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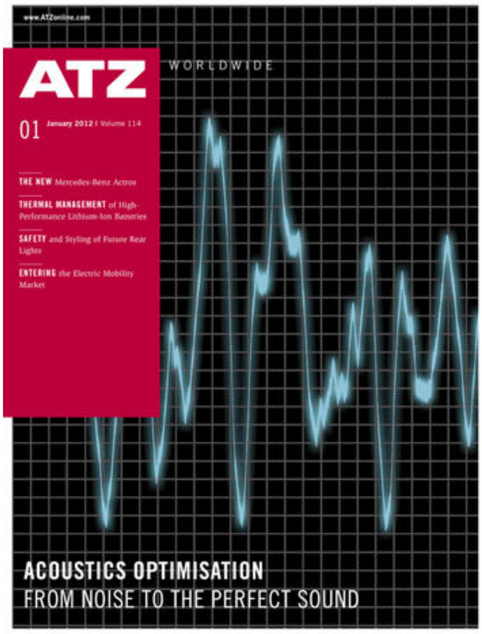

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01 January 2012 | Volume 114

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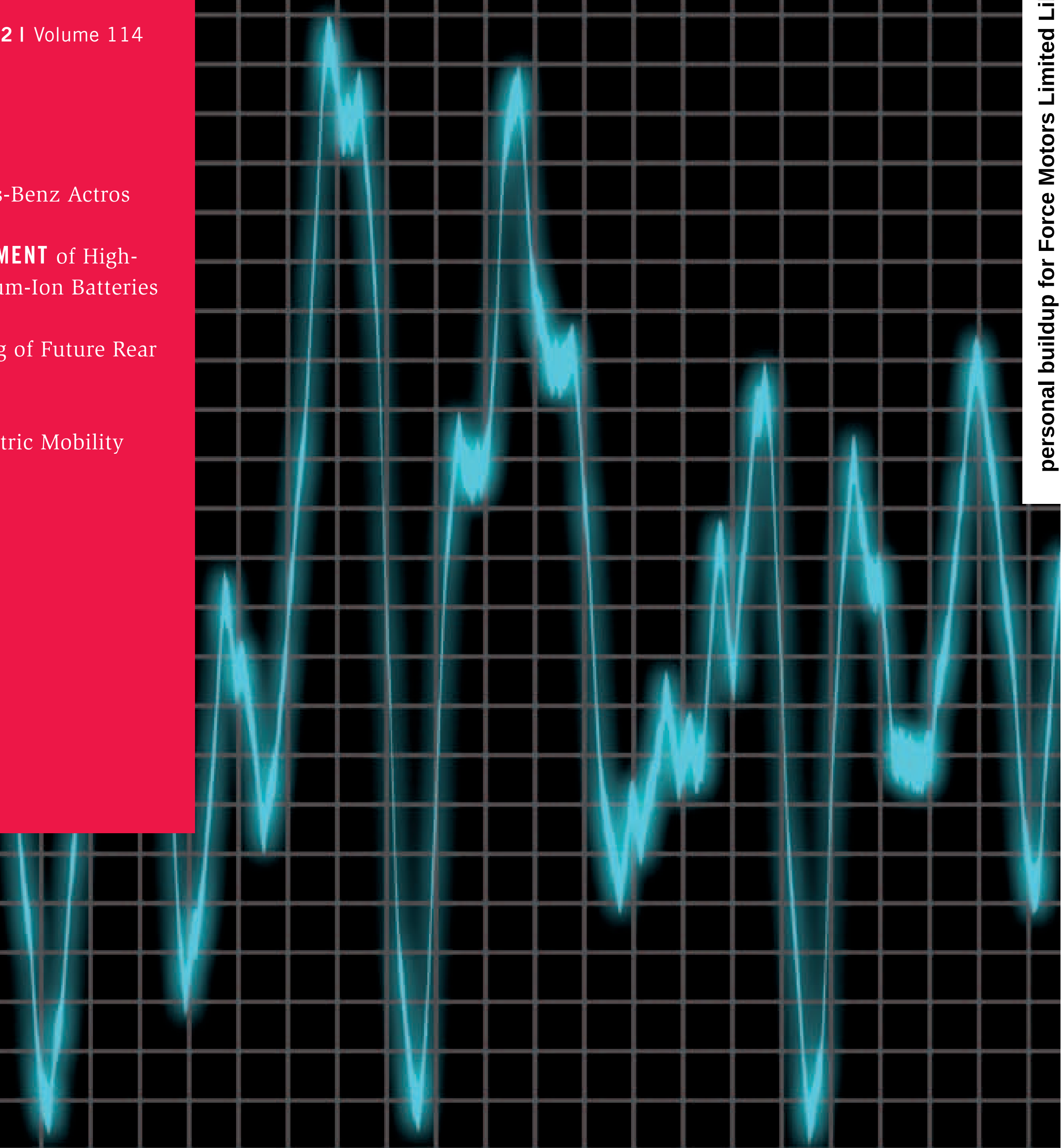
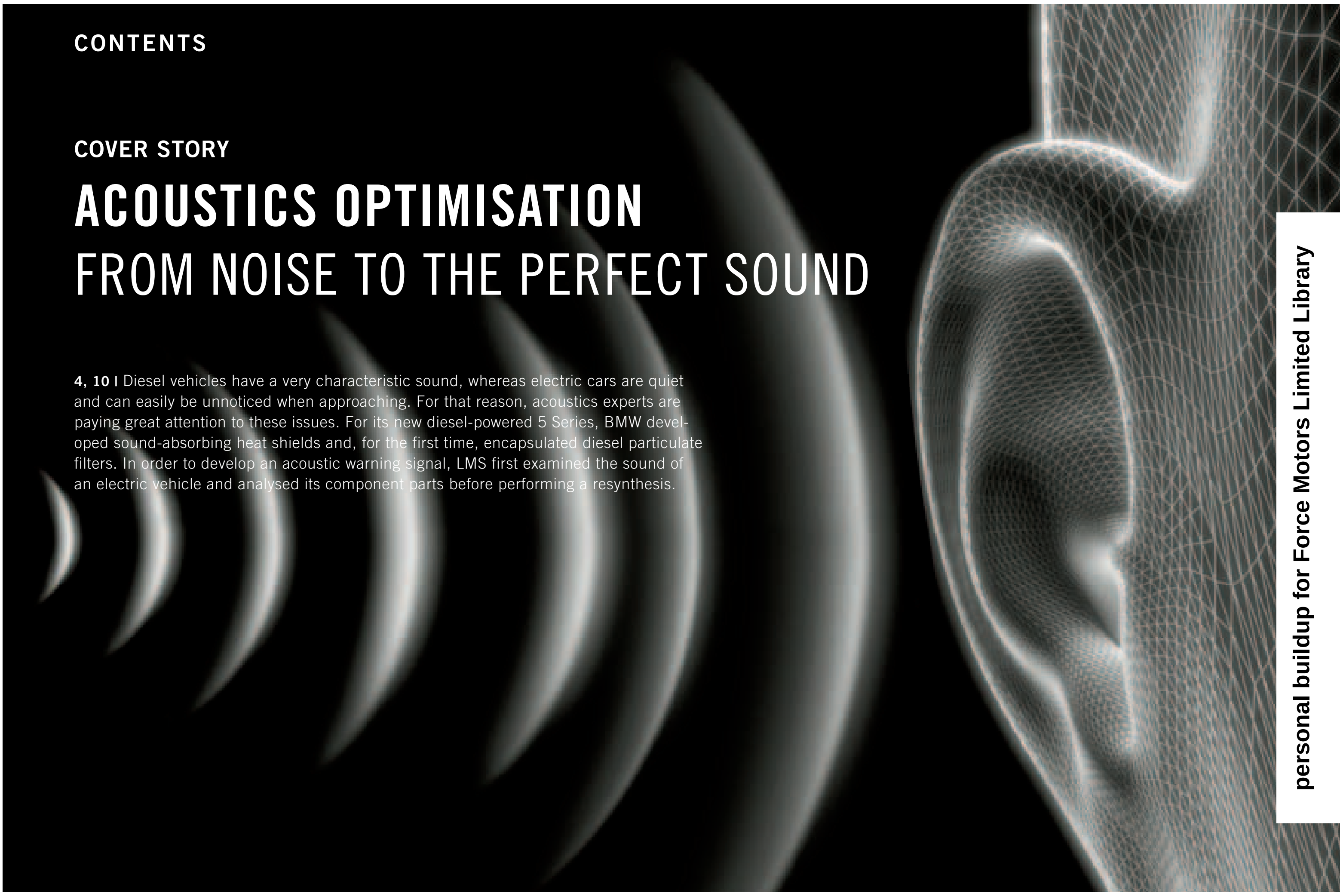


