology and brands.

Is China on its way to be the global think tank for the automotive industry?

The global automotive industry is shifting its focus to China. Many automakers start setting up technical centres in China and develop products based on Chinese market demands. More and more new models make their debut in China. Meanwhile, Chinese automotive industry is growing from big to strong.

China is dealt as one of the main players in the development of e-mobility. Your government supports this development with huge amounts of money. What can we expect from FAW and other Chinese OEMs in this term?

The Chinese government would like to promote the auto industry. As an OEM, we are willing to make a breakthrough at this golden opportunity when the government is providing strong support. All Chinese OEMs including FAW are busily developing electric vehicle products. By 2015, the world auto industry will see a large-scale commercialisation for electric vehicles and we are ready for it.

Rigidity, pedestrian protection, occupant safety: When will we see the first Chinese chassis to meet western standards?

China is adopting a regulatory and certification system that is very similar to the ECE system. However, there are many requirement differences between these two which means that a vehicle that satisfies the Chinese domestic market will still need to make additional efforts to meet western standards. China signed the 1998 Agreement on Global Technical Regulation (GTR) in 2000. Becoming a signatory to the 1958 agreement, too, is only a matter of time. Implementing equivalents to ESC and pedestrian protection regulations, the stipulated safety requirements in China will be getting closer to Western standards. In fact, regardless of these regulatory constraints, Chinese manufacturers are willing to comply with international standards as they pay respect to both their product image and the intention to penetrate Western markets. The efforts taken here are apparent. FAW's sedan project, to which we refer as the H-platform, underlines the manufacturers' desire to improve the safety record of Chinese brands in Europe. It was clearly aimed at the domestic market but the designers' objective also was to score five stars by the more stringent Euro NCAP 2012 protocol. As the president of FAW's research and development centre, I tend to think that whether or not the H-platform will pass the Euro NCAP assessing in Europe, we are getting technically prepared for that.

“Any player who wants to survive on the international car market must have his own development capacity.”

Hybrid cars are said to be a solution leading towards a low carbon society. Yet, customer expectations in terms of pricing, range and comfort are currently not met. Could you transfer your experience with the CA6100SH8 Hybrid Coach to road cars?

Range and comfort have not been the main disadvantages of a hybrid car so far. The current issues to be solved are cost, reliability and the consistency of fuel consumption in different drive cycles. Based on our experiences and study results, acquisition costs and reliability are the main issues for the commercialisation of an electric vehicle. FAW is focused on these.

According to Li, the passenger car export is one of the possible future strategies

Fuel cell seems to be the most promising solution for future mobility. What about FAW's fuel cell projects?
Fuel cell costs, lifetime and environment adaptability still fail to meet vehicle application requirements, so it is difficult to commercialise a fuel cell vehicle within a short term. FAW is therefore focusing on technology research and tracking in this field.

"Chinese automotive industry is growing from big to strong."

For military purposes, you are at present developing your CA7460 "Unmanned Limousine". Could autonomously driven cars solve the world's traffic problems?
We see the project as a demonstration platform to validate cutting-edge technologies such as advanced sensing fusion, intelligent route programming and advanced chassis control rather than as a concept to solve global traffic problems. If you ask me how to use roads efficiently and safely, then I don't think the problem will be solved on the basis of individual vehicles. FAW believes, however, that a zero-fatality traffic society can be realised with intelligent vehicles connected by an information and communication network. We have reasons to assume that, with technologies like a zero-fatality network prevailing around the world, safety and efficiency in the world's traffic will be greatly enhanced.

Li is convinced that a zero-fatality traffic society can be realised with intelligent vehicles

In 2012, Fisita World Congress will take place in Beijing and you will be the new president. What do you consider to be your mission and your targets?
All Fisita presidents are primarily committed to Fisita and its mission. Apart from that, to enhance the exchange and cooperation between China and the world will be a task for me that I consider beneficial for both China and the world automotive industry. I will also try to improve Fisita's financial situation by recruiting more members, including Honorary Committees, as the automotive industry in China and other developing countries will still be on the rise for the next decade and more and more automakers will be looking for a common platform like Fisita.

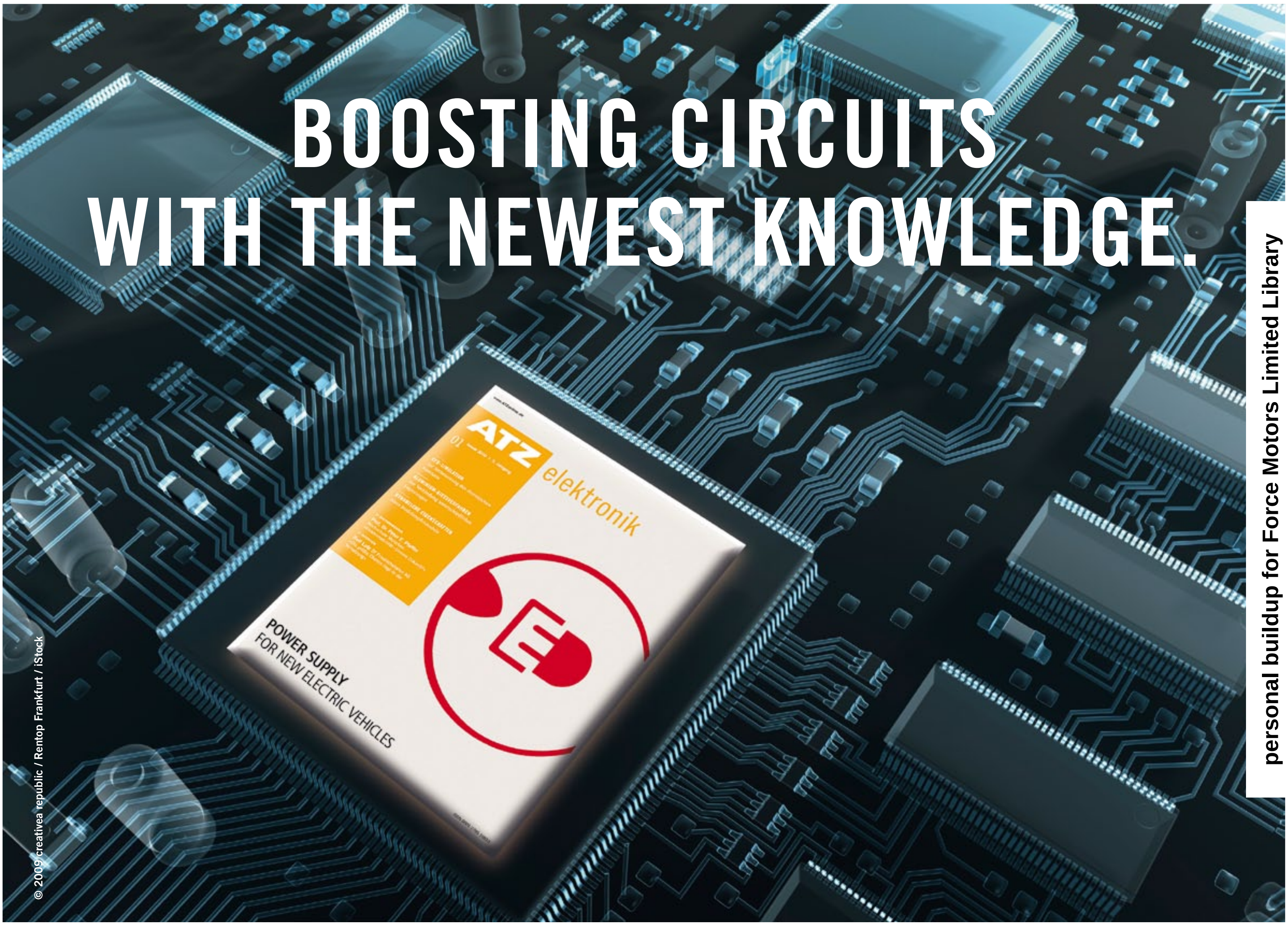
"More and more automakers will be looking for a common platform like Fisita."

Europe is said to be the most demanding automotive market. When will we see Chinese cars on our roads?
We have exported our trucks to some Eastern European countries, but our passenger cars are yet to enter the European market. Passenger car export is one of the possible future strategies, but there is currently no tangible plan.

Very successful Asian OEMs are establishing subsidiaries in Europe. When will the first European workers start to build Chinese cars in Europe?
It is the common goal of all ambitious automakers to play on the international market but how to play and when to start may vary for each player. At present, FAW has no plan to establish subsidiaries in Europe since we have a huge potential market back home in China which attracts and gathers almost all global automakers. We must make full use of this geographical advantage to explore our local market and improve our capacity.

Dr. Li, thank you for the interview.

INTERVIEW: Roland Schedel
FOTOS: FAW



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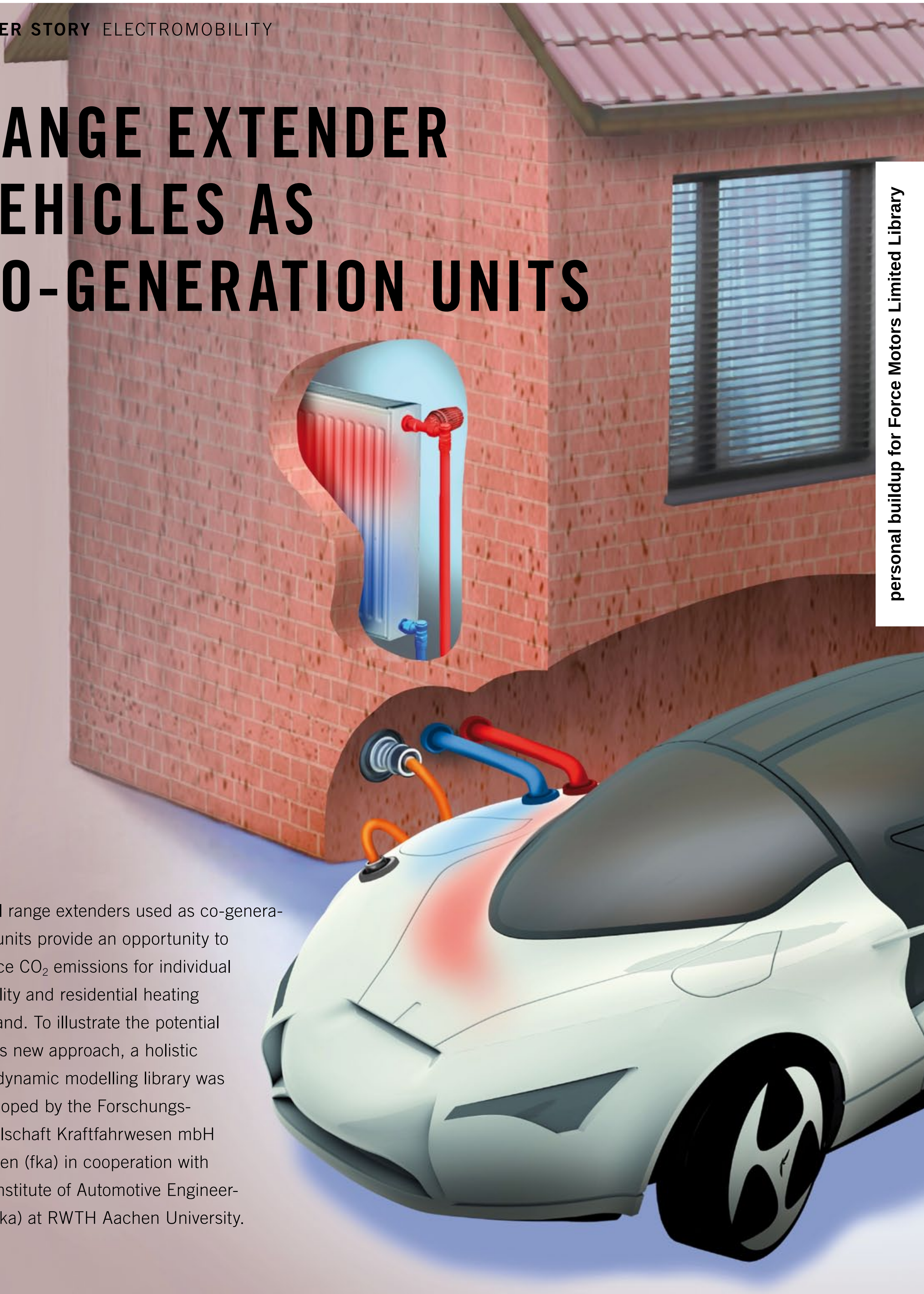
RANGE EXTENDER VEHICLES AS CO-GENERATION UNITS



Small range extenders used as co-generation units provide an opportunity to reduce CO_2 emissions for individual mobility and residential heating demand. To illustrate the potential of this new approach, a holistic and dynamic modelling library was developed by the Forschungsgesellschaft Kraftfahrwesen mbH Aachen (fka) in cooperation with the Institute of Automotive Engineering (ika) at RWTH Aachen University.

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SYNERGETIC USE

Co-generation units provide the benefit of improving fuel exploitation. For today's electricity supply, they reduce the primary energy use and thus, CO_2 emissions. In communal and industrial energy supply systems such units, for example based on combustion engines, are currently used to cover the base load of the heat and electricity demand. In the housing sector, co-generation technology is not yet established, since the available units lead to short operation times and hence, to a poor cost effectiveness.

A state-of-the-art vehicle based on an internal combustion engine may be considered as a mobile co-generation unit and consequently, would be available for combined heat and power supply in most households. This approach would have the benefit of reducing individual CO_2 emissions and improving cost effectiveness. However, today's internal combustion engines for mobile use have nominal powers exceeding the demand on the thermal side. Poor overall efficiencies and a modest potential are the consequence.

Future plug-in hybrids and range extender vehicles will have smaller nominal powers, which increase the potential as an individual co-generation unit for housing and mobility purposes. When adapted to the nominal heat demand of houses, the waste heat of the combustion engine may be used for heating purposes. The generated electricity may cover the demand of the household or be used to charge the battery. Electricity surplus will be provided to the public electricity grid. This individual co-generation approach not only leads to a better fuel exploitation. The coupling of house and vehicle provides an electric storage to equilibrate the electric demand as well. Furthermore, the vehicle may be preheated in the morning which results in a reduction of the electricity demand for cabin heating and higher cruising ranges.

A coupling of the engine's cooling and the house's heating circuits (thermal socket) as well as an exhaust gas system are required for this co-generation approach. In this paper, the energy saving potential of a synergetic use of the internal combustion engine of range extender vehicles is analysed by means of dynamic simulations.

SYSTEM DEFINITION AND EVALUATION PARAMETER

For the holistic co-generation approach, different types of final energy are purchased by the user: fuel for the range extender, electric energy for charging the traction battery, and natural gas for the boiler. To compare different scenarios, a consistent evaluation parameter must be defined. In this paper, primary energy (PE) is chosen. It takes into consideration all conversion losses from well to the system boundary. The resulting energetic flows for the co-generation approach are depicted in ❶. It clearly shows that improved use of waste heat from the internal combustion engine improves fuel exploitation. Also, the heating demand of the gas boiler in the house's heating system is partly reduced. Furthermore, an appropriate operational strategy will precondition the vehicle's cabin (for example in a garage) and reduce the electricity demand during the drive cycle.

MODELLING

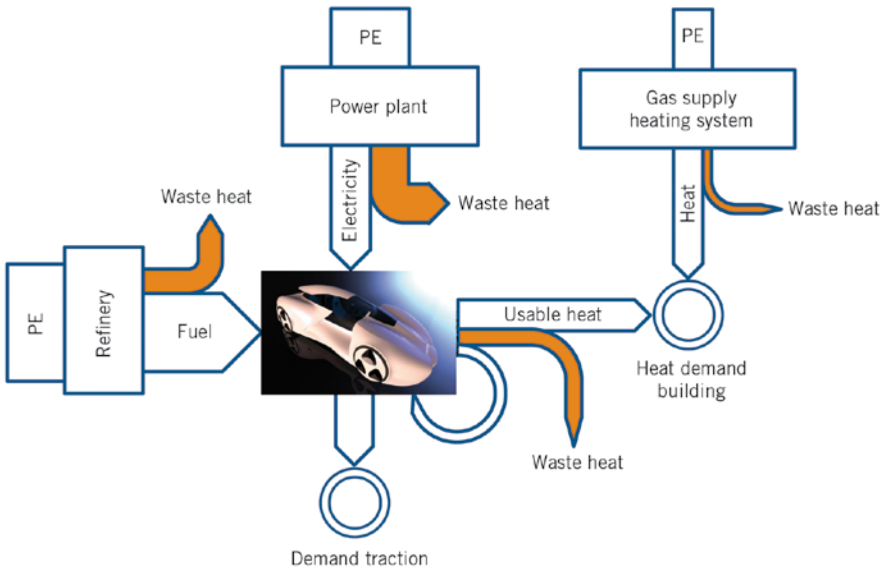
Compared to stationary co-generation units, the scenario described is mainly defined by highly dynamic use. Though depending on the defined user profile of the house, a stationary heating scenario is to be expected. However, due to the thermal capacities of the house and the vehicle's cooling circuit, a dynamic analysis is essential. Therefore, a dynamic modelling of both, the house and its heating system as well as the vehicle is necessary. In this article, a dynamic modelling library developed at the fka in cooperation with the ika is used [1, 2].

DYNAMIC VEHICLE MODEL

The physical vehicle model computes all energetic (that is mechanical, chemical, thermal, and electrical) flows for the defined vehicle. It combines detailed dynamic models of the longitudinal dynamics and the drivetrain, the vehicle's cabin, the cooling and heating circuits, and the electric power net.

The mechanical demand for driving is calculated for each time step by means of longitudinal dynamics. The accelerator and brake pedal positions are interpreted in a vehicle control unit as a target wheel torque. Dependent on the chosen operational strategy and the vehicle's drivetrain architecture, the target torque is set at the traction units (for example engine, brake). The drivetrain transfers the traction power, under consideration of transmission losses (for example map-based), to the wheels. The vehicle's velocity is calculated. If the driver notices a difference between actual and target speed, he adapts the pedal positions acting as a control unit.

The thermal demand for cabin heating and cooling is computed with a dynamic cabin model for the given boundary and ambient conditions [3]. This model takes into consideration all thermal capacities, leakages, and system boundaries for the heat transfer. The cabin is heated either with waste heat from the combustion engine or by means of a HV (High Voltage) electric PTC (Positive Temperature Coefficient) heater, ❷.

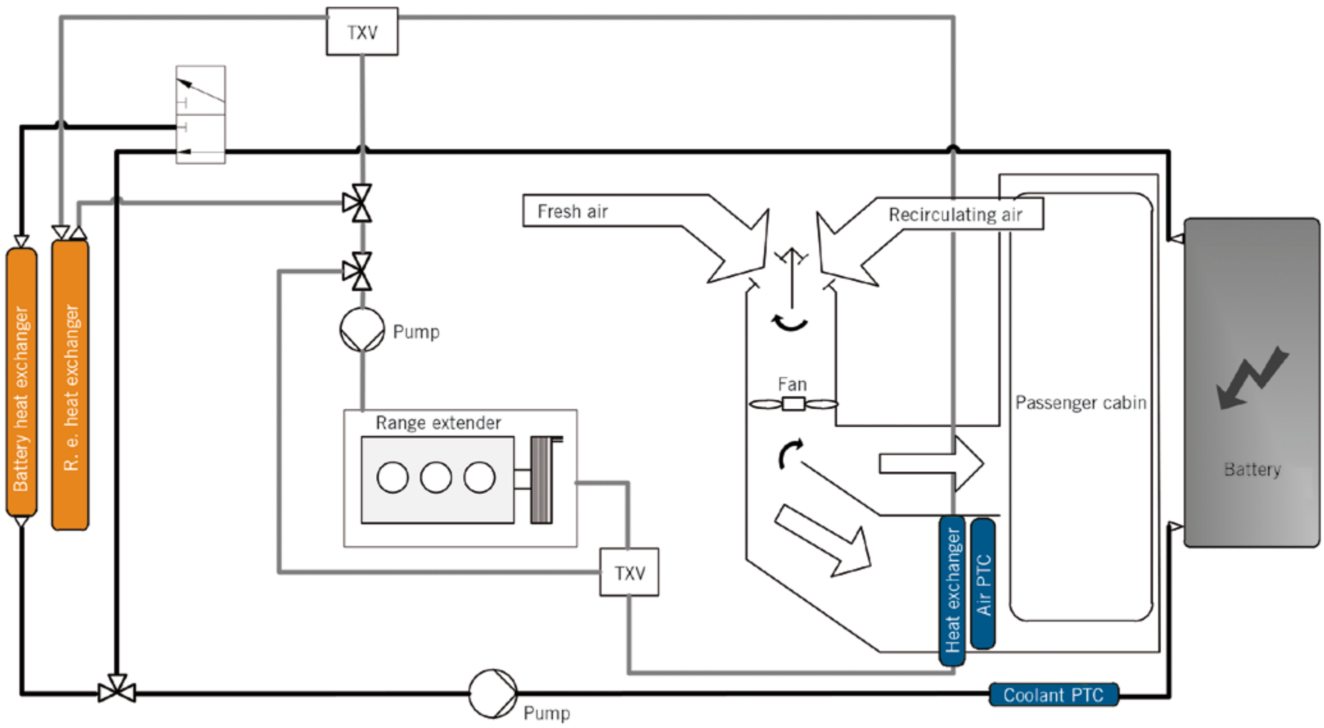


❶ Sankey diagram of the holistic co-generation approach

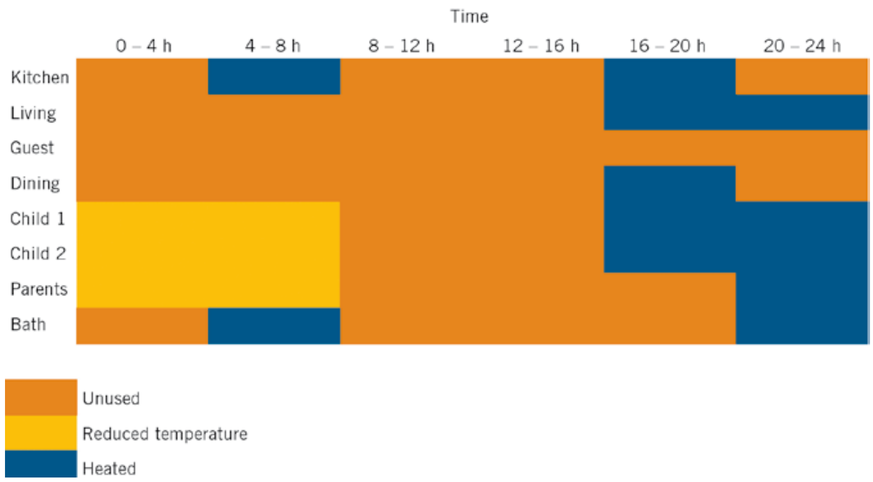
DYNAMIC HOUSE MODEL

The house's heat demand is computed again with a dynamic model, considering all thermal capacities, internal (for example humans, electronic devices) and external (for example solar radiation) heat sources. Here, a single family detached house with eight rooms and a habitable surface of 160 m² is chosen. The house's insulation is modelled according to the German specification EnEV (Energieeinsparverordnung) [4] (standard of 2007).