ACOUSTICS OPTIMISATION

FROM NOISE TO THE PERFECT SOUND

CONTENTS



COVER STORY

ACOUSTICS OPTIMISATION FROM NOISE TO THE PERFECT SOUND

4, 10 I Diesel vehicles have a very characteristic sound, whereas electric cars are quiet and can easily be unnoticed when approaching. For that reason, acoustics experts are paying great attention to these issues. For its new diesel-powered 5 Series, BMW developed sound-absorbing heat shields and, for the first time, encapsulated diesel particulate filters. In order to develop an acoustic warning signal, LMS first examined the sound of an electric vehicle and analysed its component parts before performing a resynthesis.

COVER FIGURE © icholakov I Fotolia
FIGURE ABOVE © [M] psdesign1 I Fotolia

SUBSTANCE DECIDES

Dear Reader,

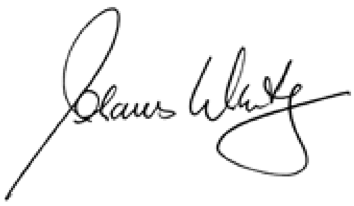
What might the New Year have in store for the automotive industry and automotive technology? There is no doubt that the insecurity of the markets has increased. But I believe that the current trend is likely to continue: and it is absolutely positive. The market shares of German manufacturers and suppliers are growing worldwide.

This success is due not only to brand strength but above all to engineering substance. It is no coincidence that the management culture of German manufacturers is focused on technical expertise and not primarily on finances. Top managers such as Norbert Reithofer, Martin Winterkorn and Dieter Zetsche have shown that detailed knowledge, acquired through studies in engineering or science, represents a competitive advantage for the entire company.

Among the broader public, with its lack of interest in technical matters, detailed knowledge is often equated with specialisation. Those who want a successful career will prefer to study business administration, marketing, international law or similar subjects. Disciplines which, by the way, were unable to prevent the recent financial crises. The major challenges of the future, such as climate change, will however demand rational action based on a scientific world view. My hope for 2012 is that, in future, substance will decide on the success of managers, ideas and products.

ATZ has always stood for substance and not stagnation, and this will, of course, continue in 2012. On additional pages, we will be publishing reports and features that analyse the latest issues of automotive development and research, written by highly regarded technical journalists. In this issue, our chief correspondent Stefan Schlott examines the question of what a charging infrastructure for electric vehicles might look like – and what still has to be done.

I wish you a successful New Year both personally and professionally.



Johannes Winterhagen, Editor-in-Chief
Wiesbaden, December 2011

COMPLETE VEHICLE AND POWERTRAIN ACOUSTICS OF THE NEW BMW 525D

In spite of a reduction in the number of cylinders compared to its direct predecessor, the BMW 525d offers further enhanced acoustic comfort. Based on measuring methods such as Reciprocal Transfer Path Analysis, absorbing heat shields designed in sandwich construction have been integrated and a thermal and acoustic encapsulation of the diesel particulate filter is used for the first time.

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INITIAL SITUATION

Now in its sixth generation, the BMW 5 Series is known for being a comfortable touring saloon that combines the typical BMW characteristics of dynamics, efficiency and comfort.

This has been achieved by numerous individual measures, as is the case in the new BMW 525d with its twin-turbocharged four cylinder diesel engine with BMW TwinPower Turbo Technology. The step from an inline six-cylinder engine in the direct predecessor to an inline four-cylinder has resulted in a significant improvement in performance.

To also improve acoustic and therefore driving comfort, a package of acoustic measures has been applied to underline the comfort standards of the current BMW 5 Series with diesel engines. In order to ensure efficient development of the car's

❶ Acoustic analysis of the car's underbody, using an underbody microphone array inside a full-anechoic room

acoustics, BMW uses modern measurement technologies and the required resources in the form of test rigs and measuring technology.

MEASURING TECHNOLOGY

For the conceptual design of a vehicle's acoustic behaviour, it is essential to collect a sufficient amount of objective measurement data. To achieve this, the driver's experience, which is a very subjective impression, has to be characterised in objective acoustic specifications. For the design of the drivetrain acoustics, it is therefore necessary to not only have a look at overall noise levels, but also at the sound characteristics and the quality of noise. Those subjective impressions have to be objectified in order to obtain reliable measurement results and to compare subjective noise qualities in an objective way. Apart from psychoacoustic quantities such as sharpness and harshness, BMW also calculates and uses its own figures, such as the "Dieselnagelindex" (diesel noise index) to characterise an internal combustion engine's operating noise.

All measurement data are acquired in standard measuring procedures from BMW's acoustics departments. The vehicle is set into different types of test facilities, where it is able to perform all driving conditions from idling to full load acceleration under laboratory conditions. The different test facilities offer full and semi-anechoic as well as reverberation characteristics to record any desired physical noise quantity.

Great importance is placed on the replication of typical use cases of a real customer. These scenarios can be completely different for exterior and interior acoustics. While literally every driving condition is important for the acoustic impression inside the car, the exterior noise is especially critical at low vehicle and engine speeds, as the drivetrain noise becomes less important with increasing vehicle speed. Typical low-speed criteria are exterior idle noise and the dynamic acoustic behaviour at slow approach situations.

Furthermore, drive-by noise is, of course, an important legal criterion.