For the co-generation scenario, the combustion engine's cooling circuit is connected to the house's hydraulic heating grid with a thermal socket (self-sealing quick connector). If the co-generation unit is either not connected or not running, the house's heating demand is covered by a condensing boiler. To reduce a frequent clocking of both heating units (combustion unit and boiler) a 300 l hot water storage supplements the hydraulic heating circuit. The combustion engine is controlled to cover the heating de-



❷ Cooling and heating circuits of the range extender vehicle (TXV = thermostatic expansion valve)



❸ Scheme of the house's user profile

	PRIMARY ENERGY FACTOR F
ELECTRICITY	2.6
FUEL	1.26
NATURAL GAS	1.11

❹ Used primary energy factors (from [4] and [5])

mand when used as a co-generation unit. The excess electricity is transferred to the public electric grid and credited as a benefit for the primary energy balance.

USER PROFILE AND BOUNDARY CONDITIONS

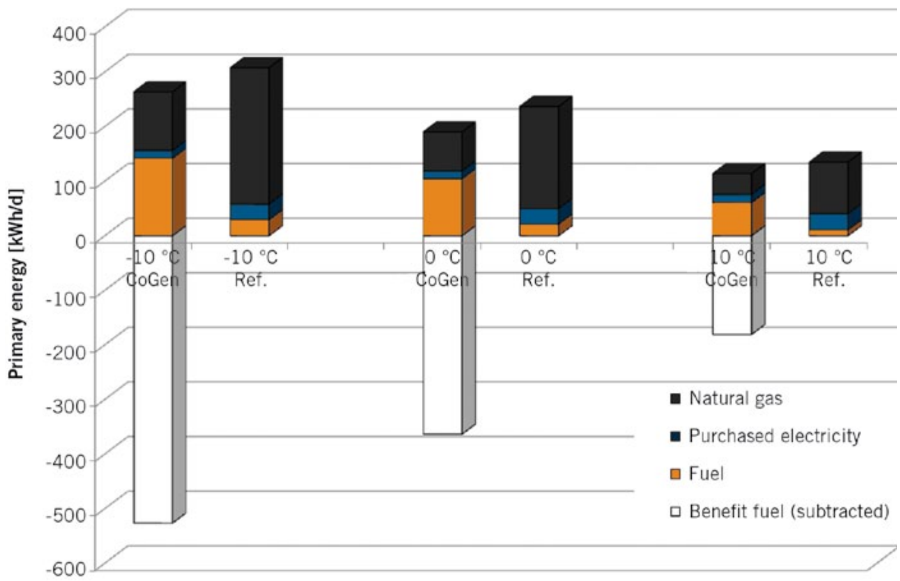
To evaluate the benefit of a holistic co-generation approach, a user profile, ❸, is needed. The heating system's control unit reduces the room's target temperature during the night and when unused. Besides the house's user profile, the vehicle's operating conditions have to be defined. In the morning, a journey to work is reproduced by three consecutive NEDCs (New European Driving Cycle). For this operational mode, the vehicle is preheated in the garage by either co-generation or boiler operation and the traction battery is charged to a state of charge (SOC) of 90 %. During the stand still at work, the car is again electrically charged and in the afternoon, a journey from work is simulated. For this drive cycle, the vehicle is not preheated. During the drive cycles, the range extender is operated as a charge sustaining unit to guarantee a SOC between 20 and 30 %. The internal combustion engine is operated in its best point with a power output of 18 kW and a mechanical efficiency of 41.9 %.

RESULTS

The simulation results will be presented below for three ambient conditions (T_U = -10 °C, T_U = 0 °C, T_U = 10 °C). The used primary energy factors to convert the purchased final energy are given in ❹.

As stated above, the surplus of electricity produced by co-generation is provided to the public electricity grid. As this will avoid electricity production in a power plant, a primary energy benefit is taken into consideration. The resulting primary energy balances are given for the three used final energies (electricity, fuel and natural gas), ❺. Here, a primary

❺ Primary energy balance for the chosen ambient conditions



	-10 °C	0 °C	10 °C
PE-saving kWh/d	44.1	46.6	21.2
PE-saving	14.4 %	19.7 %	15.7 %

❻ Relative and absolute primary energy savings

energy saving due to the co-generation approach for each simulated heating scenario becomes evident. The saving potential depends on the operation cycles of the co-generation unit and is therefore dependent on the ambient conditions and the control strategy, ❻.

The simulations show a fuel exploitation (overall efficiency of the co-generation unit) of approximately 65 % for the simultaneous supply of electricity and heat, mainly due to the use of a thermal storage in the house's heating system. Higher overall efficiencies cannot be reached, since the exhaust gases' heat is not used for heating purposes. Although an optimal efficiency for the calorific value boiler (100 %) and an optimistic electricity supply according to the EnEV was assumed for the separate energy supply, the overall efficiency is clearly improved for the co-generation approach.

CONCLUSION

The simulations show that the synergetic use of small range extender combustion units has a potential of reducing primary energy use and thus, CO_2 emissions for individual mobility and house's heat supply. Weighting the results with statistic weather data [6] lead to a saving potential of 17.6 % per year. The presented co-generation approach nearly reaches the target CO_2 emissions' reduction for 2020 by using state-of-the-art technologies. However, this approach is only realisable for single family detached houses. A thermal socket at the office building would make the co-generation approach during the day possible and increase the potential.

Besides the development of a thermal socket, an exhaust system in the garage would be essential. Moreover, taxes for fuels in a synergetic scenario would have to be discussed.

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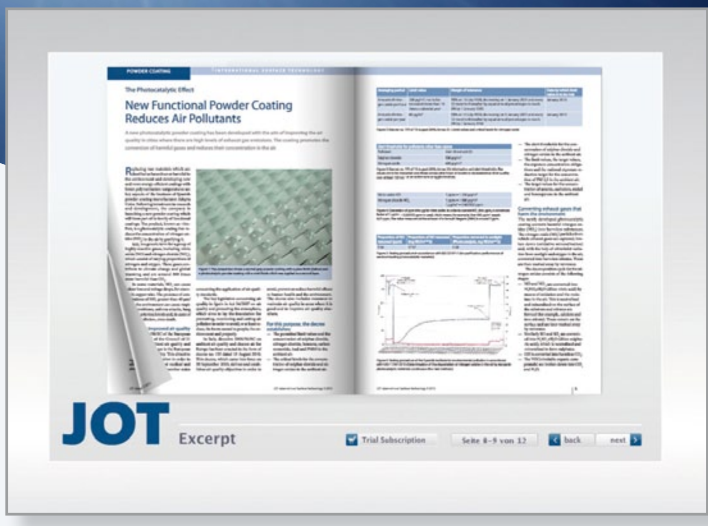

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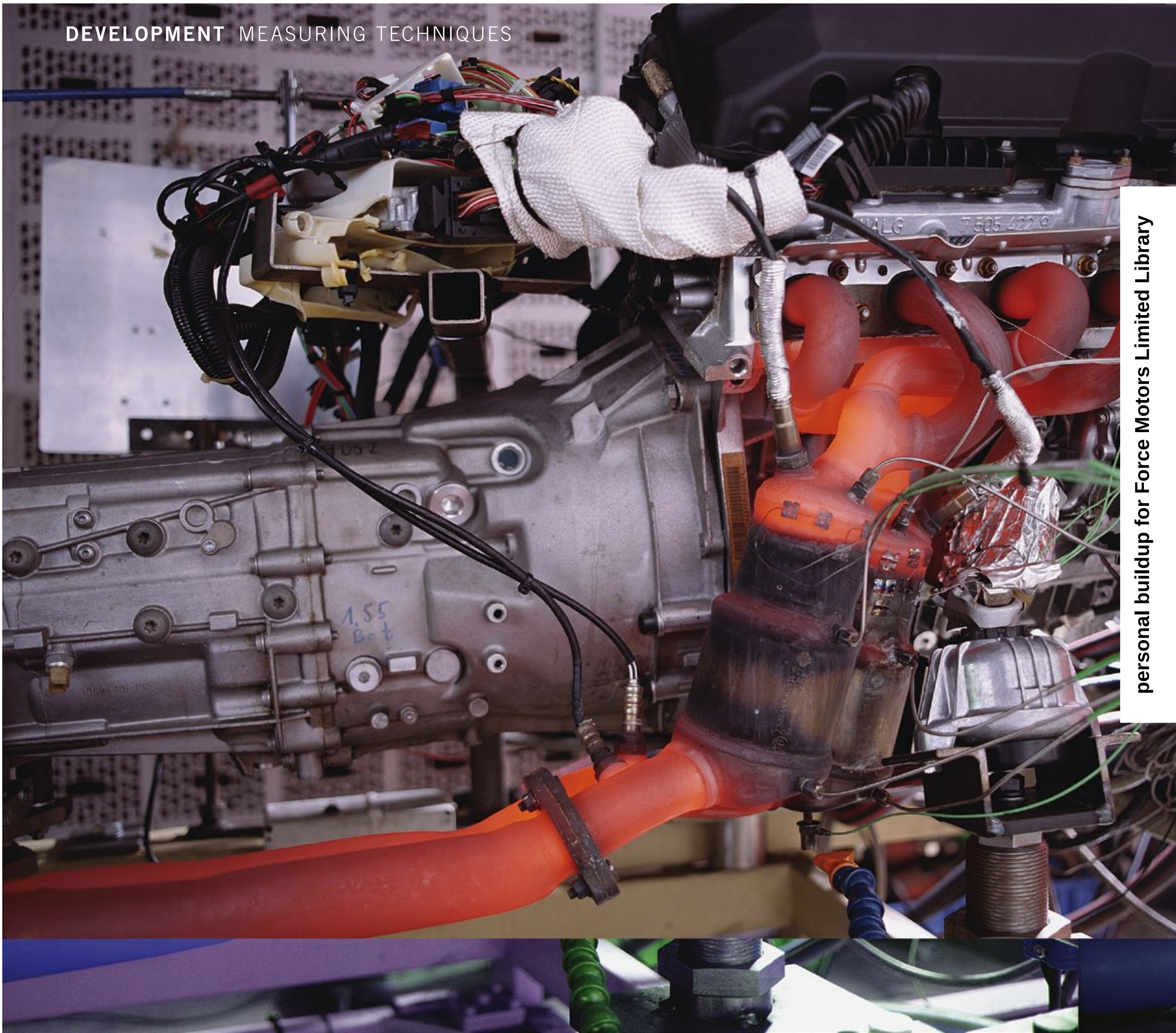
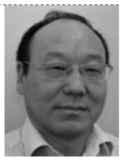


FEM-AIDED APPLICATION OF STRAIN GAUGES IN EXHAUST-GAS SYSTEMS

Although numerical simulations like finite element method (FEM) are available, experimental tests with strain gauges (SG) are indispensable in the vibration analysis and load determination of exhaust-gas systems, in order to obtain section loads across a pipe section. Because the operation temperature in exhaust-gas systems is up to 900 °C (1650 °F), expensive high-temperature strain gauges (HTSG) need to be used quite often. The purpose of the investigation presented by Tenneco is to minimise their number and to optimise their configuration and positioning regarding economical and technical goals.

AUTHORS



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ENGINE TEST BENCHES ARE NECESSARY

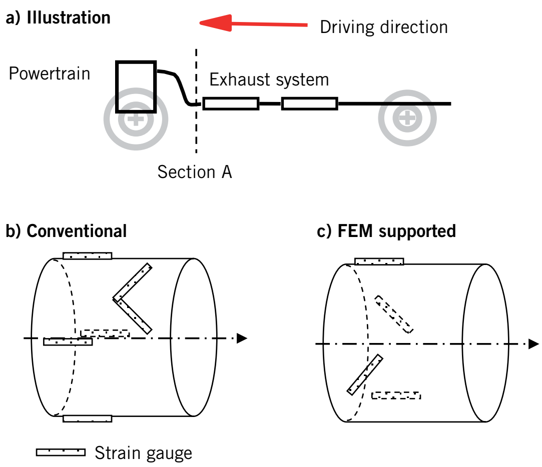
Even today the study and design of the lifetime durability of mechanical components in an automotive exhaust system becomes a challenging task for engineers. Still the experiment with physical parts on different test benches, for example engine test benches, is necessary to determine the operational load. Simulations like the FEM are not able to replace the operational load measurements with the needed accuracy [1-3].

❶ (a) shows an illustration of an exhaust system. Excitations from combustion engine and road create vibration loading on the system during operation. To exemplify the engine induced load is used, but the results are also transferable to road load. As a simple case the operational load on a muffler inlet (cross section A) should be determined. Therefore a couple of strain gauges are applied on the pipe surface. The high temperature during use requires the use of high-temperature strain gauges (HTSG).

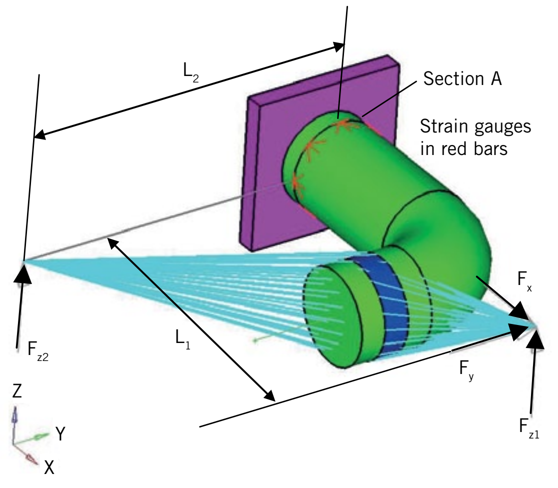
The number and configuration of HTSG are dependent of loading conditions and the geometrical structure in the concerning region. So far the determination of number, place and direction was based on experience and this lead sometimes to questionable results on strongly bended or otherwise complex structures. This resulted in unnecessary repeated measurements and the use of additional strain gauges in history. An unsuitable application degrades the calibration matrix, while the measurement results of the load are less accurate. The aim of the presented work in this paper is to develop a robust and reliable tool to optimise the application of HTSG regarding economical and technical goals.

① (b) and ① (c) demonstrate an illustrative comparison between the conventional application method and our new method based on FEM guided placement of strain gauges. Under the assumption of two bending moments and one torsional moment acting on cross section A (forces are neglected) the conventional method needs six SG, ① (b). Four of them are fixed along the pipe axis to determine the bending moments, two more are positioned in V-shape to identify the torsional moment. The opposing sensors can be connected as electrical quarter- or half-bridges.

The realised placement of the HTSG based on the FEM calculations, ① (c), needs only four HTSG. Two of them are still



❶ Comparison of the high-temperature SG application at a pipe: illustration (a), conventional use (b) and FEM supported application (c)



❷ Static calibration for bending moments, torsion and axial force

mounted along the pipe axis, two more turned at 45° against the pipe axis. In case of an arbitrarily failure of one of these HTSG, the measurement is still reliable with this layout.

STATIC CALIBRATION

In the following the application of HTSG on the examined part will be treated as a multi-axial probe. To translate the sensor signals into forces and moments, it is necessary to calibrate this probe according to the individual load components. This is done with static loads. A typical layout for the calibration for a pipe with single bent is shown in ❷. The square plate indicates that the pipe end is constrained at this position in the physical setup. The calibration according to three moments and the axial force is shown besides the fixing (cross section A). The following loads result out of this:

- bending moment about the y-axis: $b_y = F_{z1} L_1$
- bending moment about the z-axis: $b_z = F_y L_1$
- torsional moment about the x-axis: $b_x = F_{z2} L_2$
- axial force along the x-axis: $b_F = F_x$

OPTIMISING THE APPLICATION OF HTSG

② shows, highlighted in red colour, the rod elements, these are used as replacement for the HTSG in the FEM model. Other then with real HTSG, the rod elements can be placed in great numbers n_{Rod} so the analysed cross section is covered with many FEM-HTSG in different orientations and at different places to evaluate them. The goal is the optimal selection of n_{SG} rod elements, detailed below. The number for n_{SG} depends on the geometrical layout and the operational loads. In most realised cases the number is between 3 and 5.

The method was developed according to the measurement setup during the calibration. Executing a static simulation with the aid of the FEM, one receives the calibration matrix $\boldsymbol{S}$. This matrix represents the correlation between strain and load, on the one hand directly if the load is known, Eq. 1:

$$\begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \dots \\ \dots \\ \varepsilon_{n_{Rod}} \end{pmatrix} = \begin{bmatrix} s_{1x} & s_{2y} & s_{1z} & s_{1F} \\ s_{2x} & s_{2y} & s_{2z} & s_{2F} \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ s_{nx} & s_{ny} & s_{nz} & s_{nF} \end{bmatrix} \begin{pmatrix} b_x \\ b_y \\ b_z \\ b_F \end{pmatrix} = \mathbf{S} \begin{pmatrix} b_x \\ b_y \\ b_z \\ b_F \end{pmatrix}$$

On the other hand if the strains are known using the (pseudo)-inverse matrix $\boldsymbol{S}^{-1}$, Eq. 2:

EQ. 2
$$\begin{pmatrix} b_x \\ b_y \\ b_z \\ b_F \end{pmatrix} = \mathbf{S}^{-1} \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \dots \\ \dots \\ \varepsilon_{n_{Rod}} \end{pmatrix}$$

In theory a suitable selection of four HTSG is enough for a load vector with four components (example in Eq. 1 and Eq. 2). A set of four HTSG is suitable if:

- the signals are strong
- the spatial distribution is wide enough so the HTSG can be applied practically
- the resulting calibration matrix, consisting of the lines corresponding to these HTSG, has a good condition.

To assure that the loss of one HTSG does not corrupt the analysis of the complete cross section, an additional HTSG will be added (n_{SG} = 5). The algorithm of selection now has to determine a set of HTSG that is suitable and that is still working with any subset of one less HTSG. So the loss of any one HTSG can be tolerated. Regarding the example with four loads this leads to the necessity according to Eq. 3 of analysing:

EQ. 3
$$\binom{n_{Rod}}{n_{SG}} = \binom{32}{5} = 201.376$$

possible sets of five HTSG according to Eq. 4:

EQ. 4
$$\varepsilon = \begin{pmatrix} \varepsilon_{I} \\ \varepsilon_{II} \\ \varepsilon_{III} \\ \varepsilon_{IV} \\ \varepsilon_{V} \end{pmatrix} \text{ and their five subsets}$$

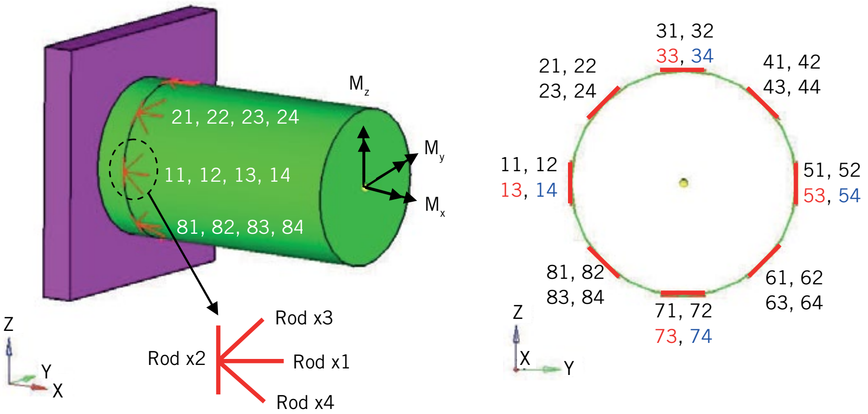
$$^{I}\varepsilon = \begin{pmatrix} \varepsilon_{II} \\ \varepsilon_{III} \\ \varepsilon_{IV} \\ \varepsilon_{V} \end{pmatrix},\ ^{II}\varepsilon = \begin{pmatrix} \varepsilon_{I} \\ \varepsilon_{III} \\ \varepsilon_{IV} \\ \varepsilon_{V} \end{pmatrix},$$

$$^{III}\varepsilon = \begin{pmatrix} \varepsilon_{I} \\ \varepsilon_{II} \\ \varepsilon_{IV} \\ \varepsilon_{V} \end{pmatrix}, \dots$$

for their suitability. If the sets are aligned in a list according their suitability, then one set of the first places will be selected.