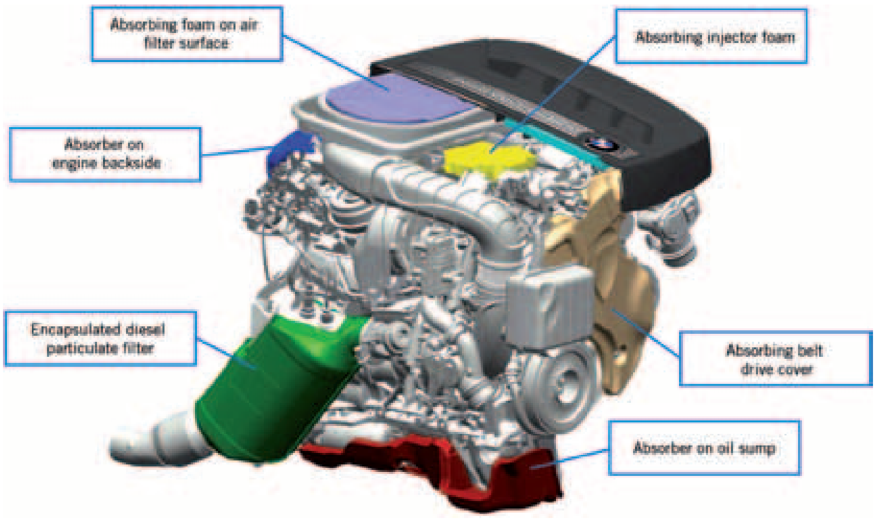
The intention of this acoustic analysis is to develop measures which manipulate either the noise source itself or the noise transfer path from the source to the receiver.

For that purpose, the vehicle geometry has to be specified in more detail by an acoustic camera. This instrument is able to precisely detect noise sources and acoustic leaks from acoustic encapsulation, ❶. In this way, it is possible to reduce the noise emission on the underbody, which is a challenge due to the need for thermal and aerodynamic apertures. Furthermore, the airborne noise transfer paths can be specified by Reciprocal Transfer Path Analysis (RTPA). This method allows the measurement of transfer path damping from different areas of the drivetrain to relevant receiver positions for specific fractions of the drivetrain noise. The documented transfer paths can then be optimised specifically via engine and vehicle body-based acoustic measures.

Finally, the acoustic development's target – to achieve the best acoustic behaviour with intelligent acoustic concepts – is always approved in a subjective way: with the human ear.

BASIC ACOUSTICS PACKAGE

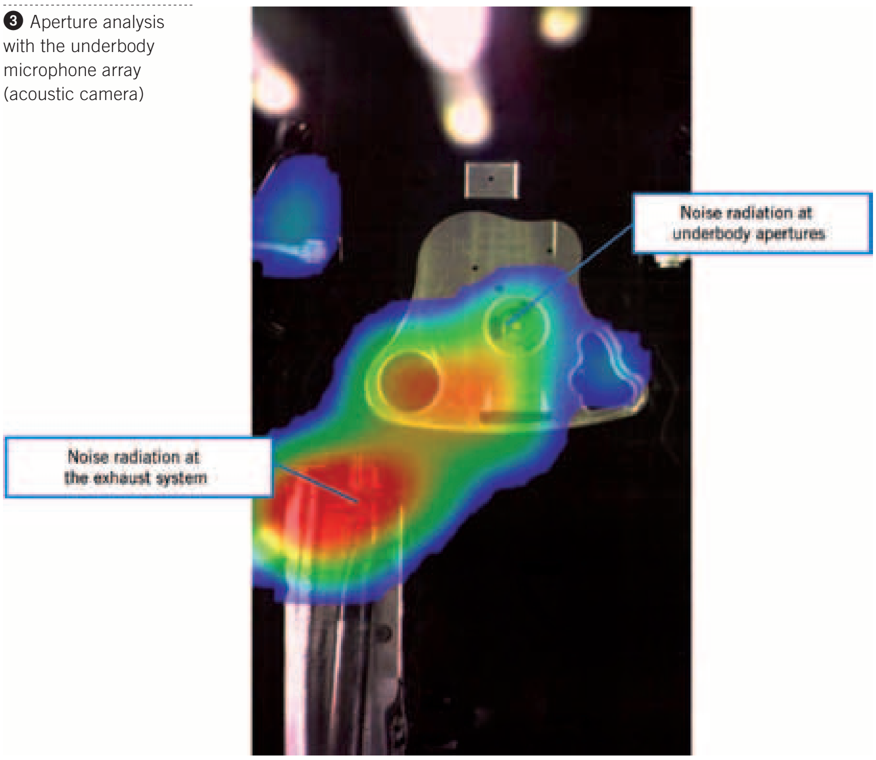
With the measuring methods described, the basic acoustic package for generation



❷ Components with acoustic advantages on the BMW 525d four-cylinder diesel engine

F10 of the BMW 5 Series has been developed. To achieve a maximum level of acoustic comfort, despite using lightweight design, it was important to optimise all noise-related components as well as to design passive acoustic measures specifically for the optimal position. Measurement methods such as RTPA enabled the design of an engine bay encapsulation with sound-absorbing underbody trim and an optimised balance between absorption inside the engine bay and the surrounding insulation. With great attention to detail, the apertures around the front suspension arms have also been significantly reduced in size. Although the BMW 5 Series has a complex double wishbone suspension and is available with xDrive all-wheel drive system, it was possible to develop an engine bay encapsulation that has almost no apertures to the wheel arch area.

❸ Aperture analysis with the underbody microphone array (acoustic camera)



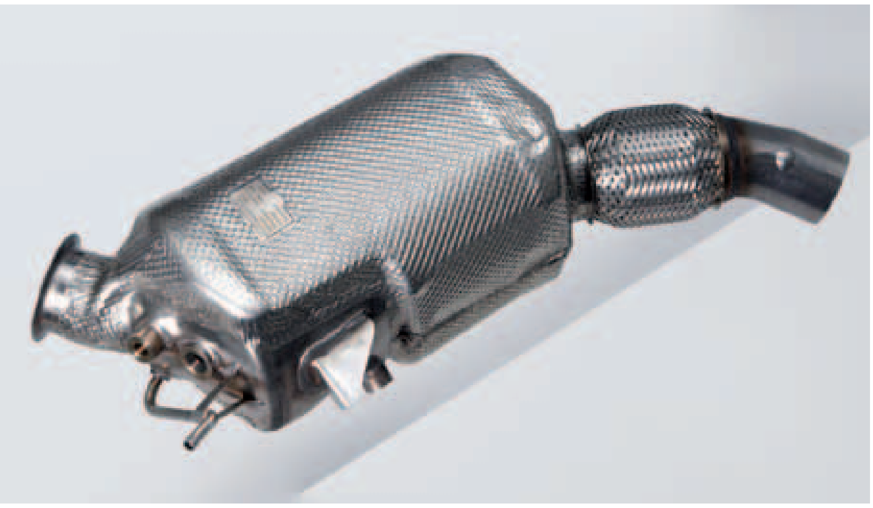
Active air flaps in front of the coolant radiator are a further improvement to the engine encapsulation. These are not only effective for airborne noise to the front of the car, but also improve the aerodynamics of the vehicle. The design of the wheel arch liner as well as the sealing of the engine bay encapsulation on different joints, such as to the engine hood, have also been optimised.

ENGINE

The four-cylinder diesel engine of the BMW 525d is based on the already familiar engine of the 520d. It features the same basic concept with an all-aluminium crankcase and integrated balancer shafts. The crankcase has been optimised for maximum strength and rigidity with cast ribs and ensures a high level of stiffness despite having a low engine weight. This is important for the vibration characteristics of the basic engine and therefore the radiation characteristics of high-frequency airborne noise. The balancer shafts are integrated into the crankcase for optimised balancing of mass forces of the second order.