Despite the redundancy the additional HTSG is also advantageous in other respects. First of all it improves the result, because effects like measurement noise is averaged over a higher number of HTSG channels. Second, the additional HTSG leads to an over-determined system of equations in the load-strain correlation, Eq. 2. This over-determination can be used for an plausibility check of the load data.

The measured strains are compared with those strains, which are calculated



❸ Layout of the strain gauges as red bars on a cylinder beam

from the load data according to Eq. 1. A good conformity acknowledges the load assumption and strengthens the confidence in the calculated loads. In the case of systematic discrepancies, these can be used to develop a better load assumption.

PLACING ROD ELEMENTS

The two groups, responsible for FEM calculations and vibration measurements at Tenneco created an Excel/VBA based software according to the described algorithm which is called FEM HTSG Tool. The typical start of the usage is the placement of rod elements on the existing FEM model. Depending on geometry of the part and load considerations the actual number can vary ($n_{Rod} \leq 1000$). The limit of 1000 is arbitrary. But practically it can be assumed, that this number will never be reached.

For the static calibration the load cases are selected in a way, so the set up in reality is simple and comprehensible.

As shown before, the best combination is found by permutation of preselected results. The tool needs less than a minute for these calculations. Additional features of the tool are the identification of loads relevant for damage, based on a dynamic simulation and the ability to do a plausibility check as described before.

VALIDATION AT THE CYLINDER BEAM

To verify the calculated results will be examined exemplary for a simple structure. In this case a elementary cylinder beam is used, ❸. Eight sets with four rod elements each are positioned in circumferential direction along a cross section close to the fixation. The application pattern of each set includes one element in circumferential direction (ID x2), one in axial direction of the beam (ID x1) as well as one element each in ±45° rotation against the beam axis (ID x3; ID x4). The load consists of three pure moments M_x; M_y; M_z. Other than in the calibration, ②, these moments are applied directly and not using a force and a lever arm, therefore no influence of the force has to be accounted for.

According to the elementary beam theory, basic unit stress coefficients can be expressed in Eq. 5 for bending moment M_y and M_z, where d is the cylinder diameter:

EQ. 5

$$\bar{\sigma}_{\text{Bending}} = \frac{\sigma_{\text{Bending}}}{M_{\text{Bending}}} = 2k$$

$$\text{with } k = \frac{16}{\pi d^3}$$

For the torsion M_x the Eq. 6 is formed:

EQ. 6

$$\bar{\tau}_{\text{Torsion}} = \frac{\tau_{\text{Torsion}}}{M_{\text{Torsion}}} = k$$

According to the basic Eq. 5 and Eq. 6 the stress coefficients for each rod element are calculated and filled in the following calibration matrix **S**:

$$\mathbf{S} = k \begin{array}{c} \begin{array}{ccc} M_x & M_y & M_z \end{array} \\ \left[\begin{array}{ccc} 0 & 0 & 2 \\ 0 & 0 & 0 \\ 1 & 0 & 1 \\ -1 & 0 & 1 \\ 0 & 1.412 & 1.412 \\ 0 & 0 & 0 \\ 1 & 0.707 & 0.707 \\ -1 & 0.707 & 0.707 \\ 0 & 2 & 0 \\ 0 & 0 & 0 \\ 1 & 1 & 0 \\ -1 & 1 & 0 \\ 0 & 1.412 & 1.412 \\ 0 & 0 & 0 \\ 1 & 0.707 & -0.707 \\ -1 & 0.707 & -0.707 \\ . & . & . \\ . & . & . \end{array}\right] \end{array} \begin{array}{c} \text{Rod ID} \\ 11 \\ 12 \\ 13 \\ 14 \\ 21 \\ 22 \\ 23 \\ 24 \\ 31 \\ 32 \\ 33 \\ 34 \\ 41 \\ 42 \\ 43 \\ 44 \\ . \\ . \end{array}$$

❹ Application of the HTSG (two of them with the numbers 1054 and 1062) at the inlet of a muffler

Build on three load components and 32 virtual HTSG a 4×32 matrix is created, because of the request for redundancy as explained before. Only the first half of the matrix is shown here, the second half is identical in value except for opposing signs. The optimisation results in two combinations with four elements out of 32 rod elements: Option 1: 13; 33; 53; 73 (position red in ③) und Option 2: 14; 34; 54; 74 (position blue in ③).

EXAMPLE OF USE: INLET OF A MUFFLER

The described software is in use since 2010 at Tenneco. Numerous instances have proven its technical and economical advantage.

One example of application for HTSG is shown in ❹. In total four HTSG are applied at the muffler inlet to detect two bending moments and one torsional moment (in ④ two strain gauges are hidden). Clearly the pattern of the sensors can be seen. One (No. 1062) is oriented in circumferential direction, the other (No. 1054) rotated 45° against the tube axis.

Because of the geometry of the bended inlet pipe strong signals in the transverse direction are expected; therefore one sensor is instrumented in circumferential direction. A conventional application would have neglected that load component, also the intuitive evaluation of the part would maybe not lead to a satisfying solution.

CONCLUSION

The interdisciplinary cooperation between the Tenneco groups responsible of FEM calculation and vibration measurement technology has created a robust method to instrument expensive high-temperature strain gauges (HTSG) on parts with difficult geometry or difficult load cases. Tenneco has therefore a tool available, that not only minimises the number of necessary sensors, but also includes a number of safeguards.

On the one hand false applications are avoided, on the other hand the resilience of the application is dramatically increased. Therefore costly and time consuming repeated measurements and follow-up dates can also be avoided. The new process and its tools have demonstrated technical as well as economical advantages in many applications, here an inlet of a muffler was used as an example. Using the in-house developed software FEM HTSG Tool, position and orientation of the strain gauges can be easily determined.

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INTEGRATED VEHICLE DEVELOPMENT AS A KEY TO SUCCESS

The integration of different development methods and the use of new development tools are key factors in vehicle development. For that purpose, AVL has designed a new-generation measuring system that allows development parameters to be measured and analysed while the vehicle is being driven on the road. The mobile instruments of AVL Move use the same measuring principles as test bed devices.

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TASK

The new methodology represents a combination of results from virtual and real environments. The virtual world of simulation is based on a physical modelling approach for the vehicle components and takes boundary conditions such as ambient conditions and driver behaviour into account.

This article describes new possibilities of integrating vehicle testing and simulation data. The areas of application range from the variation of different single components to the variation of different vehicle types.

COMPONENTS OF THE METHODOLOGY

The key components in this new approach are the instruments of AVL Move and AVL InMotion, a tool for manoeuvre-based simulation. AVL InMotion was developed in cooperation with IPG, ❶. The AVL Move system provides a fully integrated mobile measuring solution for all relevant parameters in engine and vehicle development.

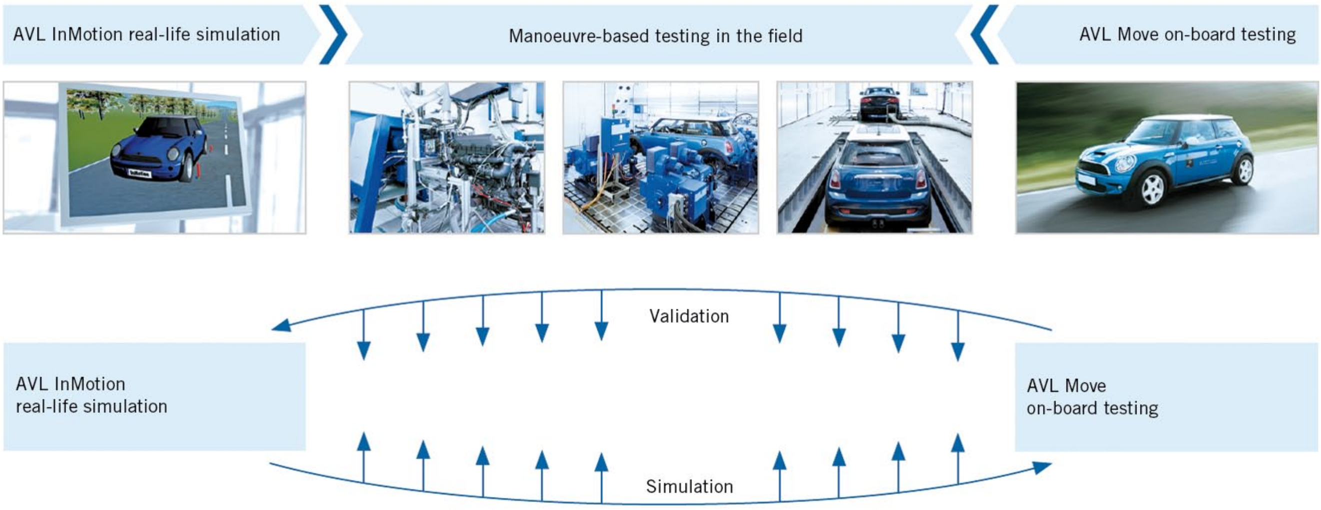
The main focus of Move is on emissions, fuel consumption and combustion parameters. All devices are integrated into a central unit that records the data and controls the devices. This high level of integration and the availability of all measured parameters in one single file simplify the handling of the system, as well as the processing of the data and the exchange of data with other testing environments.

The AVL Move system easily integrates into the bus systems on board a vehicle. It can either operate as a data source for Inca from Etas or integrate data from the vehicle CAN bus systems itself. Powerful data post-processing software allows the evaluation of the test data in combination with video sequences and Google maps in order to account for the effect of the actual driving situation and the ambient conditions on the results.

In order to make a simulation as realistic as possible, it is necessary to model the driver's behaviour, the track and surrounding conditions in combination with the actual vehicle model (including the engine, powertrain, exhaust gas aftertreatment system). AVL InMotion provides an appropriate simulation platform that uses physical models for the individual components of the vehicle. The use of physical models is a prerequisite for the possibility to extrapolate the operating conditions outside the parameterised region, which is required in the development process.

The geometry of the track would be incomplete without a proper description of the surrounding conditions and dynamic events. These can be directly configured in AVL InMotion or automatically imported from the AVL Move measured data used as a reference. This functionality makes it possible to explore nominal, worst and best cases in the simulation phases.

The driver's behaviour is at least as important for the result of a simulation as the actual track and the surrounding conditions. In AVL InMotion, the driver is characterised by the accelerator pedal position, the clutch behaviour, the gear selection, the steering and the braking behaviour. AVL InMotion contains a complete library of functions to describe the behaviour of the human driver as close to reality as possible, from a defensive to a sporty driving style and even following the traffic conditions. A tool for the automated generation of a driver type, based on measured values, is under development.



❶ AVL Real Life Testing approach

AVL InMotion describes the vehicle as a multi-body system. In the given case, AVL Cruise – a simulation tool for vehicle system and driveline analysis – is used to create a detailed model of the powertrain. However, the powertrain is only one component of the vehicle and therefore needs to be extended by additional components (chassis, suspension and tyres). These components strongly influence the longitudinal and transverse vehicle dynamics, and a consideration of their interactions is essential in the simulation. More details on the driver and vehicle model can be found in [1] and [2].

The engine model uses pre-defined components. This allows all types of engines to be designed for different fuel types, EGR variants and boosting concepts. All basic components (filter, cooler, pipes, etc.) are simulated in a thermodynamically correct manner using the mean value assumption.

For the prediction of emissions from the combustion process, a detailed model of the in-cylinder combustion is of central importance. The use of data-driven surrogates is not possible because an extrapolation could not be guaranteed. For this reason, a crank angle-based physical model is used for the combustion and the formation of toxic emissions (focused on nitric oxides).

The modelling of exhaust gas aftertreatment components is based on a transient 1D basic approach. This helps to visualise the most essential characteristic of catalysts in terms of pressure losses, thermal behaviour and the conversion of toxic emissions. Pre-defined components for catalysts (TWC, DOC, SCR etc.) and particulate filters (coated and uncoated) are available.

The models of the vehicle, powertrain and exhaust gas aftertreatment system require detailed parameterisation and validation. The corresponding process is structured in a multi-stage procedure. In the first step, measured values are used for a “stand-alone” parameterisation of the single model components, for example test bed data for the parameterisation of the engine model, light-off data for the parameterisation of the catalyst models and slip data for the parameterisation of the tyre model.

Then, the single model components are linked to an integrated vehicle model. This “raw” model is then further refined

❷ Track in Los Angeles/Riverside, California; representation in Google Maps using chassis dyno data. This has the advantage that, by excluding uncertainties such as the environment, the track and the driving behaviour, qualitative and quantitative verification of the model quality in comparison with reproducible data can be carried out. Details of modelling, parameterisation and validation are described in [3].

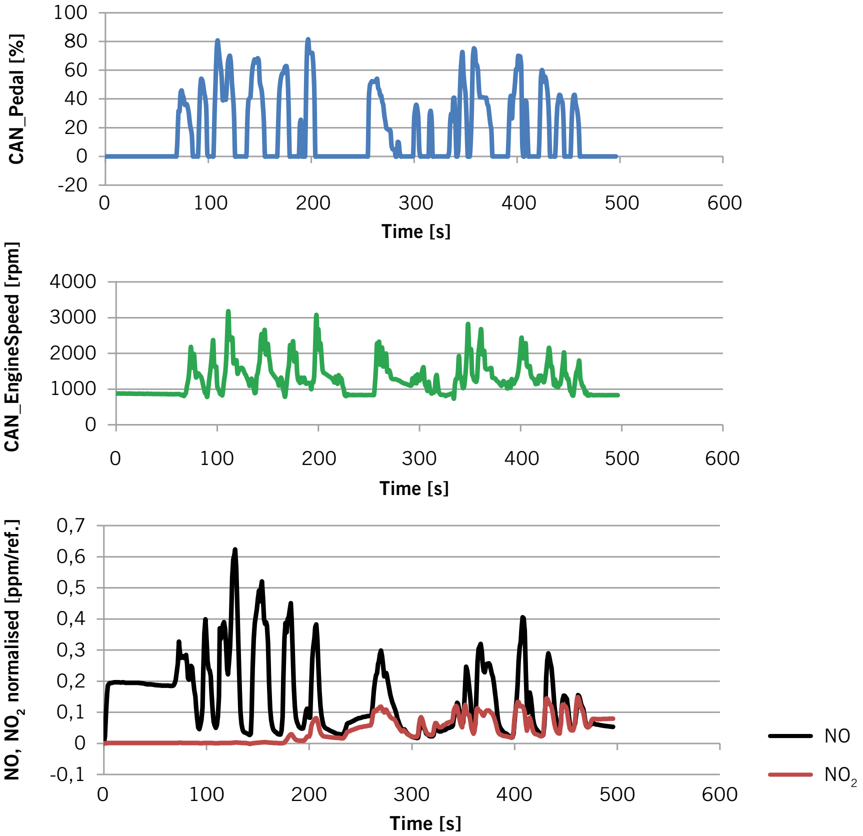
PRACTICAL APPLICATION

The individual steps of this methodology are presented on the basis of a series of test runs in Riverside, California. The AVL Move devices were installed in a VW Jetta (1.6-l TDCI with a DPF, without SCR). The system includes devices for gaseous and particulate emissions, fuel consumption, environmental conditions and GPS position. Additionally, a set of values is recorded from the vehicle's CAN bus.

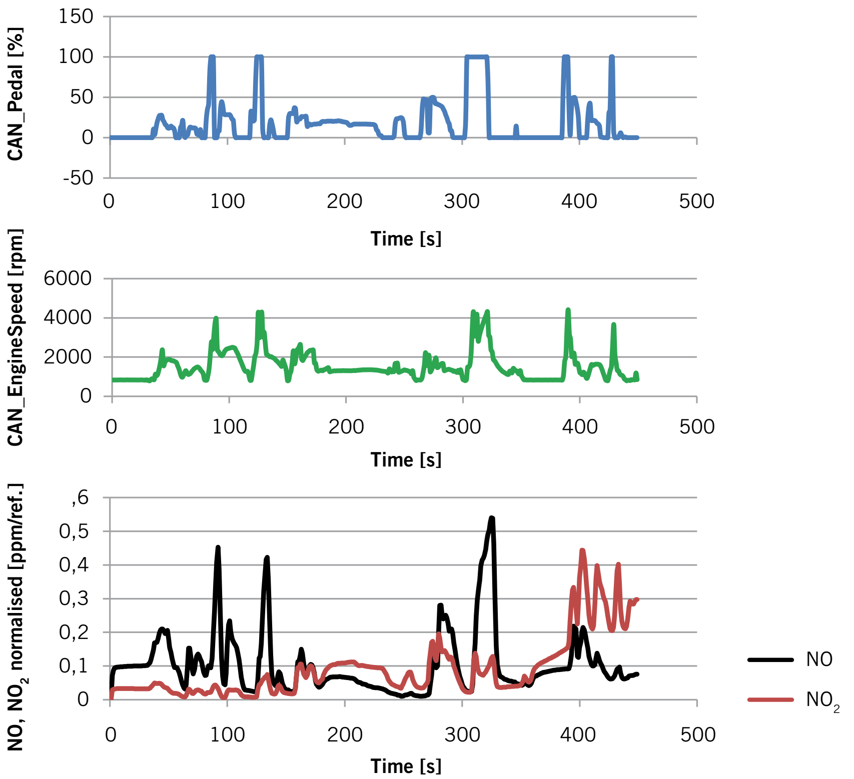
The identical track was driven by 10 different drivers at different times of the day. This ensures that the influence of the environmental conditions (temperature, traffic, traffic lights etc.), as well as of the driver and the vehicle's status (cooling of engine and exhaust system) on the results are reflected in the test results.

❷, ❸ and ❹ show the track and a comparison of the transient NO_x traces for two tests. It is clearly apparent that the influence of the driver and the environment (traffic lights, traffic etc.) does not allow a direct comparison of the data. However, a statistical analysis allows the identification of critical manoeuvres which lead to higher levels of emissions or fuel consumption. ❺ shows the emission result values relative to the average of all ten tests. The trip durations are displayed in the first column.

The carbon dioxide emissions scatter by approximately 30 % around the mean value. This is in good agreement with the common experience of reducing fuel consumption by means of predictive driving. Carbon monoxide and hydrocarbons scatter widely over the test drives. This phenomenon can be assigned to shorter or longer breaks of the vehicle between the test drives. The exhaust aftertreatment system cools down quickly. After approximately one hour, the emissions reach a level close to cold-start emissions again.



❸ Measurement values for pedal position, engine speed and NO/NO_2 emissions; cold vehicle, defensive driving behaviour (Test 2 in ⑤) – note: NO und NO_2 concentrations (ppm) are normalised, the ratio of NO/NO_2 is correctly displayed



❹ Measurement values for pedal position, engine speed and NO/NO_2 emissions; warm vehicle, aggressive driving behaviour (Test 8 in ⑤) – note: NO und NO_2 concentrations (ppm) are normalised, the ratio of NO/NO_2 is correctly displayed

	DURATION	RELATIVE TO AVERAGE (G/KM BASIS)						RATIO
	(s)	CO_2	CO	THC	NO	NO_2	NO_x	NO/NO_2
TEST 1	472	-2 %	low	64 %	13 %	-22 %	0 %	2.28
TEST 2	496	26 %	341 %	297 %	25 %	-52 %	-5 %	4.07
TEST 3	454	-31 %	6 %	-21 %	5 %	-33 %	-10 %	2.46
TEST 4	419	-14 %	low	low	19 %	-34 %	-2 %	2.82
TEST 5	382	-11 %	low	low	-12 %	32 %	5 %	1.04
TEST 6	494	-2 %	low	low	-11 %	-28 %	-17 %	1.94
TEST 7	467	2 %	low	low	-8 %	78 %	25 %	0.81
TEST 8	447	11 %	low	low	5 %	13 %	8 %	1.47
TEST 9	492	3 %	-57 %	-53 %	-26 %	2 %	-15 %	1.14
TEST 10	465	18 %	30 %	-53 %	-10 %	43 %	10 %	0.99

❺ Comparison of emissions results for ten different tests. The emission results are presented relative to the average of all ten tests on a g/km basis

Generally, the CO and HC emissions are very low after the catalyst has reached the light-off temperature (marked with "low"). The scattering of NO and NO_2 emissions around the mean value is high and is mainly influenced by the driver. Aggressive driving behaviour immediately results in higher levels for CO_2 and NO_x emissions.

It can be seen that the ratio of NO and NO_2 varies significantly. For some tests, the emissions of NO_2 are even higher than those of NO. The underlying reasons are not obvious using the available data. Here, an even more detailed investigation with additional sensors in the exhaust system would be required.

A detailed comparison of the vehicle test data with simulation results is performed for test 2, for which the conditions were close to a cold start. Good agreement was achieved for all relevant parameters, NO_x [g/km] was 4 % accurate. A similar quality of the comparison could be achieved for tests 6 and 8. The very high level of accuracy is a key for making the presented technology an intrinsic element of the future vehicle development process.

The new possibilities range from the variation of different single components (powertrain, gearbox and engine) to the variation of different vehicle types. Different legislative emission scenarios can be simulated by a variation of the EGR strategy and the exhaust gas cooler without the need to have real components. This list could be extended with more examples. The key idea behind this approach is that the adjustment with real measured data delivers a high level of validity of the simulation results. Hence, the simulation models can already be used in early development process stages and deliver high-quality results without vehicle tests. The flexibility and high measurement accuracy of the AVL Move system support this approach in an optimum way. In addition to this application, the Move measuring system is already being used in in-vehicle emission testing for legislative purposes as well as in the field of vehicle application.

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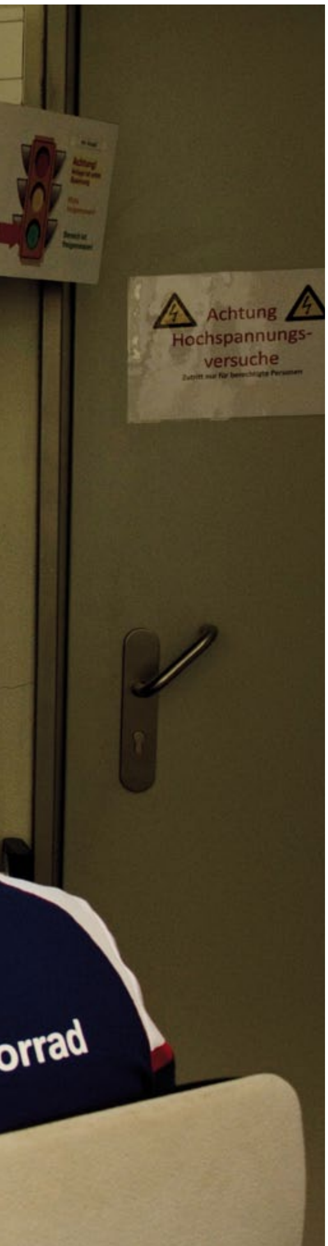
TESTING TECHNOLOGY FOR THE DEVELOPMENT OF ELECTROMOBILITY AT BMW MOTORRAD

The development of such a groundbreaking vehicle requires an innovative test field. In just eighteen months, BMW Motorrad had set up rigs for testing and safeguarding the properties of electric drive systems. These test facilities were designed from the bottom up for the specific requirements of single track vehicles. They also integrate the knowhow gained from the BMW Group Project i and the development of the KERS (kinetic energy recovery system) for the 2009 season BMW Formula 1 vehicle.



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ELECTROMOBILITY WITH SCOOTERS

The topic electromobility is a key constituent of the BMW Group corporate strategy. For BMW Motorrad, a scooter with outstanding riding properties is the ideal segment for the launch of a purely electrically powered vehicle.

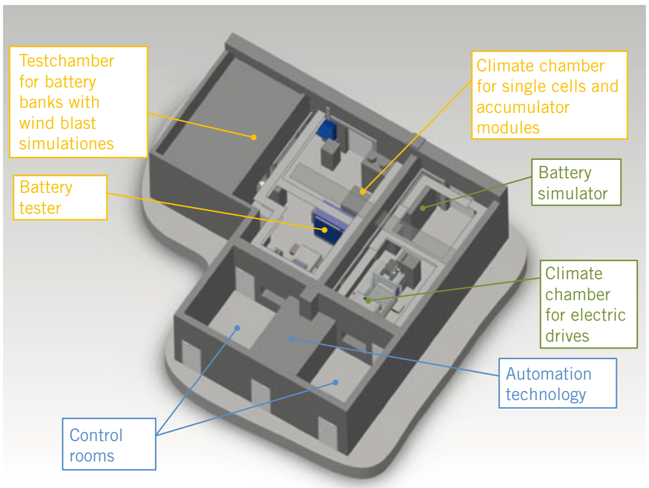
One fundamental requirement for the test field is to allow simultaneous testing on key system components – for example drive unit with power electronics, storage cells, battery bank, traction drive – thereby minimising development times. BMW Motorrad gives top priority to the implementation of all of the vehicle's safety scopes and functions according to the state-of-the-art and the pertinent standards.

Issue 3/2012 of ATZ explained the application of ECE R100 and ISO 6469 for high-voltage safety and of ISO 26262 for operational safety. The technical properties derived from these should allow their examination on both the component level and in the partial and overall system. This also demands for example the simulation of riding manoeuvres and fault conditions. In addition, the rig must depict climatic ambient conditions in the ranges relevant to single track vehicles, ❶.

E DRIVE TEST RIG

The E drive rig tests the electric machine and the power electronics. The typical tests include:
: characterising traction drives by determining characteristic maps, measuring performance and efficiency, etc.
: recording thermal properties
: parameterising machine controllers
: performing continuous runs
: performing test runs for developing functions
: supplying data to controllers.

The mechanical loads on the test object are applied by an asynchronous machine with a continuous output of 120 kW. The link takes the form of a shaft with zero backlash elastomer couplings. The fatigue endurance test can make use of a configurable toothed belt attachment that simulates the radial loads on the electric machine's bearings induced by the drive forces and belt tension.



❶ View of the E drive and accumulator test rig

❷ Electric machine and power electronics in the climate chamber on the E drive test rig

The electric drive is supplied with power from a battery simulator. The design delivering 120 kVA/600 V DC/ 600 A allows the simulation of a wide range of battery banks. The dynamic properties of this dc source can be set at a battery model.

A user programmable real time simulation system is used to actuate the power electronics and for the rest bus simulation. In conjunction with vehicle controllers, this system can be used to simulate riding manoeuvres, ❷.

The electric machine and power electronics are installed in a climate chamber that simulates a range of environmental conditions. Here the air temperature can be regulated from -10 to +85 °C, and the relative air humidity from 10 % to 95 %. The coolant for the test object can be conditioned to a temperature of -10 to +120 °C.

ACCUMULATOR TEST RIG

The accumulator test rig is used to analyse complete high-voltage accumulators, accumulator modules, individual cells, and battery management systems. The typical tests include:
: determining the parameters
: determining the available electric power outputs
: determining the self discharge rates
: investigating the thermal properties
: conducting life tests
: developing functions (balancing, degrading, calculating SOCs, etc.)
: developing and testing safety functions
: supplying data to battery management systems.

Tests on complete battery banks use a device delivering a power output of 150 kW. The max voltage is 800 V DC, the max current 600 A. A real time system simulates communication and interaction with the power electronics. The accumulator test rig can also take a drive unit with power electronics that can optionally be connected to a 120 kW asynchronous machine.

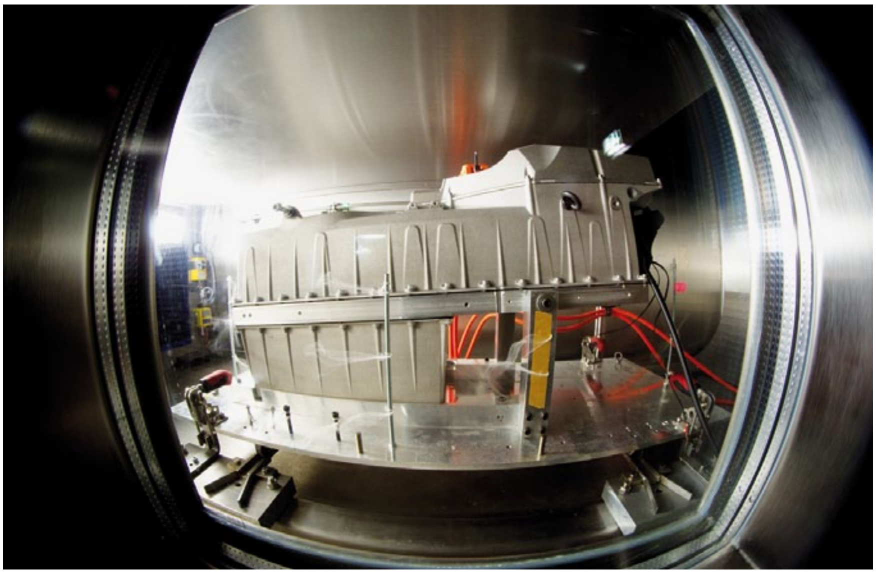
Measurements of each cell voltage and temperature are taken by a data logger that can record up to 216 channels simultaneously. All measured values are recorded with a jitter under 1 µs and a max scanning rate of 1 kHz. The inputs are electrically insulated from each other, and the insulation strength between the channels and earth is 800 V.

The thermal behaviour of the high-voltage accumulator is of key importance. The simulation of various climatic ambient conditions on the test rig is therefore an elementary constituent of the tests. In contrast to the conventional solutions on the passenger car and utility vehicle sectors, air cooled accumulators are also a potential candidate for single track vehicles owing to their space restrictions and weight. The test environment must therefore fulfil the following functional requirements:
: dynamic regulation of the air mass flow through the test object (wind blast simulation)
: high regulating precision for temperature and humidity in both stationary mode and dynamic wind blast simulations.

Also the safety features must fulfil the following:
: tests must be possible in an inert gas atmosphere
: suitable sensors for detecting damage
: firefighting equipment for the test chamber, ❸
: safe disconnection of live wires, even under high current loads.

In order to fulfil these requirements, BMW Motorrad has set up an "accumulator wind tunnel" fitted with an extensive range of safety equipment. In the tunnel's plenum chamber, the flow of air can far exceed 160 km/h. The air mass flow can be accelerated from 0 to 100 km/h in 3.5 s, and braked to 0 km/h in another 3.5 s. Any riding cycle can therefore be simulated realistically when the battery tester draws power from the high-voltage accumulator at predefined intervals in time, ❹.

❸ Test chamber for battery banks



❹ High-voltage accumulator in the "accumulator wind tunnel"

The air temperature can be regulated within the relevant ambient temperature range from -10 to +50 °C, and the relative air humidity from 10 to 95 %.

Nitrogen can be introduced to the whole "accumulator wind tunnel" for an inert gas atmosphere. At the same time, the residual oxygen in the air flow is monitored continuously. A number of spray nozzles are arranged in the test chamber. Spraying water can simulate rides in the rain or in freezing conditions. The required insulation resistances and the temperature distribution over the entire battery bank can therefore be examined even under the most demanding environmental conditions.

The early detection of damage is ensured by a fitted smoke extractor. When an alarm is triggered, the installation is shut down immediately and the test chamber inerted. A spray extinguisher is fitted as a firefighting measure.

A separate climatic test cabinet is used for testing single cells and modules. The "accumulator wind tunnel", ④, is therefore free for short term tests. The temperature control range for this test chamber has been set to -10 to 120 °C, suitable for examining the self discharge rate of cells at high temperatures. Here too, tests can be conducted in an inert gas atmosphere (with fitted spray extinguisher).

A specially designed tester draws power from the tested individual cells and modules. With a power output of 30 kW, this system can be configured for voltages up to 60 V DC and currents up to 500 A.

TESTING THE ENTIRE SYSTEM ON THE INTEGRATION TEST RIG

The E drive and accumulator test rigs can be interconnected for integration tests. In this arrangement, all components of the electric drive system can be set up and operated as a group without the need for a vehicle. This saves time and costs. The test rig also allows the development engineers at BMW Motorrad to define test cycles and riding manoeuvres as they wish and to reproduce these exactly. In doing so, they can specify environmental effects over a wide front – from the Elephant Rally to Death Valley – and modify these at the push of a button. This reproduces reliably an extensive range irrespectively of the season or weather.

TESTING THE VEHICLE ON THE ROLLER TEST RIG

For tests on the entire vehicle, roller test rigs for continuous runs and a roller test rig for functions were fitted with electric power filling stations. The automated switchover between riding and loading cycles makes unattended operations possible.

Accelerated continuous test profiles serve to verify the mechanical strength of drive components. As a measure to save time charging the battery bank, a battery simulator can be used here too to simulate the high-voltage supply. In this configuration, a real time system simulates the battery management system.

SUMMARY

If we are to respond quickly to market requirements and new technologies, we must be able to pursue and safeguard various lines of development work simultaneously. So that it can continue fulfilling these requirements, BMW Motorrad has set up a new electric test rig at the heart of its development centre in Munich. Modular test facilities and extensive simulation technologies allow engineers to process under the one roof all stations of system integration and verification – whether functional tests on single elements, component tests on modules, system tests on complex partial systems, or integration tests on the entire drive system. With its new E test rig, BMW Motorrad can now make use of another flexible tool for the scheduled development of innovative products on the highest quality level.

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INTELLIGENT SEAT CONTROL FOR ADJUSTING TO THE COURSE OF THE ROAD

SmartFit is an innovative control system for seats through which the driver's seat position can be determined and adjusted. In the near future, the system developed by Faurecia can even consider severe road curves by activating the side bolsters.

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FATIGUE-PROOF SEAT ADJUSTMENT

In an effort to advance future business models based on apps, Faurecia has developed a promising application with its smartphone based system for optimal seat adjustment. The purpose of this system is a health promoting and fatigue-proof seat adjustment in addition to utmost comfort and easy operation. It has initially been developed for the front seats of luxury vehicles, but it can also be integrated in second row seats without a problem. Tentatively, SmartFit will be available in 2014 or 2015. Faurecia develops and produces the entire system.

Fundamentally, the SmartFit system is a seat-based electronic control unit (ECU). Depending on the seat functions and to minimise cables, it is installed either beneath the seat cushion or in the back of the seat. The ECU is configured similar to the existing ECU's currently installed in vehicles.

The major difference is that the ECU by Faurecia is able to perform numerous seat functions, ❶. To achieve this, it accesses a cloud-based database with the aid of a smartphone and generates the ideal seat adjustment based on an algorithm. The system can be expanded to two ECU's. One controls the pneumatic comfort system and the other controls the central heat and air (seat heating and ventilation).

SCALABILITY AND MODULARITY

The ECUs communicate through LIN or CAN. The data exchange with the automobile electronics is achieved via CAN or Bluetooth. Faurecia is able to provide a modular and scalable system with a cost effective functional range using this approach. The entire system is based on a complicated comfort and ergonomic algorithm and an additional control app. Other functions include electric and pneumatic heat- and ventilation adjustment options.

It is designed for easy operation. In an initial process, the user creates a digital image of his body with the aid of the app on his smartphone. The default settings are created based on this data. If the driver or passenger sits in the seat, the pneumatic system automatically fine-tunes the conditions. The seated party can adjust the seat heating and ventilation manually.

The prerequisites for using the system are a standard seat with electric seat regulator. The ECU also controls up to 24 electric motors installed in the seat. The pneumatic comfort system as well as the heating- and ventilation system is controlled by the same ECU as well.

Initially, the gross seat adjustments are calculated. This includes the seat distance from the steering wheel, the seat's back inclination and height as well as the inclination of the seat cushion. In order to gather the required data, the body measurements are recorded with a smartphone based interface.

While the information regarding gender, height, and weight are entered manually, the distances from the head to the lower back, lower back to knees and knees to heel are assigned by an image created with the smartphone. The measurements, ❷, can be drawn on the touch screen. The arm-length is designated by using the acceleration sensor on the

❶ In addition to the automatic settings for seat comfort, all settings can be adjusted manually

❷ SmartFit considers six different angles and twelve different lengths and distances to calculate the optimal seat position

smartphone and swinging the phone up and down several times with an outstretched arm. The digital model created hereby is combined with the anthropomorphic data stored in the cloud.

MATRIX DATABASE FOR EMPIRICAL VALUES

A specially developed algorithm calculates the optimal seat position based on the vehicle-specific data. Thereafter the seat coordination is transferred to the smartphone and sent to the seat's ECU, ❸, in order to execute the seat adjustment. Upon completion the automatic fine-tuning where the seat contour is adapted to the drivers or passengers individual body type is performed.

A pneumatic system enables the adjustment of the lumbar support, side bolsters and seat/back hardness. Various pressure sensors defining the body measurements of the seated party are installed in the seat to achieve this. The data is then compared with the anthropomorphic data over the smartphone and the algorithmic results are sent to the ECU in the seat.

A special algorithm combined with an extensive database containing the anthropomorphic data is behind the entire setting. Both are stored on a cloud-based Faurecia server. The database consists of datasets containing all of the empirical values gathered for the ergonomically correct and comfortable seat position for every body type. The databases special feature is the fact that it is not a linear but rather a multi-dimensional matrix database, which enables the creation of countless dataset combinations.

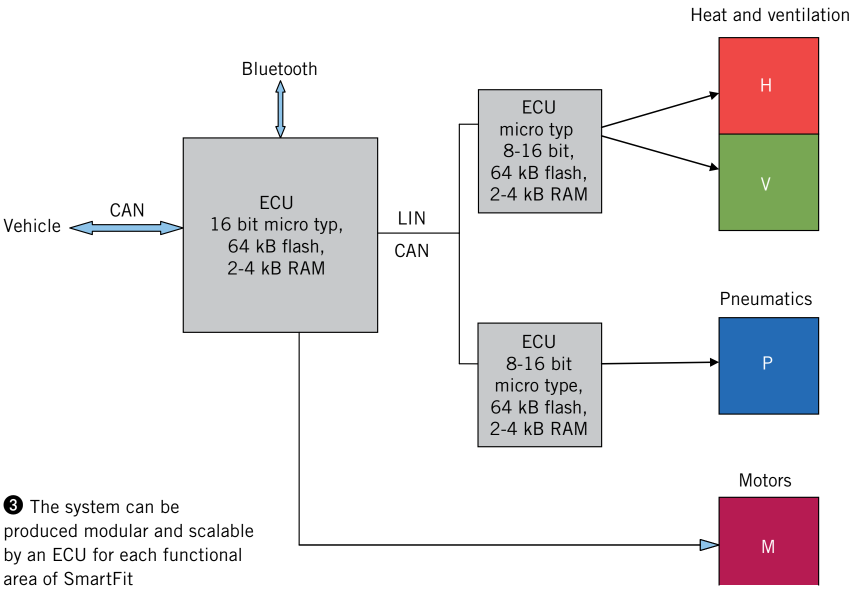
The algorithm combines the data of the seated party and the database for optimal seat configuration. The data recorded in the smartphone and the pressure sensors in the seat is transferred to the algorithm as an input vector by W-Lan. In the second step, the algorithm accesses the data in the comfort database locally and determines the correct seat position. This is then transferred through the smartphone to the seat's ECU as an output vector, which initiates the electric motor motion in the seat. The adjustment is completed within seconds. A manual individual adjustment can also be performed at any time. The system "learns" any changes made by the driver.

VEHICLE ADJUSTMENT THROUGH DATA TRANSFORMATION

The various seat and seat- or vehicle surrounding represented a big challenge during product development: The same type of seat requires different output data in the event it is installed in different vehicle if the steering wheel and seat rails are positioned differently, for instance. Vice versa, a different seat in the same vehicle requires different default data for different adjustment mechanisms.

In order to determine the optimal seat position in these cases as well, the data for the seat- and the vehicle conditions are required. Only then can the settings be properly adjusted to accommodate the respective vehicle and seat type. All of the in-and-output vector data for a specific seat and the environment is transformed thereafter.

In order to ensure compatibility with the systems of the leading automotive manufacturers, standard programmes are utilised for programming. This also serves for minimising the automotive manufacturer's effort of integrating the system. C and C++ are the programming languages used for programming the seat adjustments. The key algorithm is programmed in Matlab, Simulink and State Flow Base. The smartphone apps



❸ The system can be produced modular and scalable by an ECU for each functional area of SmartFit

❹ GPS and other data recorded by the vehicle and smartphone can be processed in order to adjust the seat to the driving conditions at any time

❺ When the driver sits down the pressure sensor immediately determines which pneumatic cushion has too much (red), too little (yellow) and right (green) air filling

are created in the software language Java. The control units use software standards Misra (Motor Industry Software Reliability Association) and the ISO standard ISO 26262.

SEAT DATA IS SENT WITH AN ENCRYPTION

Security is of course a decisive factor during system development [1, 2]. Usually the safety and security standards have been predefined by the automobile manufacturers. The entire SmartFit system is protected by a system firewall in the prototypes. A password requirement prevents unauthorised access.

A Faurecia encrypted algorithm is used for the source and code system. The safety protocol developed especially for this purpose protects the information flow between the seat, smartphone and the database. All data is processed though a central gateway. There it is coded and/or decoded to be sent to the ECU or the cloud database.

The seat and the smartphone interact through a fully qualified Bluetooth 2.0 interface including the Compliance Standards EDR (Enhanced Data Rate), CE (Conformite Europeene) and FCC (Federal Communications Commission). In the SmartFit prototypes, the smartphone is still connected with the Bluetooth interface of ECU in the seat. The connectivity to the seat only takes approximately one second. The alternative would be a connection through a centralised Bluetooth interface provided by the vehicle, which also enables the communication of all other devices present in the vehicle.