To effectively reduce airborne noise radiation, different passive measures for the engine's surface have been developed, ❷. The intention is to gain a maximum acoustic effect while adding as little weight as possible to the body. Therefore, insulation measures with a high dimensional weight have been avoided. Instead, lightweight absorber materials are used for specific parts across the engine's surface. The absorber parts on the oil sump and the engine's rear as well as top surfaces not only absorb airborne noise from those areas, but also work as thermal insulation. The belt drive cover on the engine's front surface is designed with fibre and foam materials, enabling it to work as an absorber for both sides of the cover.

A technical innovation for the BMW 525d is the noise optimisation of the turbocharging system. Because of the thermal conditions, conventional acoustic measures can hardly be integrated. To optimise these structures for airborne



❹ Diesel particulate filter with acoustic encapsulation, designed as integral insulation

noise behaviour, new ways of acoustic treatment have to be found.

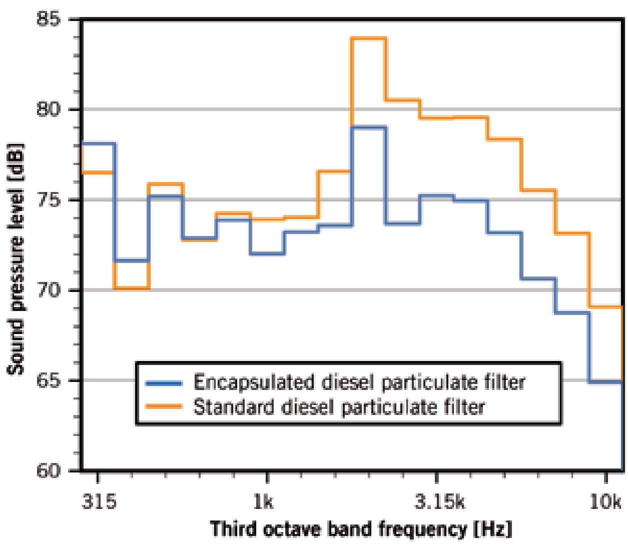
DIESEL PARTICULATE FILTER

Measuring methods such as Reciprocal Transfer Path Analysis illustrate that close-coupled exhaust conducting parts make a significant contribution to a vehicle's exterior noise, ❸. Because of the necessary apertures to the vehicle's underbody near the exhaust system, relatively low transfer path damping from those parts can be achieved. As the noise radiation of exhaust conducting parts is typically in a subjectively displeasing high frequency range, special attention to those components is required. In addition to absorbing heat shields designed in a sandwich construction, thermal and acoustic encapsulation of the diesel particulate filter is used for the first time.

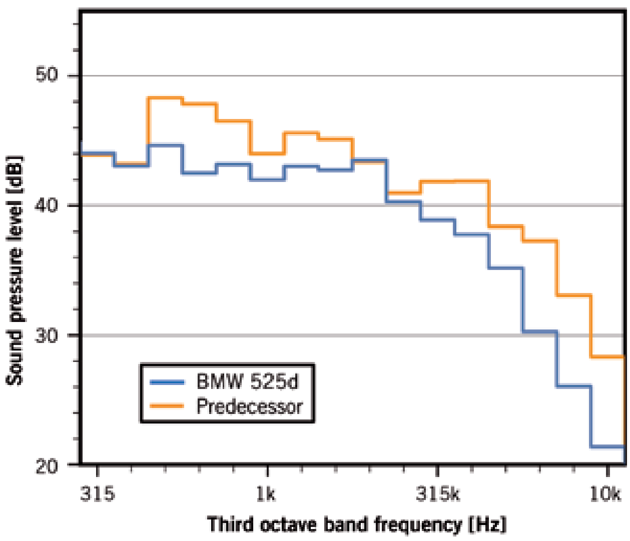
Designed as direct insulation of the component, the encapsulation features a synergetic effect with both acoustic and thermal effects, ❹. The insulation is designed with two half-shells of fibre composites, which are applied directly onto the surface of the diesel particulate filter. To fix the shells in place, a micro-perforated stainless steel liner cover is attached on top of the fibre composites and welded with the base component at the inlet and outlet cones. The combination of fibre composite material and a perforated liner adds up to an acoustically effective element. The airborne noise radiation of the surface is reduced, while airborne noise around the component is also absorbed due to the insulation's absorbing characteristics. As the encapsulation causes higher temperatures inside the component, it has a positive influence on the warm-up period of the particulate filter and the catalytic converter after a cold start of the engine. Because of the large surface area of the diesel particulate filter, the part works as an effective absorber in an important geometric area, as it is placed near the exhaust aperture to the vehicle's underbody, ❺.

SUMMARY AND CONCLUSION

With these acoustic measures, the BMW 525d achieves an acoustic quality that is an even further improvement to the six-cylinder predecessor, ❻. The targeted application of new acoustic concepts, such as the encapsulation of the diesel particulate filter, developed with modern analysis methods such as Reciprocal Transfer Path Analysis, also further improve the sound characteristics.



❺ Effects of the particulate filter encapsulation: significant improvements in high-frequency areas



❻ Exterior idling noise of the BMW 525d compared to its predecessor – a more comfortable running noise is achieved by the acoustic measures implemented

EXTERIOR SOUND DESIGN FOR INCREASED ELECTRIC VEHICLE SAFETY

The design of a warning sound system for electric vehicles requires a proper sound development, balancing warning effect with ambient annoyance, and a sound system configuration design to locate and size the sound sources. For the presented sound synthesis approach by LMS the noise of an electric vehicle was decomposed into its different contributions allowing a parametric resynthesis. Furthermore, this approach permits the accurate prediction of sound dispersion and the simulation of sound levels at listener locations.

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INTRODUCTION

The increasing development of electric and hybrid vehicles requires that next to the obvious energy efficiency design proper attention is paid to critical functional performances such as NVH (Noise, Vibration, and Harshness) behaviour, driveability, safety and durability. Acoustic developers are especially occupied with the interior NVH behaviour of electric and hybrid vehicles. The absence of masking combustion noise and the introduction of new sources such as electric motors, battery cooling and, for hybrid vehicles complex transmission systems require critically revising the NVH design approach.

Not only comfort aspects are relevant regarding electric or hybrid vehicles acoustics. Also important is the relation between the exterior sound of quiet road vehicles and the safety of Vulnerable Road Users (VRUs). In particular at low speeds, before the tire noise becomes observable, the absence of any perceived engine noise and hence the absence of any vehicle proximity warning may cause danger to other road users.

This has been investigated by the NHSTA (National Highway Traffic Safety Administration) and authorities in Japan and Europe. The discussion is actively driven by organizations representing specific classes of VRU such as visually impaired people. Within UNECE (United Nations Economic Commission for Europe) the Working Party on Noise investigates this issue. The main proposed approach is to equip quiet vehicles with artificial warning sounds.

In Japan, a guideline for such sound is proposed [1] and a first generation of systems is installed in recent vehicles such as Nissan Leaf [2]. The present article investigates the sound and sound system engineering challenges, explains a sound synthesis approach and discusses a number of related design engineering experiments. The two main challenges are the sound design and the sound delivery at the critical VRU locations.