Currently Bluetooth is the preferred interface. However, other interfaces are tested during development. A final decision will be made in collaboration with the automotive manufacturers. This includes the selection of the smartphone model and the protocol to achieve the connection to the vehicle. In comparison to the overall system, the changes made to the communication protocol with the smartphones are minor.

THE EXPANSION: GPS-CONTROLLED SEAT SYSTEM

Based on the SmartFit platform, Faurecia has expanded the system by two applications, GPSFit and MicroFit. The functional expansion GPSFit, ❹, combines the information of the original SmartFit system with the GPS data of street type, vehicle speed and environmental conditions. The data is provided by the car and an additional smartphone app. The system upgrade adjusts the seat position in a dynamic and prudent manner to achieve the best possible driving experience.

The necessary street and speed data are provided by the GPS vehicle's system. The smartphone app determines short-term traffic problems, if an inclement weather warning has been issued or other factors influencing the driving condition on the road. In these cases, the seat function automatically re-calibrates to accommodate the changing conditions. For example, if a tight right curve approaches the left side bolsters are adjusted to a harder level to keep the driver in the seat by providing additional side stability.

The second application, MircroFit, controls the pneumatic seat system, ❺. It provides comfort and support, which is not offered by just roughly moving the seat. While SmartFit initially calibrates the seat cushion height, the back of the seat, the reclining position, and the tracking, the upgrade uses the pneumatic system to adjust the pressure standard. This does not require the installation of technical details because the existing resources can be used.

The various pressure levels a passenger's body applies to the seat surface are measured by the sensors in the pneumatic system. These sensors are installed on the five bubbles in the back of the seat and two bubbles on the seat cushion. The system expansion reads the various pressure standards and automatically balances the pneumatic system by adding pressure where the pressure is low and vice versa. Compared to the original version, additional measurements are now conducted per second and the seat continuously adapts, the comfort level of the seat is improved, not only based on the driver's height but also based on the weight distribution.

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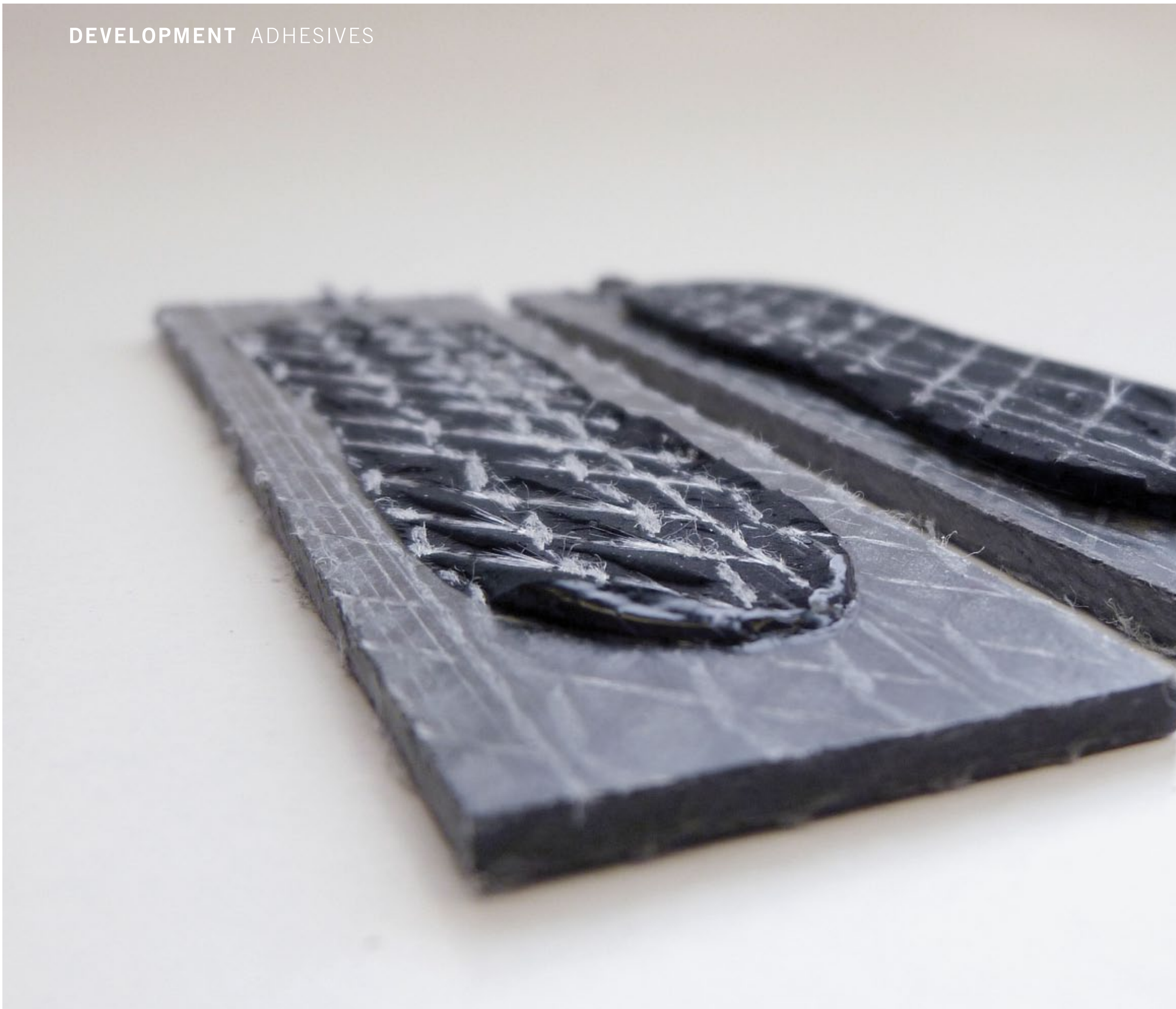

RAPID-CURING ADHESIVES FOR FIBRE-REINFORCED COMPOSITES

The trend in the development of vehicles with hybrid or electric drives confronts the automotive industry with new challenges. Electric vehicles require lighter materials than conventional automobiles. To enable these materials, such as glass or carbon fibre reinforced plastics, to be integrated in the vehicle structure, automobile manufacturers require high-performance adhesives that cure rapidly while at the same time offering easy application and processability. Henkel develops adhesives to meet these requirements.

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REQUIREMENTS FOR ELECTRO AND HYBRID-DRIVEN VEHICLES

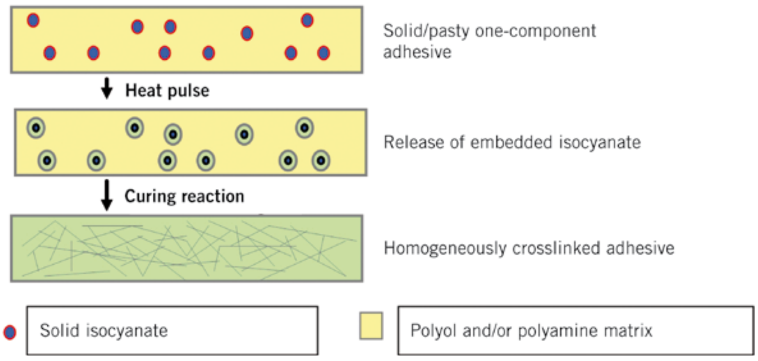
Destined to become more widespread in future vehicle generations, hybrid or electric drives, together with their requisite energy storage units, weigh more than conventional internal combustion engines. Therefore, all other components of the vehicle need to be made even lighter to keep overall weight at an acceptable level thus maximising the travel range. Lightweight construction concepts based on a material mix comprising various substrates provide a solution here. For design and structural elements, fibre reinforced composites are particularly suitable. They offer strength values equivalent to those of steel while having a fraction of its weight.

ADVANTAGES OF ADHESIVES IN JOINING DISPARATE MATERIALS

Good bonding is crucial to the durability of composites comprised of different component substrates. Adhesives offer the advantage of being able to join materials over their interfacial area, thus allowing the properties of the elements to be optimally utilised in the same way as it is already successfully practiced with exclusively steel structures. Moreover, adhesives allow fibre-reinforced materials to be joined without damaging the fibres or the resin matrix, unlike in case of mechanical joining techniques. Damage to the fibres in particular means a reduction in the isotropic material properties and leads to the occurrence of weak points in the overall assembly.

FLEXIBILITY, STRENGTH AND ADHESION PROPERTIES

Adhesives can perform structural, stiffening, insulating, acoustic-damping or sealing functions, or offer a combination of such properties. When it comes to joining different materials such as plastics with steel or the light metals aluminium and magne-



❶ Schematic representation of the WarmCure curing reaction

sium, the different degrees of expansion and contraction that take place between the mating parts in response to temperature change are of particular significance. The properties of the adhesive therefore need to be aligned not only to surfaces, applications and loading patterns involved, but also to the physical properties of the materials themselves in order to guarantee a stable joint. Sufficient elasticity combined with high strength and optimum adhesion properties are the key to achieving successful structural bonds. Stress relief between the mating materials, achieved through adhesive elasticities in excess of 100 %, is a particularly important factor in this regard. The electrical insulation of carbon fibre reinforced plastics from metals is another relevant aspect due to the need of eliminating galvanic elements from the structure thus permanently precluding corrosion.

TWO-PACK VERSUS SINGLE-COMPONENT ADHESIVES

Up to now, two-component polyurethane adhesives that cure at room temperature were primarily used for the bonding of composite components. More user-friendly single-component products either cure too slowly or require temperatures far beyond the damage limit for the substrates. Additionally, there are often differing thermal expansion values of the various substrates. These become an even greater problem with high oven-cure or stoving temperatures and larger components. Adhesives that require temperatures below 100 °C to fully cure can alleviate the situation. As no in-plant mixing of components is necessary, single-component adhesives are cheaper as well as easier and safer to use in terms of the application technology required. This also eliminates a source of error.

FAST AND SECURE BONDING

The WarmCure technology used in the Terolan product range provides a solution here. This is a family of single-component isocyanate-based adhesives and sealants that quickly and effectively cure at temperatures below 100 °C. The key is a special kind of reversible deactivation of the curing agent. With activation occurring at temperatures above 80 °C, good storage stability of the products at temperatures up to 40 °C is ensured.

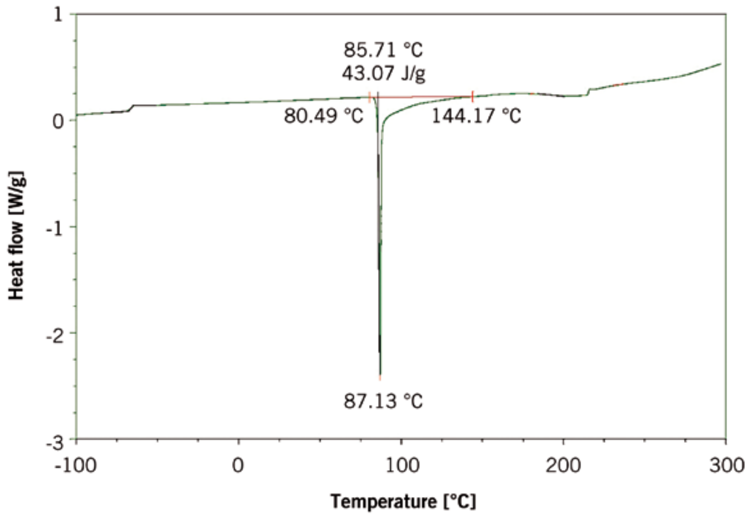
The adhesives and sealants are cured by raising the temperature to deactivate the integral capsules containing the curing agent. Cross-linking commences immediately and completes in a matter of seconds, resulting in a thorough curing process irrespective of the level of ambient moisture present. Below this temperature threshold, the adhesives offer an almost unlimited shelf life. ❶ shows the schematic representation of the curing reaction.

Based on this technology, a range of Terolan products was developed offering various mechanical bonding properties, ❷, from very soft and flexible sealants with very high elongation values of up to 400 % to structural adhesives with tear strengths of up to 12 MPa and an ultimate elongation value of 120 %. Terolan 1510 is particularly suited to the bonding of crash-relevant composite components such as B pillars, side members, central tunnels, and also of structural reinforcements in fitted components such as the hood and tailgate. Such applications involve using the adhesive to permanently join composite materials not only together but also to painted steel and aluminium structures.

The product family shows a rapid curing of the adhesive once the reaction temperature has been reached. This can be documented, for example, by means of a series of DSC (Differential Scanning Calorimetry) measurements to reveal the energy balance of the cross-linking reaction: In case of these one-pack adhesives, energy is always released. An extremely fast-curing product is shown in the test record, ❸. Here, the onset temperature lies at 80 °C, rising to a maximum of 87 °C. The narrow peak gives evidence of the high reaction rate.

PRODUCT	REACTION TEMPERATURE	TENSILE STRENGTH	ELONGATION AT BREAK	CHARACTERISTIC
Terolan 1102	85 °C	4 MPa	250 %	Standard
Terolan 1104	100 °C	3 MPa	400 %	Low-viscous, high elasticity
Terolan 1106	90 °C	5 MPa	150 %	Capable of bonding many plastics
Terolan 1510	85 °C	12 MPa	120 %	High-strength, fast curing

❷ Products available on the basis of WarmCure technology



❸ DSC test of a Warm-Cure adhesive

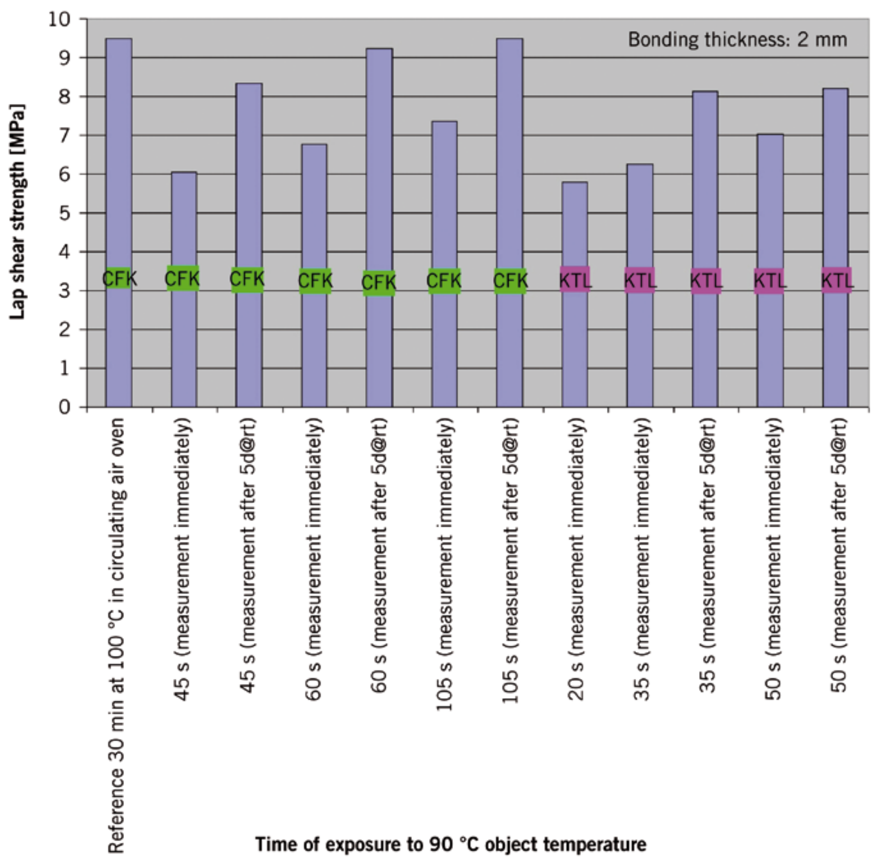
Due to their limited heat resistance/thermal shape stability, composite materials currently available cannot be used in processes characterised by temperatures that can rise to up to 210 °C. With the new technology, however, low-temperature processes and processes with, for example, warming stations, can be incorporated within innovative vehicle production lines. Tensile shear tests prove the fact that "bond on command" is now also achievable. ❹ shows a series of characteristic tensile shear strength values following extremely short oven-cure cycles. The tests were based on two substrate combinations: CRP-CRP (carbon reinforced plastics) and CIP-CIP (cathodic immersion painted steel sheet). The left bar shows the reference value achievable following complete curing in a circulating air oven. In case of the CRP-CRP bond, over 60 % of the maximum achievable tensile shear strength was achieved after just 45 s of curing time, rising to 70 % after 60 s. The system subsequently undergoes final curing at room temperature and, after five days, reaches the strength of the fully cured reference system. With CIP steel sheet, the behaviour observed is comparable, albeit the strength values remain at a lower level due to the lower stiffness of the steel.

A further relevant property of polyurethane systems is their glass transition temperature (Tg), the exceedance of which leads to massive changes in material properties. For the designer, it is therefore important that this temperature lies outside the envisaged working range of the component and that the mechanical properties are rendered as constant as possible. The products presented here react accordingly. Their Tg lies between -40 °C and -60 °C, which means that the products are in the elastic state above these temperatures. In the working range up to 90 °C, no further phase transition occurs.

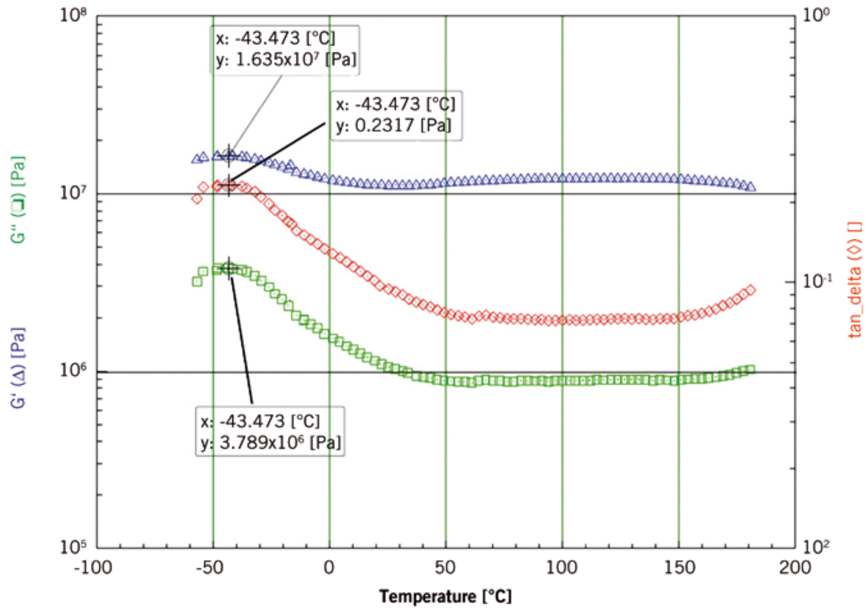
This property can be investigated using dynamic mechanical analysis (DMA). ❺ shows the moduli of a fast curing adhesive (storage modulus and loss modulus, G' and G'') and also their quotient (tan δ). The consistency of readings across a wide temperature range is clearly to be seen.

On principle, it is possible to manufacture adhesives from pliable to high-strength using this technology. Therefore, effectively tailored solutions can be found to all applications from sealing to structural bonding. Components with relatively large dimensional tolerances can also be bonded together to achieve high joint strength values. Depending on the adhesive film thickness, achievable tensile shear values range from approximately 15 MPa at 0.2 mm to not less than 5 MPa even at thicknesses of 7 mm.

Due to the adhesion properties – depending on the plastics used or the quality of the matrix resins employed for the fibre composites, and the internal and external release agents employed – bonds can be produced with complete process reliability without any need to pretreat the materials. Mechanical grind-



❹ Tensile shear strength values as a function of the curing conditions



❺ DMA analysis of a WarmCure adhesive

ing, plasma or flame pretreatment, priming and laser surface preparation can be rendered completely superfluous, provided that compliance with appropriate boundary conditions is guaranteed.

TECHNOLOGY WITH MOISTURE-CURING COMPONENT

A further possibility of meeting the requirements for fast bonding of composite components with one another or with coated or painted metal components offers the so-called DualCure technology. It is a single-component, moisture-curing polyurethane adhesive and sealant family from the Terostat product range which contains a second, temperature-sensitive curing agent. This enables components to be initially tacked together by the adhesive through application of a brief thermal shock above 80 °C. A portion of the adhesive reacts in less than a minute, developing an initial strength of up to 1 MPa. The components are thus securely bonded and sufficiently stable for handling or transportation. As a second curing phase, the moisture-curing component of these polyurethane adhesives reacts over time under normal ambient conditions until the product has reached its final strength. Full cure is achieved at a rate of up to 4 to 5 mm per 24 hours.

If the thermal curing phase is omitted or only partially utilised, for example because component tacking is only desirable at certain points, the product will still moisture-cure completely to its final strength. The available curing properties of the adhesive can be utilised in accordance with process and cycle time requirements to achieve a good result with respect to process cost and prevailing technical/operational requirements. Highly flexible adhesives with elongations of up to 400 % and tensile strengths of up to 7 MPa can be manufactured.

SUMMARY AND OUTLOOK

The technologies presented here offer users of composite materials a broad range of advantages since they require no special plant or equipment and are easy to use. As the products manufactured on the basis of WarmCure technology do not react with atmospheric humidity, they offer very long exposure times/pot lives without skinning. Low reaction temperatures make them suitable for heat-sensitive substrates. The rapid curing process reduces production cycle times and renders intermediate assembly storage unnecessary – characteristics that are essential today for the use of composite materials in automobile production. The variability of these adhesives qualifies them as a multi-use product family suited to the adhesive bonding and sealing of components made from composite materials.