SOUND SYNTHESIS BASED DESIGN

The vehicle warning sound generation system must generate sound that is perceptible at the VRU locations of interest and that will attract attention of the VRU. Perceptual considerations for the sound design [1, 2] lead to considerations regarding harmonic and narrow/broadband spectral content, speed dependency and modulations. To be relevant at potential VRU listener positions, the propagation of the sound from source to receiver has to be considered, taking into account the influences of the surrounding structure and space, like car body, road, road obstacles, road layout, and taking into account the masking effect from the traffic noise.

To support the process for designing the sounds and the sound system, a sound synthesis approach is proposed. It consists of a sound synthesis system based on the so-called Virtual Car Sound method developed at LMS and the simulation of the propagation of the generated sound to arbitrary locations in the traffic environment. Warning perception at the VRU location considering masking noises (from traffic or environment) as well as annoyance perception by non-traffic users can be simulated and assessed.

Such sound synthesis approach allows engineers and designers to:

: listen to the alert sound in driving conditions, interactively with throttle and brake
: identify the optimal locations for the sound sources on the vehicle
: design target sounds in terms of optimal spectrum signal features and strength.

SYNTHESIS OF WARNING SOUNDS

The total alert sound is the sum of a number of tonal and broadband components. Each component has its own sound characteristics according to one of four typologies:

1. Orders: Harmonics of multiple baseline tones
2. Frequency domain: third octave noise spectra
3. Modulation structures: time envelope structures and frequency modulations
4. Time recordings: recorded sounds.

A vehicle sound signal can hence be synthesized based on combining signal building blocks from all four typologies, taking into account speed and/or rpm dependencies. The synthesis of the sound is based on a Sound Quality Equivalent (SQE) model that can be defined by the user or can be modelled on the basis of an existing noise. The SQE model was developed in order to have a synthesis of a recorded sound reproducing the human perception of the noise under study. The aim is not to achieve high accuracy in reproducing the physics of all noise features since a pure physical synthesis often results into a sound signal that is perceived as artificial or synthetic. In addition, such a pure physical approach would require a far more intense computational load than the presented model approach.

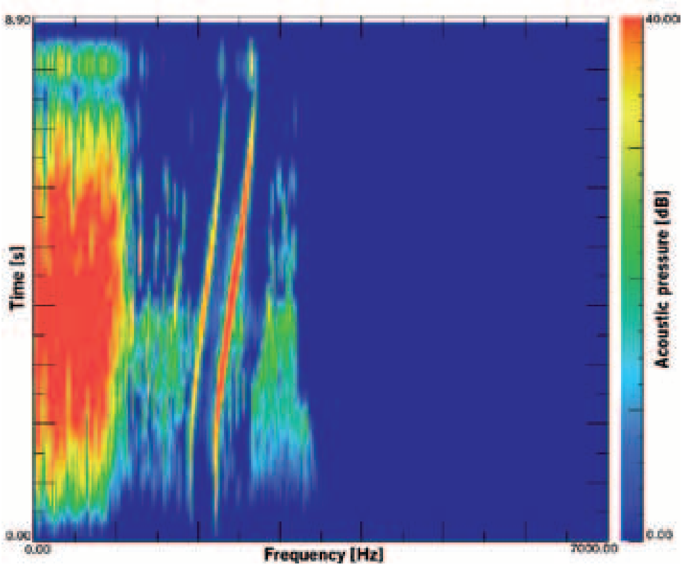
As an example, the sound from the electric vehicle Nissan Leaf was used. The sound was captured from a public source and does not necessarily represent the serial product sound. Therefore this sound can hence only be considered as a example. It was analyzed and resynthesized. During resynthesis, parametric modifications can easily be applied, providing a straightforward way to perform further studies.

❶ shows a spectral analysis of a drive-by signal at low speed measured at a fixed observation position. A number of different signal components can be discerned. A first component has a low frequency broadband content with a peak at 600 Hz and an important contribution up to 1000 Hz. This could be a combined effect of artificial low frequency contribution described in [2] and ambient noise. A secondary broadband group is in the range of 2800 to 3500 Hz.

A second harmonic signal part has speed dependent frequencies. Two groups are found, a first dominant one with the two nominal frequencies 2000 and 2200 Hz and a secondary group with three nominal frequencies 1100, 1350 and 1600 Hz, active in the first part of the measurement window.

For the various signal components, a modulation study was furthermore performed by means of an envelope spectral analysis diagram for amplitude modulations and some narrow-band spectral analysis for FM sidebands. In the present study, no distinction can be made between vehicle-level signal effects and effects from driving conditions or environmental noises.

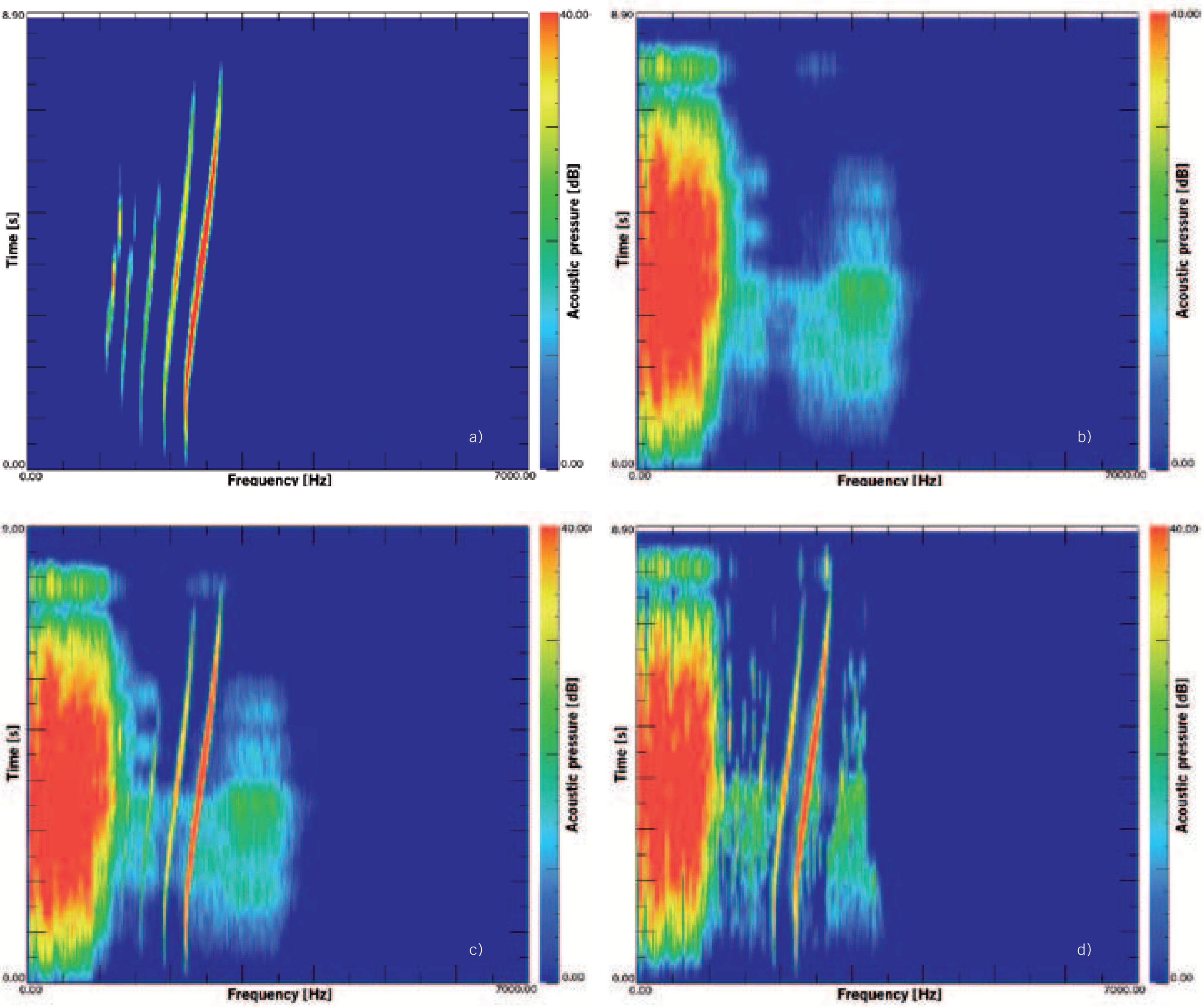
Based on this analysis, each of the extracted signal groups can be resynthesized separately, allowing to act on spectral value, amplitude level and profile and



❶ Low-speed drive-by analysis of a recorded signal

modulation depth. Tonal components can be synthesized starting from a user defined carrier frequency, assigning a time, speed or rpm dependence to the each of the tonal components. Since no direct speed info was available, only time dependency was applied. The tonal components can be characterized by a time or rpm/speed-dependent frequency modulation.

The broadband noise synthesis consists of a white noise defined in third octave bands, segmented in time blocks. Each time block is associated with a value of energy content that belongs to a time/rpm/speed dependent curve which is defined in the model. ❷ shows a resynthesis of the broadband and the tonal



❷ Resynthesis of recorded signal: (a) tonal components and (b) broadband resynthesis. Comparing the total synthesized sound (c) to the original spectrum (d), a very good correspondence is observed.

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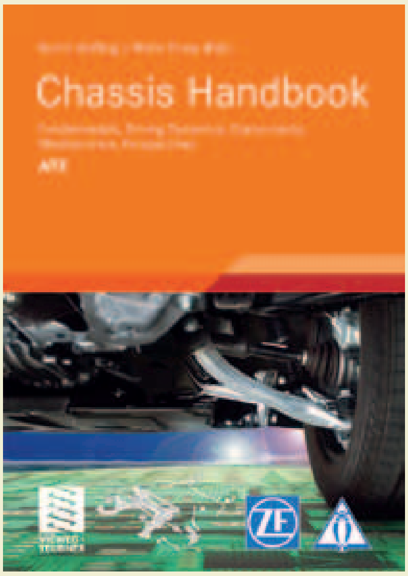
Tyres, wheels, suspension – how comfortable are our cars?



Bernd Heißing | Metin Ersoy (Eds.)

Chassis Handbook

Fundamentals, Driving Dynamics, Components, Mechatronics, Perspectives

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

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

With its revised illustrations and several updates in the text and list of references, this new edition already includes a number of improvements over the first edition.

The contents

Introduction - Fundamentals - Driving Dynamics - Chassis Components - Axles in the Chassis - Driving Comfort: Noise, Vibration, Harshness (NVH) - Chassis Development - Innovations in the Chassis - Future Aspects of Chassis Technology

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components. Comparing the total synthesized sound to the original spectrum, a very good correspondence is observed.

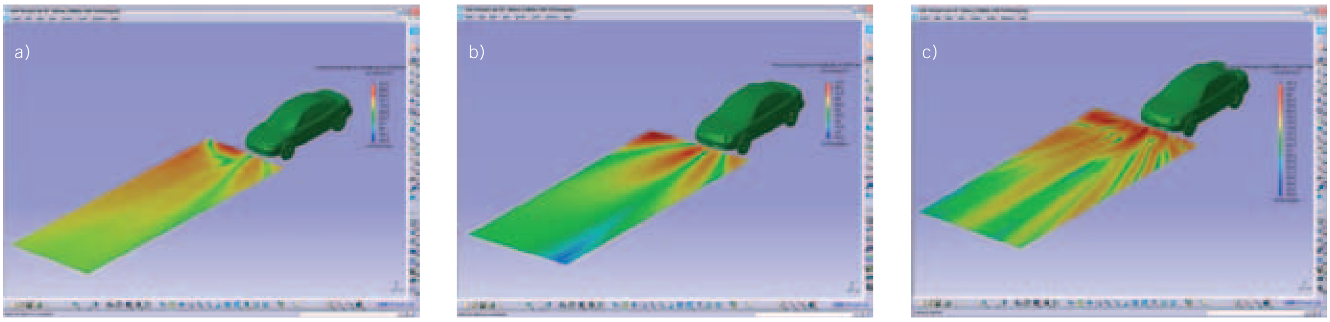
WARNING SOUND PROPAGATION

The second challenge in designing a vehicle warning sound system is the prediction of the propagation of the generated sound to the location of the listener. This propagation is frequency and space dependent, varying with the vehicle geometry, the location of the source on the vehicle, the road environment (sound obstacles and shaping profiles). Furthermore, masking effects of other traffic and ambient noise sources like wind and machinery will have an impact on the perception.

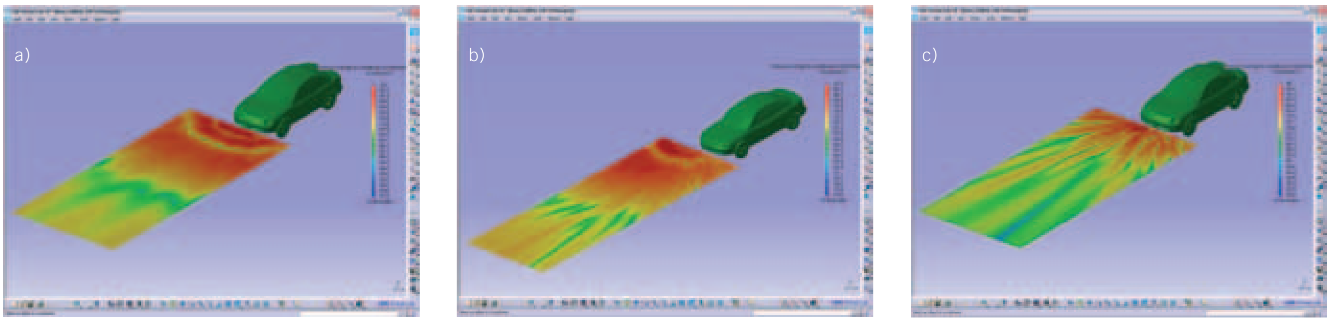
Approaches such as the multipole BEM (Boundary Element Modeling) frequency and time domain methods and the Ray Tracing method can be used to simulate the directivity of the source and the level of noise in the vehicles surrounding, leading to an optimal source configuration and allowing to derive component and sound system specifications.

In the present study, the sound emitted by sources at six different positions on a representative car was calculated for two frequencies, 650 and 2500 Hz, which according to [2] are within the most audible frequency ranges by human beings. The applied BEM approach uses 2D elements for discretizing the scattering surface of the vehicle. A high density microphone array was defined in front of the car as response grid. A symmetry plane was used to account for the road surface reflection. As source model, a monopole with unity amplitude corresponding to a power of about 101 dB was used (all results are fully scalable in level). Due to the size of the acoustic mesh, an advanced fast multipole BEM solver was used. The computation took 3.5 h per frequency for six load cases on a 48 GB RAM Windows 64-bit machine with two quad core processor units integrated.