DualCure adhesives are particularly suitable for fast fixing and tacking processes; that means for operations in which temperature-sensitive components need to be initially bonded to a strength which allows them to be handled. The adhesive film then fully cures in the course of the ongoing production process without further measures being required.

Particularly when it comes to using plastics and composite materials in electric vehicles, it is highly likely that it will be adhesives technology that provides the necessary solutions and innovations – because it not only facilitates design and process flexibility in conjunction with a non-invasive joining technique, it also brings to the fore the material-specific benefits of plastics and composite substrates.

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About the Author

He has worked together with international partners to offer numerous seminars preparing students for construction projects abroad.

COST-EFFICIENT HYBRID POWERTRAIN SYSTEM WITH 48 V NETWORK

To meet the twin challenges of global climate change and increasingly stringent legislation, the automotive industry needs to reduce greenhouse gas emissions significantly. As the market will take more than a decade to adopt electric vehicles (EVs), the hybridisation of the thermal engine is one of the most promising ways to reach future CO_2 targets. Valeo's cost-efficient hybrid powertrain, from system analysis to mass production solution, is shwon here.

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BOUNDARY CONDITIONS

Valeo expects that even by 2030, more than 90 % of all vehicles will still be powered either by combustion engines or hybrid powertrains. Hybrid vehicles already available demonstrate significant benefits. Some of them achieve CO_2 emissions lower than 100 g/km without compromising on performance, comfort or cabin space.

However, cost has prevented the mass introduction of complex hybrid systems. Up to now, batteries still represent the major cost item. In Addition, high voltages of up to 600 V currently required by the electric motor generate further costs on both, power electronics and safety devices. To increase market penetration and to obtain significant CO_2 reduction on vehicle fleets, Valeo developed a cost-efficient hybrid approach.

DEVELOPMENT APPROACH

The main objective of the so-called Hybrid4all architecture was to optimise the cost to benefits ratio. For this purpose, four levers were identified:

: optimisation of components: minimised energy storage and electric motor downsizing without compromising fuel efficiency in the relevant test cycle
: standardisation: use of the same parts on various vehicle platforms to reduce cost through volume
: implementation: additional functions for advanced operation modes, such as electric driving mode
: integration: flexibility in installing electric components in different parts of the vehicle, ❶.

The levers were comprehensively studied through simulation using a dedicated physical model and energy management algorithms. Design of experiment (DoE) was performed to rank the solutions on various driving cycles including homologation and real life operation. After simulation analysis and system specification, components were developed and validated. In the final phase of the development process, the cost to CO_2 emissions ratio optimised system was integrated into a vehicle to demonstrate its capability, drivability and performance.

SYSTEM ANALYSIS

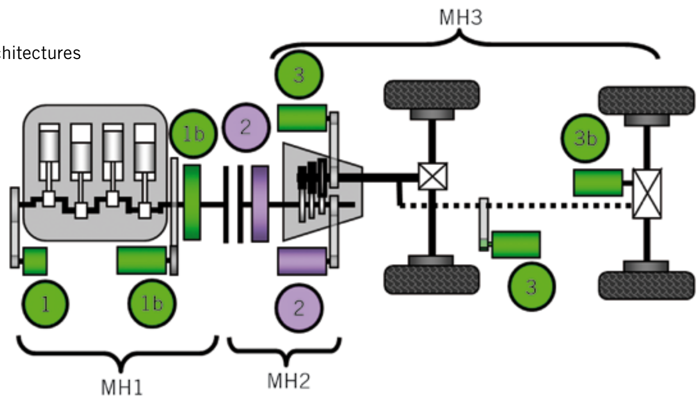
Taking into account the cost versus CO_2 emissions ratio in different mission profiles and adding drivability constraints like duration and availability of the electric mode, the optimal size of the energy storage of a B-segment vehicle was set to a usable energy value of around 200 kJ.

For the electric drivetrain, the optimal component sizing must correspond to the highest power reached at a voltage of less than 60 V in air-cooled conditions. These technological constraints require an electric motor design with a peak power of less than 12 kW, ❷, ensuring a robust pure electric driving mode during vehicle start and steady-state operations.

The belt driven electric drivetrain architecture not only achieves one of the best cost/CO_2 ratios, as it only requires a single electric motor, but it can also be integrated with minimal effort as an add-on solution. Other hybrid architectures need a belt driven machine such as an alternator and a controlled gearbox, the additional components and their integration generating higher costs.

❶ Hybrid electric architectures

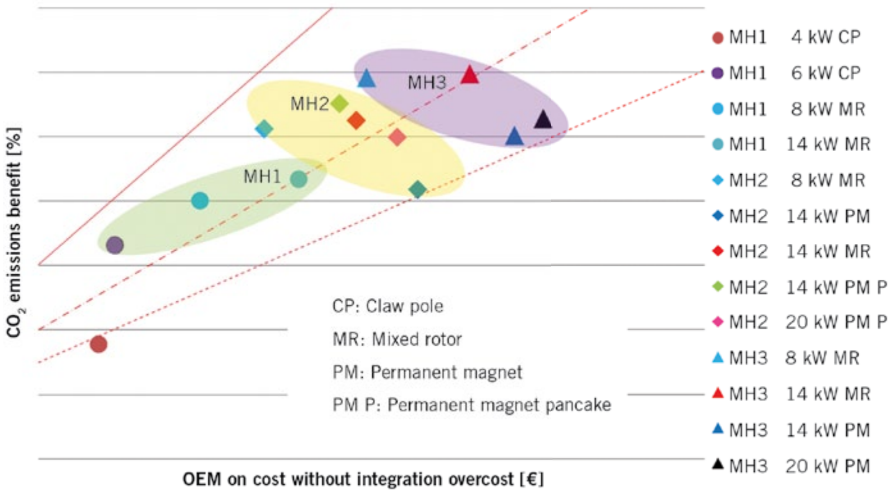
1/1b: E-motor related to internal combustion engine
2: E-motor between internal combustion engine and transmission
3/3b: E-motor behind the transmission



For the advanced hybrid operation, the functions considered were:

- start/stop function including coasting and optimised stop duration in combination with a manual gearbox
- electric mode during vehicle start or constant driving where the energy stored in the battery is sufficient and the power required is within the electric motor capability range
- generation and regenerative braking modes to recover part of the energy delivered by the thermal engine during vehicle driving and deceleration
- torque assist and overboost functions to provide a share of the torque required for vehicle traction or additional torque to powertain during high transients.

Breakdown analysis of these functions was performed by simulations on the New European Drive Cycle (NEDC), ❸. It showed that introducing a pure electric mode leads to additional CO_2 emissions benefits. This mode must be coupled with generation strategies to improve electric energy recovery and the dedicated control of pumping losses by using optimised throttle positioning strategies or cylinder valve deactivation systems.



❷ Mild hybrid solutions ranking by simulation

DEFINITION OF COMPONENTS

Mission profiles show that a power of 12 kW in transient mode (20 s) is sufficient for hybrid functions. These rated powers are not compliant with a 12 V network. However, they are fully compliant with 48 V networks. Below 60 V, safety protections and insulated power networks are not required. In addition, with 48 V, the cell number of the storage unit is less than with 60 V. These improvements help to achieve a very low cost to CO_2 ratio.

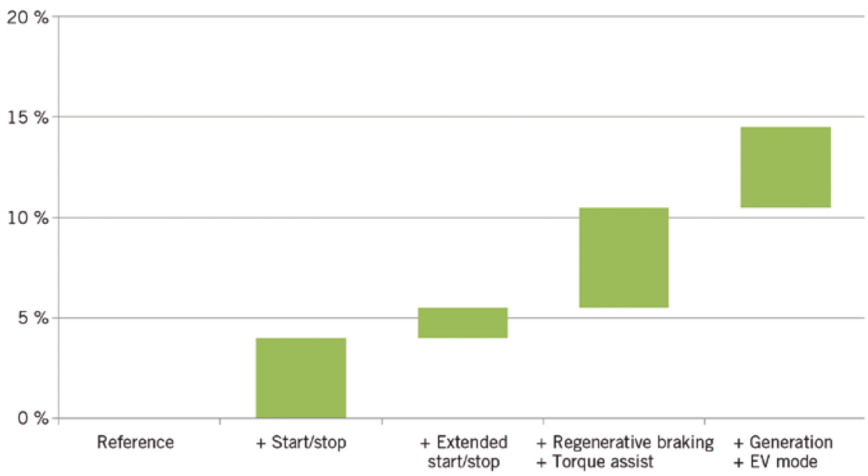
For fast cost-effective vehicle integration, the first generation of the system is a belt driven architecture with standalone components. The electric motor replaces the conventional generator and is controlled by a standalone inverter supplied by a 48 V storage unit via an additional direct current (DC) network. Fixed transmission of the belt sets the maximum speed of the electric motor to 18,000 rpm. A specific belt tensioner was added to guarantee torque transmission over the full speed range. A 48 V/14 V DC/DC converter replaces the conventional generator and supplies the standard 12 V power network. It provides 2.5 kW power with an efficiency of up to 96 %.

Due to the limitations of the belt and Li-ion battery in cold conditions, a conventional starter and low voltage acid battery are retained. The 48 V electric motor covers the start/stop function without impacting the 12 V network. Hence, the electrical architecture, ❹, does not require a voltage stabilising system.

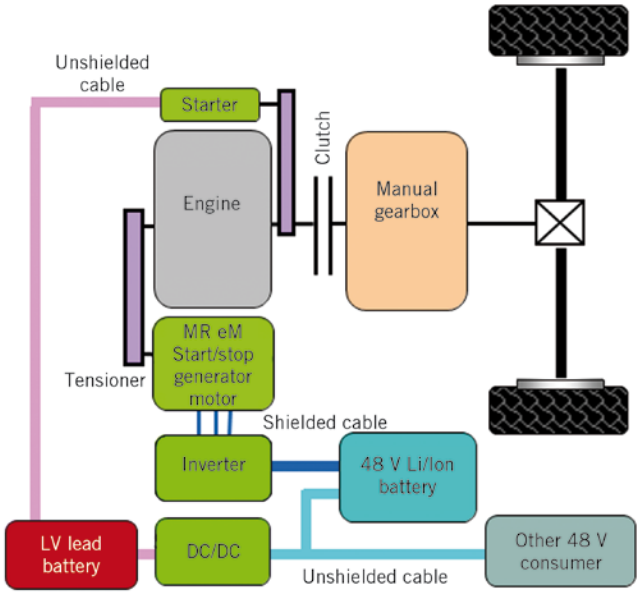
The specifically developed air-cooled electric motor, with an efficiency of higher than 90 % throughout the operating range, provides 12 kW peak power and 55 Nm starting torque to optimise energy recovery. This definition is compliant with all mission profiles and helps to achieve CO_2 targets.

For the 48 V inverter driving the electric motor, a dedicated space vector control was developed to ensure accurate torque control. For the first generation, it is a stand-alone, air-cooled device operating in a voltage range between 35 and 60 V.

The cost of the second generation hybrid architecture will be further reduced by removing wiring and EMC (electromagnetic compatibility) filters, combining the inverter with the electric motor and the DC/DC converter with the Li-ion battery. Further potential saving can be gained by removing the conventional starter and low voltage battery while adapting the belt drive for low temperature starting.



❸ Breakdown simulation of CO_2 benefits on NEDC (B-segment gasoline vehicle)



❹ System architecture of the hybrid concept

sharing or torque support. Additional benefits were demonstrated on turbo lag compensation, using electric motor torque assist at low-end engine speeds.

The main challenge to integrating an electric mode in a belt driven architecture is to obtain a seamless switch between thermal and electric driving modes. This was achieved with dedicated torque control algorithms. As no perceptible noise variation is detected during transitions, driving remains intuitive. Electric mode can be activated depending on vehicle conditions (power requested and available stored energy) not only during running, but also at vehicle start. Using electric vehicle take-off and idling control, drivability is significantly improved while powertrain vibrations are greatly decreased compared to thermal engines. In urban driving conditions, tests showed that the electric driving mode could be used for up to 20 % of driving time, resulting in significant CO_2 emissions reduction.

VEHICLE INTEGRATION AND RESULTS

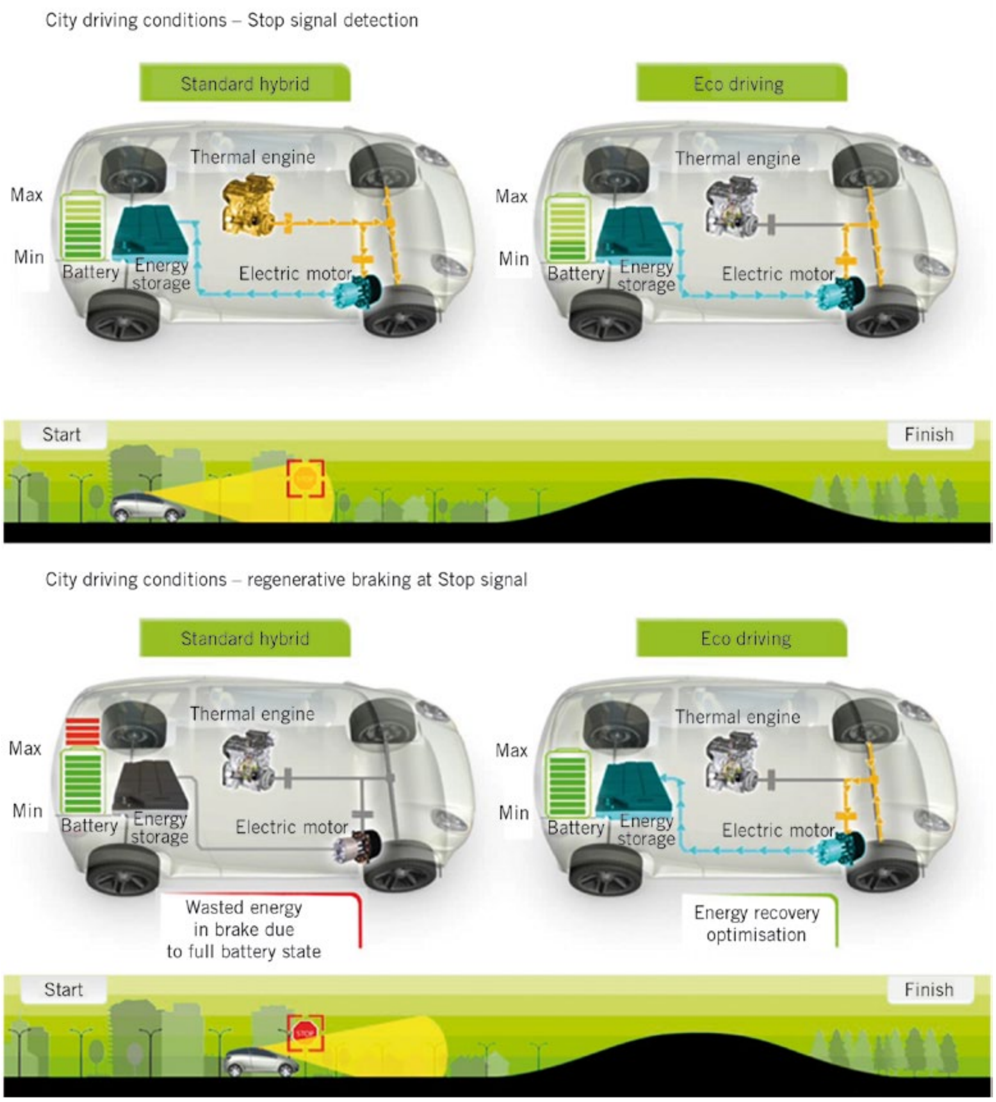
The hybrid architecture was installed on a Peugeot 207 with a 1.6-l turbocharged gasoline direct injection engine, equipped with a manual gearbox, ❺. All previously studied hybrid functions were integrated and validated.

Using a 12 kW belt drive ensures an advanced start/stop functionality compared to a starter or a starter/generator due to the increased starting torque. The combustion engine is directly brought to idle speed without any injection. Using a speed control strategy, cranking is ensured with a very low vibration level. A so-called change-of-mind strategy was also implemented to restart the engine during stalling. Finally, coupling the electric motor to a direct injection system leads to better rail gasoline pressure control during engine starts. Engine stop is also improved using an engine stop assist strategy which decreases engine stop time by up to 70 %. Oscillations are highly limited, and energy is recovered by the electric motor. The coasting function is also improved. With this function, the combustion engine can be stopped at speeds of up to 70 km/h. Torque assist achieves the expected results in terms of CO_2 emissions and vehicle performance through torque

ADDITIONAL PERSPECTIVES THROUGH DATA FUSION

Two major levers of fuel economy are regenerative braking and electric driving. To further lower CO_2 emissions in real life operation, energy management of these two modes can be improved by predicting upcoming road profiles. For instance, anticipating traffic lights, stop signals or descending roads, allow battery charge to be decreased to the minimum level. This ensures that full benefit is derived from regenerative braking, ❻.

❺ System definition and product perimeter on demonstration vehicle



❻ Hybrid operation optimisation through road anticipation

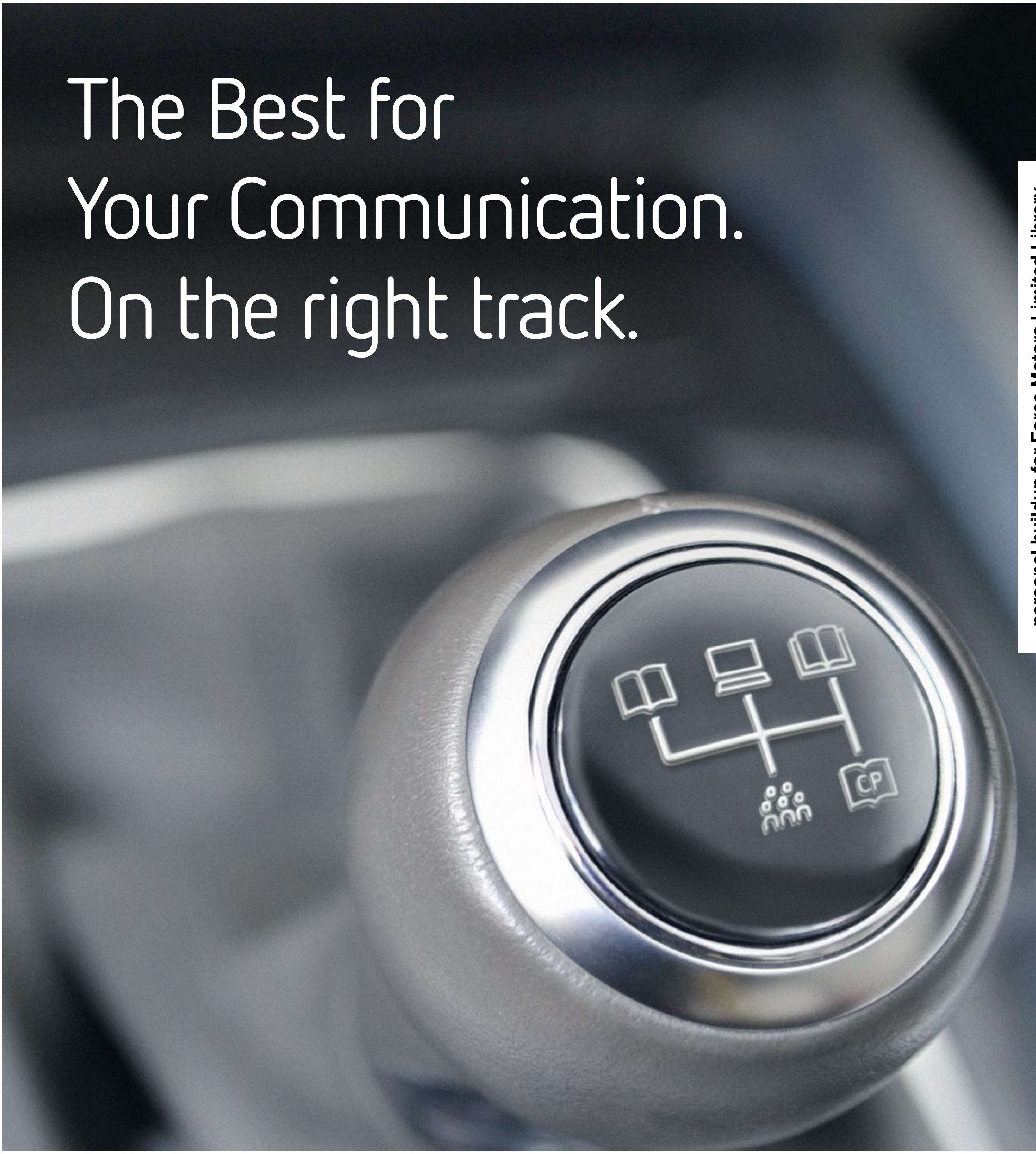
At this stage, no change to the driver's input or autonomous driving is taken into account even if these would be further improvement levers. To predict road profile, information is already available onboard through driving assistance sensors, cameras, GPS and telematics. Data fusion consists of merging all available information to obtain accurate short to long range anticipation of the driving condition.

Road prediction ability was embedded in the powertrain simulation model to investigate and quantify the benefits of hybrid optimisation with data fusion. A simulation study demonstrated two main benefits: additional CO_2 savings from 1 to 5 %, depending on the architecture, driving conditions and the potential cost reduction of components through battery size optimisation. Data fusion was implemented on the test vehicle to validate benefits, to enhance predictability and to develop new functions.

CONCLUSION

Given CO_2 regulations for 2020 and beyond, it is clear that powertrain electrification is no longer only an option. The system architecture presented here is driven by two principles. Firstly, to develop a cost-efficient hybrid architecture by using lower voltage components to reduce battery costs as a main lever. This requires limiting the power of the electric motor. The second consists of leveraging the experience in start/stop micro-hybrid systems to develop cost effective, alternator-based electric motors.

The tests on the demonstration car validate the simulation work illustrating optimised value-to-cost. This represents a major step forward in the new investigation of system optimisation to further reduce costs and CO_2 emissions.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VEHICLE INTEGRATION AND DRIVING CHARACTERISTICS OF THE BMW ACTIVE E

The electric car ActiveE on basis of a BMW 1-Series Coupé is already the second important step taken by the BMW Group to create a mass production electric vehicle. Whereas the first fleet test with the small car Mini E involved research into user behaviour in particular, the objective of ActiveE lies above all in testing the completely new and developed in-house electric drivetrain for the BMW i3 for 2013. Special attention was paid to optimising the driving characteristics of the electric vehicle. A highlight here is the so-called one pedal feeling with only one accelerator pedal.

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INCLUSION OF EXPERIENCE FROM THE MINI

Obtainable as of 2013, the electric vehicle BMW i3 is especially designed for e-mobility (purpose-built). In contrast to the BMW i3 which is based on a so-called Life Drive architecture with CFRP cabin weight-optimised for the electric drive, the ActiveE, ❶ (middle), is still a "conversion" vehicle; in this case, a remanufacturing of the BMW 1-Series Coupé which is optimised for conventional drives. The background to this is the rapid availability of the vehicle for testing the drive, enabling the inclusion of experience from the more than 1000 ActiveE vehicles in the development of the BMW i3.

In addition to describing the vehicle integration of the electric drivetrain, consisting of a high-voltage accumulator, electrical machine, drive electronics, and transmission, this article describes the driving functions and operating strategies enabled by this integration.

DEVELOPMENT OBJECTIVES

A range of 150 km in customer operation was regarded as sufficient following the more than 15 million kilometres driven in the fleet test with the Mini E, ① (left). However, the need for more cabin and luggage space for the customer in particular was recognised [1]. This meant that retaining all four seats used in the BMW 1-Series Coupé and ensuring a substantial luggage compartment capacity (approximately 200 l) had the highest priority from a customer perspective to significantly increase the utility value of the ActiveE compared to the Mini E.

From a strategic perspective, it was decided that the drivetrain of the BMW i3, ① (right), would be developed completely by BMW in-house and (except for the drive electronics) would also be produced by BMW itself. This is another objective of the ActiveE, that means to test the components of the drivetrain of the BMW i3 as thoroughly as possible in advance.

As a result of the higher efficiency of the electric drive and despite an unladen weight that is approximately 350 kg higher, it is possible to fit a high-voltage accumulator with a slightly lower energy content (approximately 28 instead of 29 kWh net energy content) and still achieve the same range as the Mini E. In addition, there has been a switch from air cooling to liquid cooling that also enables heating of the accumulator and ensures full accumulator performance under all environmental conditions. The driving performance objective at 0 to 100 km/h in 9.0 s also takes its orientation from the positive customer experience with the Mini E and can be achieved with the drive (125 kW and 250 Nm) intended for the i3. ❷ provides an overview of the general technical specifications.

VEHICLE INTEGRATION

The electric drivetrain of the ActiveE consists basically of the following three components, whereby their integration into the vehicle is shown in ❸:

Mini E 2009 | BMW ActiveE 2011 | BMW i3 Concept 2013

❶ The BMW Group's path from the Mini E over the BMW ActiveE towards the mass production electric vehicle BMW i3 Concept in 2013

1. lithium-ion high-voltage accumulator
2. electrical machine
3. power electronics.

Whereas it was possible to integrate the electrical machine with the flanged-on drive electronics directly into the rear axle, the high-voltage accumulator had to be split into three parts for integration into the 1-Series Coupé which is optimised for conventional drives (tank, tunnel and bulkhead accumulators). The drive components are described in detail in [2] and ❹ shows the significant extent to which the body platform of the BMW 1-Series Coupé had to be adapted.

FUNCTIONAL INTEGRATION

Prior to integration of the drive [3] into the vehicle, a drive test rig was used to commission the components in the integrated system and validate them. Alongside the static validation of the drive system with the focus on terminal control, startup and sleep characteristics of the control units, establishing vehicle readiness, and charging, the drive was dynamically validated on the test rig.

It was run in the full four-quadrant mode of the electrical machine in all output and rotational-speed ranges. This enabled a significant reduction in the startup time for new software in the vehicle and validated the operational reliability of the integrated system.

CONTROL UNIT FRAMEWORK OF THE DRIVETRAIN

Whereas the component-related functions of the high-voltage accumulator and electrical machine are implemented in the high-voltage control units "Accumulator Management Electronics" and "Drive Electronics", the higher-level coordination of these components, which are decisive for driving characteristics, takes place in the Digital Engine Electronics for Electric Vehicles (eDME). The control units communicate across a CAN bus. The functional structure of eDME originates from the in-house BMW function design kit, which has been specially extended for application in electric vehicles.

Alongside the high-voltage power electronics which optimises distribution of the electrical energy in the vehicle, special attention was paid here to optimising the driving characteristics of the electric vehicle. A highlight here is the so-called one pedal feeling of the accelerator, which shall be described in more detail later.

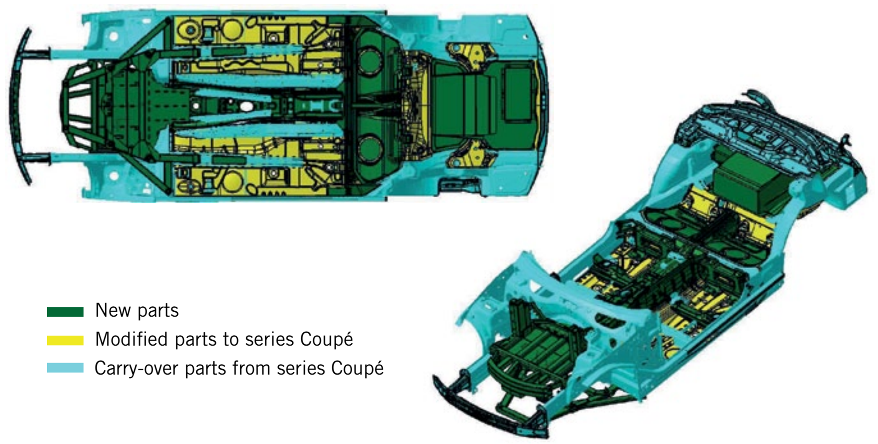
DRIVING FUNCTIONS

The range configuration of the electrical machine up to 12,000 rpm in conjunction with the high torque of the electric motor at a standstill meant that there was no need for a manual transmission in the ActiveE. Instead, a fixed gear ratio of 1:9.7 was implemented, which corresponds to approximately the second gear of a conventional vehicle. The constant power development of the electrical machine from a standstill without the tractive power interruptions that occur when changing gears enables very agile

Electrical system		**Vehicle performance data**	
: Battery capacity	32 kWh (total)	: Acceleration 0-60 km/h	4.5 s
: Battery charging time	10 to 12 h at 230 V/12A (2.6 kW), 4 to 5 h at 230 V/32 A	: Acceleration 0-100 km/h	9.0 s
		: Top speed[1]	145 km/h
		: Range in conformity with NEDC[2]	205 km
: Eco Pro mode	Extension of range by: : adjustment of the accelerator pedal : reduction of heating and air-conditioning output	: Range with customer driving	160 km
		Efficiency	
		: Overall including charging	0.16 kWh/km
		: CO_2^*	0 g/km

❷ General specification data of the BMW ActiveE; [1]electronically controlled, [2]New European Driving Cycle (consumption/emission test), *requires electricity from 100 % renewable energies

❸ Integration of lithium-ion high-voltage accumulator (1), electrical machine (2) and power electronics (3) into the electric drivetrain



❹ New, modified and carry-over parts of the body platform in comparison to the series version BMW 1-Series

urban driving characteristics. This can be clearly perceived when starting off at traffic lights, for example. The rapid torque build-up of the electrical machine means that each acceleration request is implemented practically without delay. This is a real advantage that is greatly appreciated by the customer, especially when lane hopping, that means frequent lane changes in urban areas.

Alongside the ride comfort when driving in urban areas, maximum agility and acceleration characteristics that are easily applied and implemented in particular were in the focus of development. The electrical machine also enables elimination of a mechanical reverse gear. The genuine four-quadrant operation means that reversing is implemented directly by the electrical machine rotating backwards.

ONE PEDAL FOR ACCELERATING AND BRAKING

The philosophy of the "one pedal feeling" already implemented in the Mini E has been consistently refined in the ActiveE and functions that are appreciated by the customer have been added. The driver can accelerate and brake the vehicle with only one pedal. This special accelerator pedal configuration allows the driver to brake the vehicle accurately to a standstill using only the accelerator. The recuperation by means of accelerator pedal progression has been adapted to the progression of the brake pedal, enabling maximum application of the deceleration characteristics via the accelerator at any time. The vehicle shows identical driving characteristics on reversing, which also enables parking without moving your foot from one pedal to the other.

For braking, the electrical machine switches to the generative mode. The energy recovered during recuperation is fed back to the high-voltage accumulator and is not lost through frictional heat at the brake discs as is the case with conventional systems. The three phases of the "one pedal feeling" are shown in ❺ and consist of:

1. braking: recuperation up to vehicle standstill
2. coasting: torque-neutral rolling (same as "disengaging the clutch" with a manual transmission)
3. accelerating: calling up the drive torque.

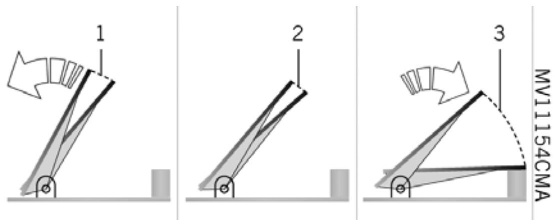
The recuperation means that the vehicle decelerates with a maximum of 0.16 g and/or 102 Nm, enabling a harmonious accelerator pedal configuration and recuperation of almost all of the kinetic energy in both the standard and customer cycles during customer operation. Overbraking of the rear axle to a low coefficient of friction is prevented by the road handling control (DSC), which has been specially adapted to the electric vehicle and reduces the recuperation torque before the vehicle becomes unstable. As the torque interventions have a great influence on the comfort of longitudinal dynamics, particular attention was paid to harmonisation of the interface between the DSC and electric drive.

If the driver operates the brake pedal, the mechanical wheel brake is activated in addition to recuperation via the electrical machine. The configuration of the accelerator pedal also enables the driver to coast. Here, the vehicle rolls without torque – comparable to a manual transmission with the clutch disengaged – and minimises energy consumption with an anticipatory driving style. The available pedal travel of the coasting plateau has been enlarged depending on the driving speed *f*(*v*), which enables rapid adaptation and/or simple and intuitive relocation of the coasting position at any time, ❻.

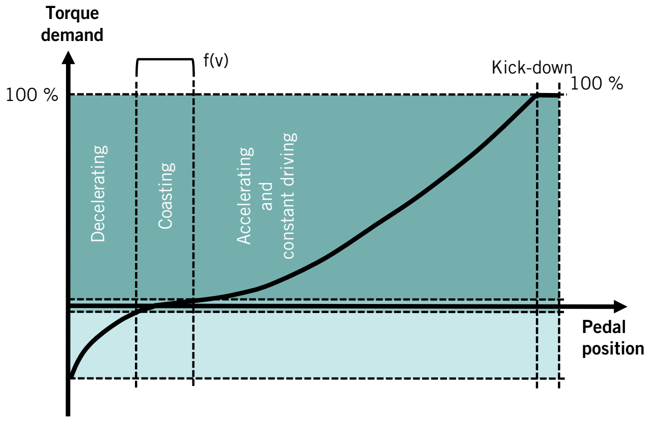
Ultimately, the driver can drive the vehicle with an anticipatory driving style during the entire journey without using the brake function of pedal at all. This not only gives him the feeling they are operating an energy-efficient vehicle; but it also gives him the certainty that the frictional brake has not been activated without operation of the brake pedal. Customer surveys with the Mini E have shown that driving without a brake pedal is not only a pleasant feature for the driver but it also promotes maximum use of energy recuperation very well, just as an electric vehicle should.

ECO PRO MODE FOR DRIVES WITH OPTIMISED CONSUMPTION

The Eco Pro mode can be activated by means of a button. This allows the driver to drive with optimised current consumption due to an adapted accelerator characteristic curve that differs with regard to the accelerator pedal progression and the driving off progression and vehicle dynamics. Furthermore, the



❺ The one pedal feeling in three phases braking (1), coasting (2) and accelerating (3)



❻ Accelerator pedal position and torque demand in the three phases decelerating, coasting and accelerating

driver has a broader coasting plateau available in the accelerator, enabling them to minimise the deceleration phases even more easily using an anticipatory driving style.

The deceleration progressions and thus the recuperation characteristics of the vehicle remain the same in the Eco Pro mode and normal mode, providing the driver, on the one hand, with deceleration characteristics of the vehicle that are always identical. On the other hand, they have the maximum possible recuperation available in both modes at any time, which means no kinetic energy is wasted on deceleration.

In addition, the maximum engine output that can be called up is reduced by approximately 15 % provided the driver does not fully press down the accelerator. If the maximum torque is needed, for example for overtaking, it can be called up using the kick-down, ⑥. With the measures described before, the Eco Pro mode makes it even easier for the driver to optimise the consumption of the car.

Yet another important contribution to reducing current consumption in the Eco Pro mode – and thus extending the range – is made by the optimised vehicle energy management. This reduces the energy consumption of the components connected to the 12-V vehicle electrical system, for example the seat heating or cabin fan, which means that less energy has to be added to the 12-V vehicle electrical system from the high-voltage system by means of the DC/DC converter. The ancillary component management will also be optimised and this will above all reduce the interior air-conditioning and/or heat output of the two high-voltage components electric coolant compressor and electric continuous flow heater. With a moderate driving style, the Eco Pro mode thus enables the driver to achieve a reduction in consumption and/or range extension of up to 20 %.

SUMMARY

The drive of the electric car BMW ActiveE has succeeded in achieving the best possible compromise between efficiency and dynamics for an electric vehicle. The decisive factor for success was the consistent in-house development of the drive components. The corresponding understanding all the way to the most minor detail level was what enabled optimisation of the overall system in the first place.

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10 | 2012 _ October 2012 _ Volume 114
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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.

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DETECTION AND CLASSIFICATION OF CRITICAL INCIDENTS BY MEANS OF VEHICLE DATA

Data from field operational tests is more and more used to analyse the impact of advanced driver assistance systems. Due to the high amount of collected data the analysis of this data is time-consuming. At the Institut für Kraftfahrzeuge (ika) of RWTH Aachen University an automated detection process for recognition of relevant driving situations based on vehicle data has been developed. By means of the automation the analysis can be conducted within a reasonable time period. Moreover the algorithm for detection of the relevant situations have been defined and tested, in order to ensure a reliable detection.

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RECEIVED 2011-12-12
REVIEWED 2012-01-30
ACCEPTED 2012-06-01
REVIEWED BY EXPERTS FROM RESEARCH AND INDUSTRY.

1 MOTIVATION AND STATE-OF-THE-ART
2 METHODOLOGY AND DATA MANAGEMENT
3 AUTOMATED EVENT RECOGNITION
4 INCIDENT RECOGNITION AND CLASSIFICATION
5 INCIDENTS DUE TO VEHICLE DYNAMICS
6 INCIDENTS DUE TO DISTANCE BEHAVIOUR AND DRIVER REACTION
7 CONCLUSION

1 MOTIVATION AND STATE-OF-THE-ART

More than 1.2 millions of people worldwide die each year in road traffic [1]. Several initiatives have been started in the Europe in order to identify possible solutions for reducing the number of accidents and especially the number of fatalities. However an increase of road safety is still one of the main challenges in road traffic. High potential to increase road safety and driving comfort can be achieved by advanced driver assistance systems (ADAS). To assess the actual benefit of ADAS field operational tests (FOT) are conducted [2, 3].

Started within the seventh framework programme of the EC, the euroFOT project establishes a comprehensive, technical and socio/economic assessment programme for evaluating the impact of ADAS on safety, traffic efficiency, environment and user acceptance in real life situations. Altogether, about 1000 vehicles, which are equipped with different ADAS technologies, are used to collect data within the field operational test. The fleet of the euroFOT project is coordinated by five vehicle management centres (VMC) across several European countries. At the German-1 VMC a fleet of 200 vehicles is managed, consisting of 60 trucks from MAN, 100 passenger cars from Ford and 40 passenger cars from VW. All 200 vehicles are equipped with data acquisition systems (DAS), which allow recording and temporary storage of all relevant measured values as well as the transfer of previously recorded data to a central storage server.

As a result of this huge amount of data a detailed analysis of the complete data within the planned period of time is not feasible. Hence a limitation of the evaluation to relevant driving events is necessary, in which the particular tested functions have an influence (for example critical distance situations). These events are extracted from the collected data by an automated event recognition process. The event recognition algorithm automatically detects certain patterns (combinations of different measures) in the CAN and GPS data. Although this approach demands high computational performance, it enables saving a considerable amount of time compared to manual processing of the large amount of data [4].

2 METHODOLOGY AND DATA MANAGEMENT

The relevant data to be collected within the field test has been derived from the research questions of the project. Based on these research questions hypotheses to be tested (for example "Usage of ACC decreases the number of incidents") have been defined. By means of these hypotheses the required signals and data sources have been identified. For each operation site an adapted experimental design has been defined, in order to consider the specific basic conditions. In general the experimental design consists of a baseline (system-off period) as well as a treatment period (system-on period). At the German-1 VMC the first three months of the field operational test will serve as a baseline period during which the ADAS functions will be deactivated. During the following treatment period the tested functions will be activated. Data on driving behaviour (for example vehicle speed, acceleration) is collected in both periods. Comparisons between recorded driving behaviour data for the same participant in the treatment and baseline periods will be made, in order to test the defined hypotheses and to assess the impact of the functions.

The equipped test vehicles will collect data from up to four vehicle CAN busses and additionally GPS information. Other signal sources, such as video sensors are not used at the German-1 VMC, in order to avoid modifications on the customer vehicles. The required signals are recorded continuously with defined sampling rates. The DAS at the German 1 VMC offers the possibility to upload wirelessly the recorded information to a centralised server system, while the DAS is collecting data simultaneously. ❶ presents an overview of the process stages of the German-1 VMC approach.

After the data has been uploaded to the server, further processing steps are conducted. Thereby the data will be enriched with additional attributes from a digital map (for example road type, speed limit) and the automated event recognition conducted. Finally the processed data is filled in tables of a data base. The data collection and upload procedures are designed and implemented to work fully autonomously, in order to ensure recording of naturalistic driving. No driver interactions are required. Hence the drivers can fully concentrate on the driving task.

3 AUTOMATED EVENT RECOGNITION

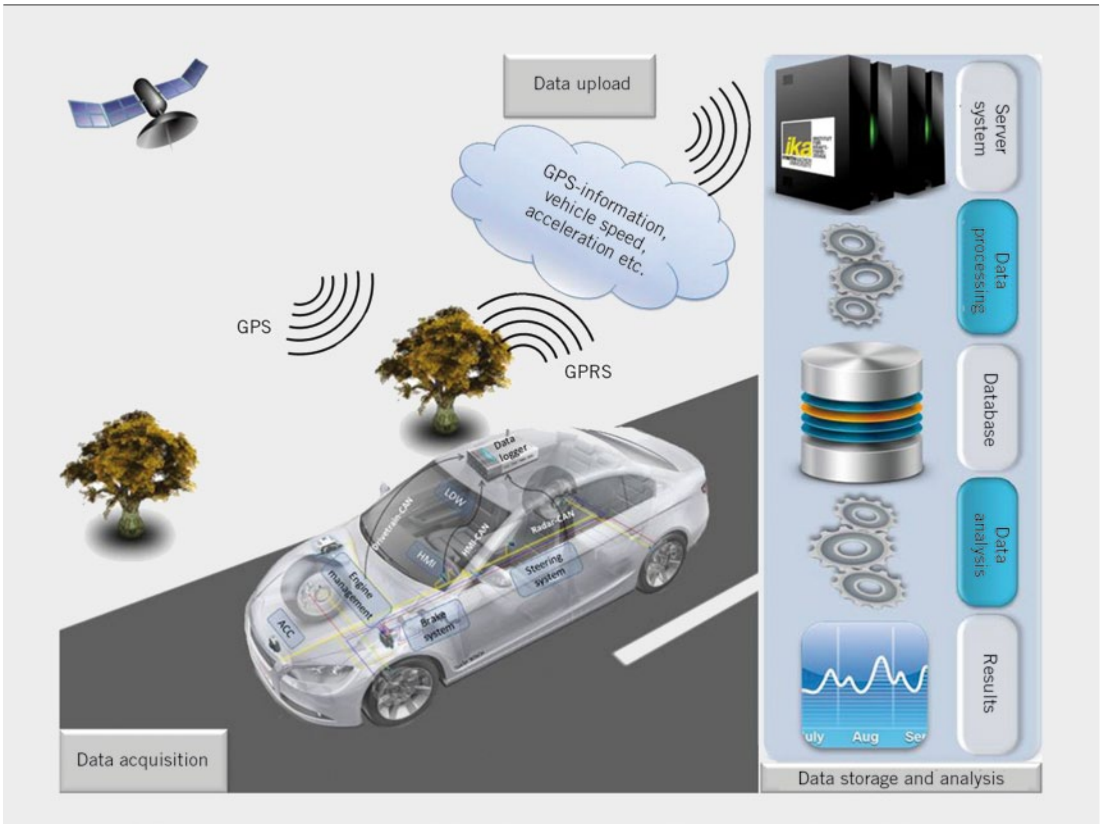
A substantial part of the data processing is the automatic event recognition process, in order to handle the large amount of collected data. These relevant driving situations are used as a basis to analyse the data [5]. Besides the events recognition situational variables are detected, which provide additional information with respect to environment and the vehicle state (for example weather conditions). The detection of the situational variables is performed separately from the event recognition process, because situational based event detection is due to insufficient sensor accuracy not possible. By using in addition situational variables it can be ensured, that the comparison is performed under the some condition (for example weather). Thus effects due to different driving and environment conditions are avoided. By means of the combination relevant driving scenarios for the analysis are determines, ❷.