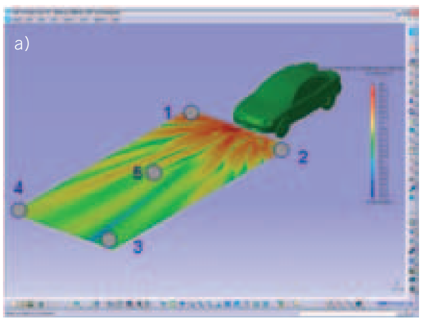
Some typical results for three sound source positions are shown in ❸ for 650 Hz and ❹ for 2500 Hz. More simulations were conducted for sources at other positions allowing an optimization design. ❺ shows



❸ Typical results of sound propagation for three sound source positions at a frequency of 650 Hz: (a) bumper centre, (b) bumper extreme right and (c) wheel housing right



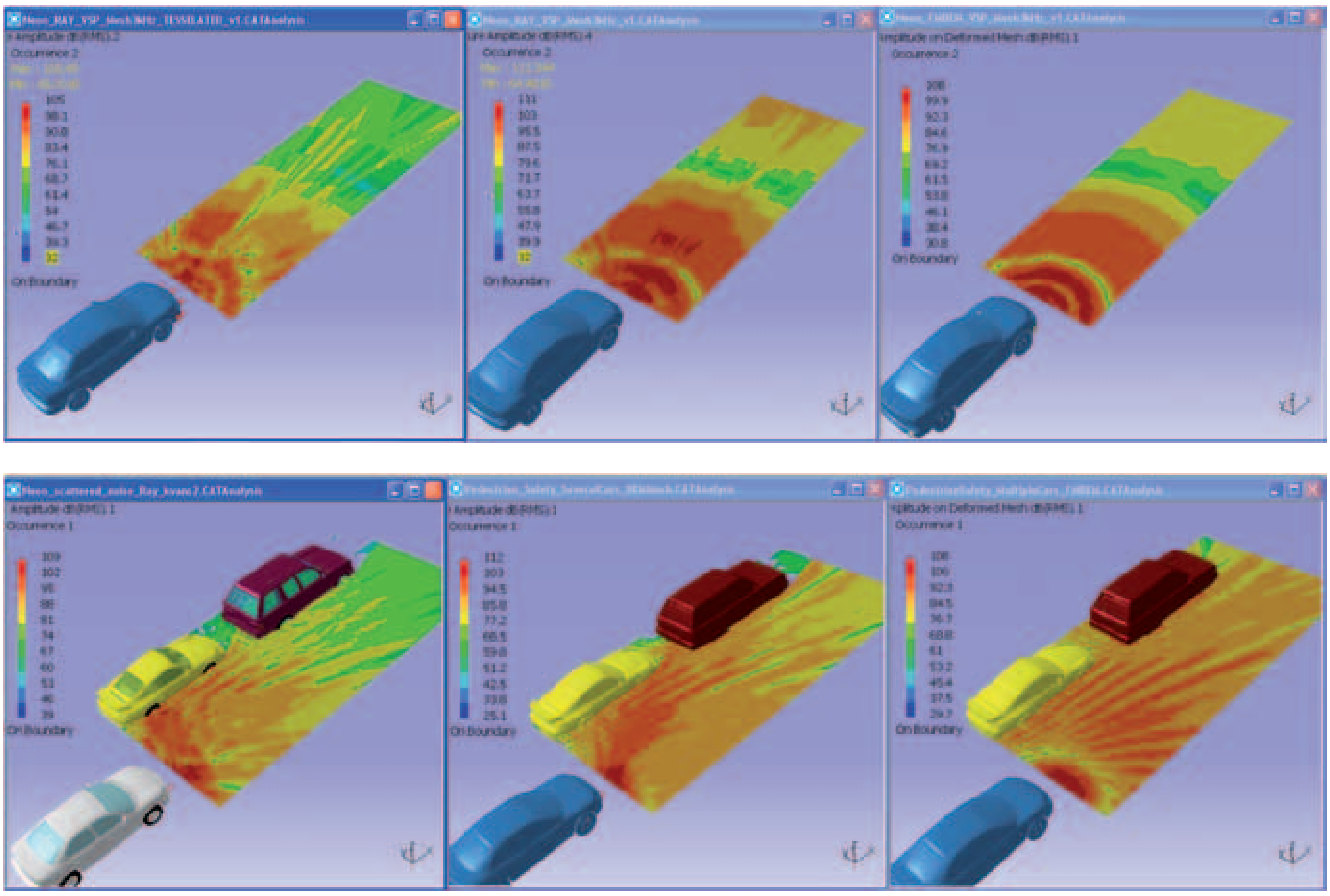
❹ The sound propagation for the three sound source positions at 2500 Hz: (a) bumper centre, (b) bumper extreme right and (c) wheel housing right



b) LISTENER RESPONSE VALUE [dB]

Location	Bumper centre 650 Hz	Firewall 650 Hz	Wheel housing 650 Hz	Bumper centre 2500 Hz	Firewall 2500 Hz	Wheel housing 2500 Hz
1	81	97	70	80	88	82
2	73	84	78	80	80	78
3	79	71	60	73	64	69
4	79	80	62	73	69	59
5	84	85	67	72	70	70

❺ (a) relevant listener locations in surrounding of the vehicle and (b) acoustic values at these different locations



❻ Warning sound propagation in the presence of parked cars at 650 Hz

possible positions of listeners and summarizes the acoustic response values at these locations.

PERCEPTION OF THE WARNING SOUNDS

The presented methodologies, which have proven their usefulness in pass-by-noise simulation, are shown to be instrumental for a proper configuration design of the sound sources to reach maximal warning effect in the danger zone with minimal annoyance for the environment or other traffic users. They also allow investigating the noise propagation impact of road and infrastructure objects, for example allowing optimizing the system design for perception by roadside listeners shielded by parked cars. ❻ shows an example of the impact of parked cars on the sound propagation.

To analyze the real perception it is necessary to combine the sound simulation with the source signal design and to interpret in terms of subjective perception and alert/warning level by actual listening tests. To realize this, the frequency domain BEM propagation results can be transformed into time domain filters as is applicable also in pass-by-noise testing. This approach is actually a time-domain equivalent of the source contribution analysis methodology derived from Transfer Path Analysis [3].

Finally, in addition to the perceived sound emitted by the loudspeakers also the masking effect of the ambient sound is important. In order to have an assessment of the audibility of the sound at the target location, the warning sound contribution as obtained after the application of the propagation filters is summed with a recorded or synthesized ambient sound.

An interesting test that can be performed using the LMS tools is the synthesis of a number of internal combustion engines located next to the VRU in order to have a measurement of the masking effect of the ambient sounds. During this phase it is also possible to use recorded ambient sounds to simulate the passage of an electric vehicle in a pre-defined environment, for example an industrial district where the ambient sound can be complex and loud.