For the implementation of the event recognition process the main requirement has been to ensure reliable detection. Especially for the German-1 VMC this is of importance, because no video data is available to enable a later verification of the detected events. The first evaluation of the developed algorithms has been made by means data collected within the five month piloting phase. This evaluation revealed a high number of false detections due to improper thresholds. The thresholds have been mainly defined based on a literature review of different previously performed FOTs, in which generally video data has been deployed [6, 7]. In these FOTs potential events, which have been detected by the algorithms, were finally assessed on the basis of the video data.

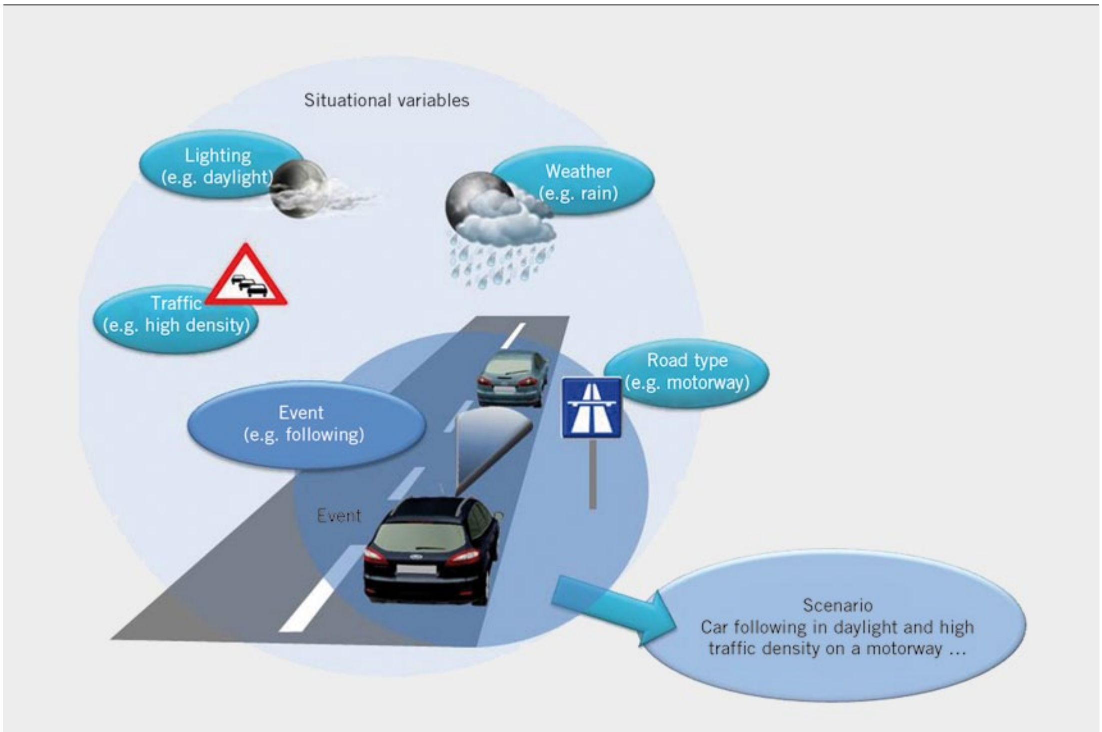
Hence the decision has been taken to equip pilot vehicles with additional video cameras, in order to collect video data for verification purposes. Altogether approximately 40 h of video and CAN data have been evaluated in the pilot phase. The results were incorporated into the optimisation of the automated event recognition process. Based on the revision of the detection algorithms a significant improvement of the reliability has been achieved.

4 INCIDENT RECOGNITION AND CLASSIFICATION

Several tested functions are safety related. A major challenge for the evaluation of the functions is the provision of relevant safety



❶ Data acquisition and processing at the German-1 VMC



❷ Procedural steps to cluster data for analysis purposes

INCIDENT LEVEL	DESCRIPTION
Level 1	Driving situation in which the critical threshold of the defined relevant indicator has been exceeded
Level 2	Increased accident risk
Level 3	Imminent danger of an accident

❸ Classification of incidents

impact indicators. These safety indicators are changes in the number of crashes, fatalities and injuries. But these indicators cannot be provided directly by FOT data, since the expected number of accidents during the FOT is not sufficient to enable statistically valid evaluation [8]. Therefore surrogate measures (for example critical time to collision) are needed, in order to estimate the changes of the relevant safety indicators. An approach to determine these indicators can be realised by using critical driving situations (incidents). A relation between these incidents and accidents is established by in-depth analysis of accident databases.

Incidents are detected at the German 1 VMC by means of a set of indicators composed of time headway (THW), time to collision (TTC), relative speed, forward collision warnings, lateral and longitudinal acceleration as well as intervention of the safety systems anti-lock braking system (ABS) and electronic stability programme (ESP). Moreover the driver intention is taken into account in order to classify the severity of the incident. The incidents are basically divided into incidents due to vehicle dynamics and incidents due to distance behaviour. Depending on relevant indicator thresholds, different levels of incidents can be detected (level 1 to 3), ❸.

5 INCIDENTS DUE TO VEHICLE DYNAMICS

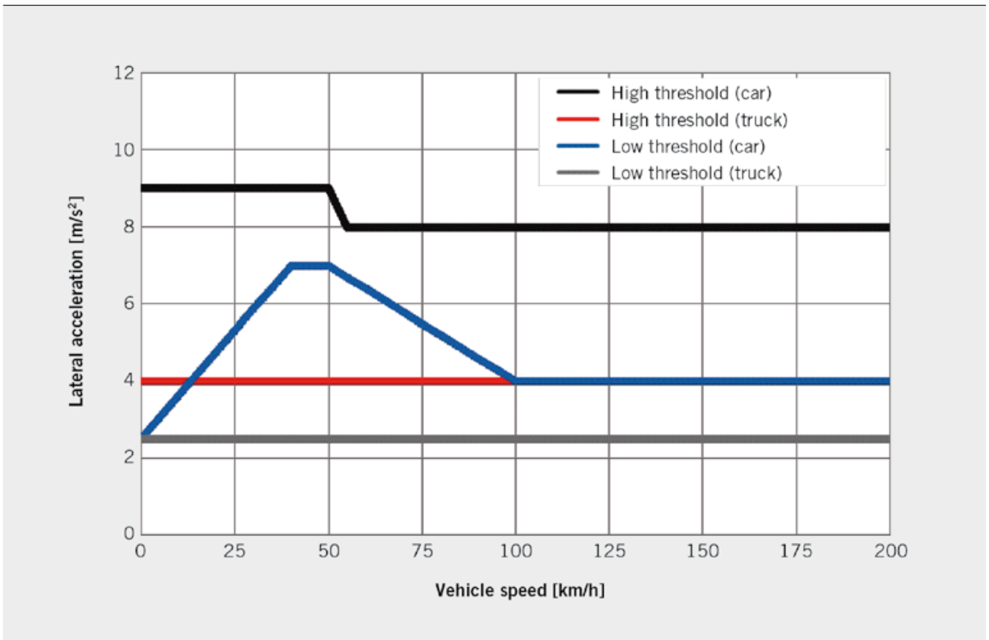
Incidents due to vehicle dynamics are detected by means of longitudinal and lateral acceleration, yaw rate as well as the state of the ABS and the ESP. The evaluation of the CAN and video data of the pilot phase revealed a high number of false detections for the thresholds, which were defined based on literature review. For further optimisation of the incident recognition, test drives with 20 subjects on a pre-defined test route have been conducted and analysed next to the data available from the pilot phase. Based on these test drives the distribution of relevant indicator thresholds in regular driving situations has been determined for different speed values. The highest values detected within the test drives have been used as the incident thresholds. The determined thresholds for the lateral and the longitudinal acceleration for passenger cars and commercial vehicles as well as for the incident levels 1 (low threshold) and 2 (high threshold) are presented in ❹ and ❺.

Furthermore several situations were reproduced on a test track, in order to have a better understanding of the occurrence characteristics of these incident events.

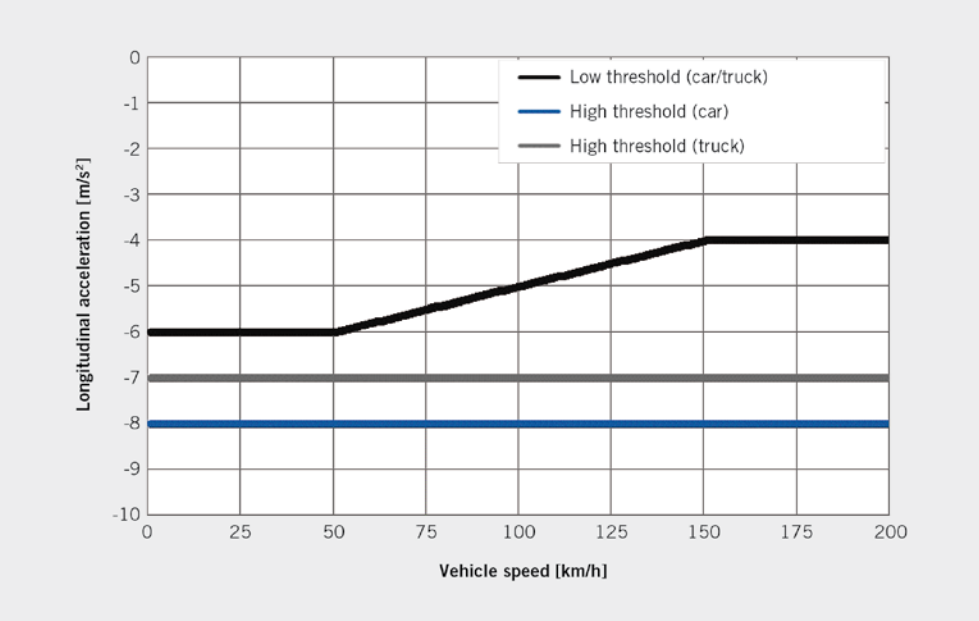
6 INCIDENTS DUE TO DISTANCE BEHAVIOUR AND DRIVER REACTION

The second category of incidents is identified by means of the vehicle speed, THW, TTC, relative speed and the state of the brake light. Since the FOT vehicles are equipped with production sensor systems, only the situation in front of the vehicle can be detected. The analysis of the video data revealed a high number of false detections. This is partly due to the fact that in previous FOTs additionally video data have been used to verify the detected events. Due to the lack of video data at the German-1 VMC the thresholds need to be adapted in advance (piloting phase) as no further validation is possible during the field test. As a consequence further validation of detected incidents (second category) by means of the driver reaction is considered. The thresholds for the incidents due to distance behaviour are presented in ❻.

The idea for considering the driver reaction to assess the criticality of the detected incidents has been developed after the collected video data of the pilot phase has been analysed in detail. The evaluation of the video data showed that a high number of the



❹ Thresholds of longitudinal acceleration



❺ Thresholds of lateral acceleration

INCIDENT LEVEL	THRESHOLDS DUE TO TIME HEADWAY (THW)			THRESHOLDS DUE TO TIME TO COLLISION (TTC)		
	THW [S]	RELATIVE VELOCITY [KM/H]		TTC [S]	STATUS BRAKE LIGHT [–]	
Level 1	0.5	>20	OR	1.75	off	Driver reaction
	0.35	>10		–	–	
Level 2	0.35	>20		<1	on	
Level 3	–	–		<1	off	

❻ Overview thresholds incidents due to distance behaviour

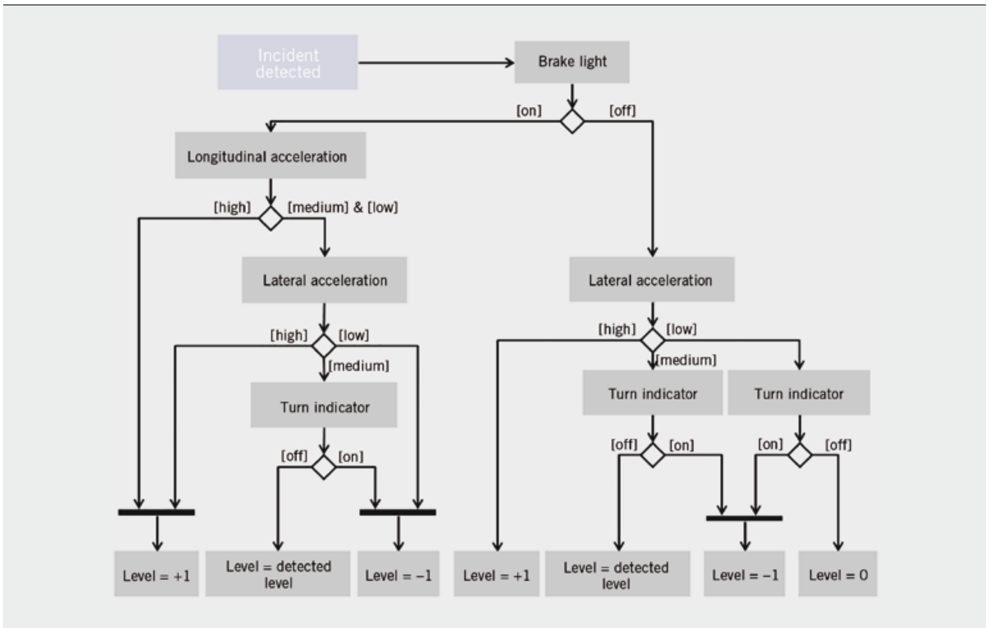
detected incidents were not critical, because the driver has been aware of the situation (for example in overtaking situations). In these situations the host vehicle follows the front vehicle in a very close distance and the THW respectively the TTC fall below the incident threshold for a short time period, which is intended by the driver in these cases, in order to perform a quick overtaking manoeuvre.

While performing these manoeuvres the driver usually observes also the situation in front of the predecessor, in order to assess, whether the predecessor is going to initiate any actions. The probability that the predecessor will perform a hard braking manoeuvre while no vehicle is in front is very low. This information for example is used by the driver to estimate whether a close approaching can be performed for a quick overtaking manoeuvre. Unfortunately this information is not available on the CAN bus because only information on the relevant target (vehicle in front of the host vehicle) is available. Hence the driver is able to consider more information during the driving process. Therefore it is possible that the driver and the algorithms assess a driving situation differently.

In order to compensate this lack of information the driver reaction is additionally considered for the incident recognition. The basic idea of this approach is that the driver intention can be derived by means of the driver reaction. If the situation is in fact critical, a driver reaction (for example steering or braking manoeuvre) has to be initiated, in order to avoid a collision. If no driver reaction has been detected and no collision occurred, the criticality of this situation is downgraded. In this situation the intention of the driver to perform the manoeuvre (close distance to vehicle in front) and the corresponding driver awareness is assumed. Incidents which are solved due to manoeuvres by other drivers are not considered. The required information to detect these situations cannot be provided by the available sensors.

After the incident has been detected and classified to an incident level the analysis of the driver reaction is applied. For this purpose the longitudinal and lateral acceleration as well as the state of the turn indicators and the brake lights are analysed for a time period of 5 s before and 1 s after the incident has been detected. For each measure different categories have been defined, into which the driver reaction is classified. Based on the different categories the classification of the incident level due to the distance behaviour is adapted according to the flowchart in ❼.

If the driver has performed a high deceleration or a high lateral acceleration, the incident level is upgraded by one step (situation is critical due to reaction of the driver). In case the deceleration was medium, low or the brake light switch off, the lateral acceleration will be taken into account. For medium and low lateral accelerations the state of the turn indicator is considered in a further validation step. The incident level will be downgraded

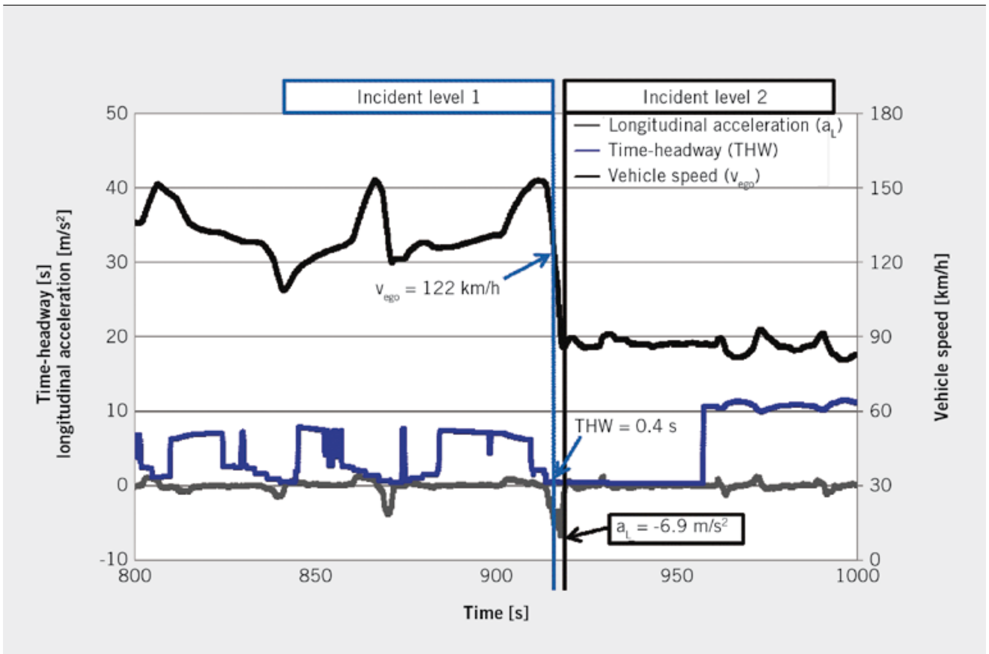


❼ Classification of incident level by means of the driver reaction

by one step in situations with medium or low acceleration and activated turn indicator. An incident level is downgraded directly to zero in situations with low lateral acceleration and not activated turn indicator. In these situations the driver did not react at all and no collision is detected afterwards. Thus it will be classified as non-critical.

❽ presents an example of an incident due to the distance behaviour. The incident occurs at a relative speed of 30 km/h (fast approaching to leading vehicle). In the beginning the incident severity is classified as level 1, because of the relative speed and critical time headway less than 0.5 s. Afterwards the driver initiates a hard deceleration of a maximum value of 6.9 m/s². Due to the hard deceleration the incident level has been upgraded to level 2, because a strong driver reaction is necessary to resolve the situation.

By means of considering the driver reaction as well as the adjustment of the thresholds for the incident detection, the number of detected incidents as well as the number of false detections within the pilot phase has been significantly reduced from 75 % based on literature to a value of 3 %. The results of the comparison between the version of the algorithm based on literature specification and the current version (adapted version) are presented in ❾. Therewith, the number of detected critical incidents decreased.



❽ Recognition of an incident by means of THW and longitudinal acceleration

DETECTED INCIDENTS	CURRENT VERSION	FIRST VERSION
Total	31	145
Correct	27	21
False	1	109
Not classifiable	3	15

❾ Number of incident detections during pilot phase

7 CONCLUSION

The detection of critical incidents presents an important step to investigate the safety increase of advanced driver assistant systems in field tests. Therefore, an automated process was developed during the euroFOT project. The current version of the incident detection divides the incidents into two categories (incidents due to vehicle dynamics and distance behaviour). Moreover the driver reaction has been integrated as an additional step for verification purposes. By means of the driver reaction the level of detected incidents due to distance behaviour is verified. By means of video data modifications of the incident detection algorithm have been made, which result in a significant reduction of the number of false detections.

The evaluation of the current version shows a reliable detection for different conditions, vehicle types and drivers within the pilot phase. This version is currently used for the analysis at several vehicle management centres in the euroFOT project.

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