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THE NEW MERCEDES-BENZ ACTROS

After a model lifespan of 15 years, Mercedes-Benz has now launched a new generation of the Actros. The new Actros has been developed specifically to comply with the Euro VI emissions standard. Its six-cylinder inline engine is based on the company's heavy-duty engine platform already used at Detroit Diesel for the US market. At the heart of the new truck is a modular system with seven different cabs, a new frame, a more dynamic chassis and a comprehensive package of driver assistance systems.

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MOTIVATION

While the current Actros generation achieved the Euro II, III, IV and V emissions levels, Euro VI represents the next major challenge regarding a further drastic reduction in emission limits beginning in 2014. In order to implement Euro VI without sacrifice to the driver and operator, Mercedes-Benz Trucks took a very deliberate decision to develop a completely new vehicle. Besides avoiding increased fuel consumption and higher servicing costs, this also enabled the efficient integration of optimizations resulting from new technological advancements. The expectations placed on this kind of new development are correspondingly high. In addition to technological aspects, the focus remained on the needs of the customer and was defined by three key development goals:

: ride comfort
: driving dynamics
: economy.

To ensure target-based product design and efficient development work, the interdisciplinary project work and strict process orientation were also complemented by cross-project investments. This was the only way to achieve and ensure the standards of quality and reliability detailed in the specifications book for the new Actros. Another important milestone in this regard was the establishment of the Development and Testing Center at Wörth. This not only allows calculation/simulation and bench testing to be carried out, but also comprehensive tests involving the overall vehicle under real condi-

❶ Cab versions

tions, for which the boundary conditions are also completely reproducible.

Furthermore, the standardization of reliability validation at Mercedes-Benz Trucks was completely reorganized. These elements ensure that the new Actros arrives on the market equipped with technical innovations as well as optimized details.

NEW CAB

The key priorities as the cab was being developed were economic efficiency for the freight forwarder and well-being for the driver. The manner in which the cab is developed exerts a direct influence over these as a result of optimized aerodynamics, component design and component weight. However, cab development can only impact influential factors such as the everyday stress of transportation operations indirectly. This includes an optimized and ergonomic design for the driver's cockpit as well as maximum comfort and the largest possible cabin interior for the driver's rest periods. Studies conducted in this area show that only a refreshed driver can drive efficiently and effectively in a manner that conserves resources and fuel, thus contributing significantly to a reduction in operating costs [1, 2].

A modular cab in white concept was developed to allow for the wide variety of cabs in a cost-effective manner, ❶. The cab for the new Actros is offered in two different widths of 2.3 and 2.5 m. Two

❷ Aerodynamic development

mounting heights on the frame, also known as cab setup heights, are offered. The high version is fitted with a flat floor in all cases, regardless of the cab width. As a result, also a 2.3 m cab can be offered with a flat floor for the first time. A total of five different roof heights are available. These range from an extremely low roof for car transporters through to the normal, high and Aero roofs all the way to the Giga roof, offering maximum interior space for comfortable headroom.

The last few years have seen a steady increase in the requirements in terms of durability, rigidity and strength of the cab in white structure. These high strength requirements for the new Actros cab (including ECE-R29/03) ensures for the high degree of passive occupant protection that has been achieved. In combination with the coordinated active restraint systems (airbag and belt tensioner) it set new benchmarks, thus reducing the risk of head, neck and chest injuries.

EXTERIOR

The numerous exterior variants are made possible by a modular concept. By combining various add-on parts, it is possible to assemble all basic vehicle types with the associated cabs. The design of the front module, which gives the new Actros its striking appearance, was dictated largely by aerodynamic and stylistic requirements. Thanks to its stylistic perforations, the slatted grille fulfills the extreme cooling performance requirements associated with Euro VI while at the same time providing the front with a visually coherent form.

Two main areas of emphasis stand out from the overall scope of aerodynamic development, ❷:

- The entire cab is designed with wide radii and defined separation edges in a way that optimizes airflow around and under the vehicle.
- The airflow through the engine compartment is regulated actively by means of a radiator shutter. This is particularly important due to the large cooling vents used for Euro VI.

As a result of these measures, for example, the air resistance of the new Actros is reduced by approximately 10 % for the basic cabin alone compared to the predecessor model.

❸ Solo Star cab

INTERIOR

Key requirements for the interior include a high level of comfort for the driver and premium-quality interior components. Studies conducted both by Daimler Research and respected external institutes have arrived at the following conclusion: Only a well-rested driver is capable of performing transport duties efficiently, effectively and safely [1, 2]. The driver must work, live and sleep in the cab around the clock. This means that the cab is the home of the long-distance driver and is designed accordingly as a "three-room apartment". Particular attention was devoted to implementing this concept in the Solo Star cab, ❸. The individual areas are:

- working: the driver's cockpit
- sleeping: the bunks
- living: the stowage facilities and the corner seating unit.

The cockpit is the control center interface between the driver and the vehicle. The driver receives information, operates controls and transmits commands. For this reason, ergonomic design plays a central role in the layout of the cockpit. However, the scope of development also included other considerations, such as appealing design, good tactile qualities and clear forms, all tailored to cope with the tough trucking environment. Only by using a new patented cockpit production process based on Dolphin was it possible to balance the conflicting priorities of optimizing costs and the high quality standards of soft-touch trim parts. The evolution of the driver's seat represents a milestone in terms of cockpit ergonomics. It is 40 mm wider to take account of future anthropometric trends. It also features enhanced individual adjustment possibilities. For example, the shoulder area of the seat can now be specially adjusted.

The sleeping area is completely redesigned from a comfort perspective to provide drivers with the best possible surroundings in which to rest and recuperate [1, 2]. The previous bunk design from the Actros has been improved substantially and enhanced by the addition of a significantly larger mattress and a large-area backrest adjuster. The bunk now consists of a seven-zone cold foam or premium comfort mattress. The latter offers comfort levels equivalent to those found in premium domestic mattresses. To ensure a pleasant microclimate, all mattresses are fitted with a 3D spacer fabric as an underlay.

CHASSIS

Market research has shown that customers consider ride comfort and driving dynamics as being very important. For this reason, the following chassis-specific development targets were defined:

❹ Rear axle

- striking improvement in ride comfort and vehicle dynamic properties
- lightweight design that also retains the brand's defining characteristics of ruggedness and long-term quality
- greater modularity resulting in improved body-mounting flexibility
- consumption-optimized chassis systems and axles.

The chassis of the new Actros adheres to the shared chassis architecture, and the axles originate from the shared axle platform of Daimler Trucks. As a result, architectures and interface dimensions are defined across brands, which enable chassis and axle components to be exchanged efficiently and easily. The chassis layout was re-defined based on the boundary conditions dictated by Euro VI. The basic premise in this context is the one-box concept of the exhaust aftertreatment system, which was positioned as closely as possible to the hot side of the engine to ensure efficient thermal management and NO_x conversion.

FRAME

The frame is a conventional ladder-type frame with a spread frame front end. The rear axle on all vehicles is fitted with air springs, which allows the frame track to be increased compared to the predecessor vehicle. The integrated tubular cross-member is the central element of the frame. This is an innovative welded structure consisting of a steel tube center section and weight-optimized and functionally integrated side sections. The tubular cross-member ensures high torsional strength and shear rigidity of the frame. Along with the wider frame and spring tracks and combined with the frame head and reinforced front-axle connection, this forms the basis for significantly improved driving dynamics. Additional the tubular cross-member is an adept multitasker: It holds the control arm, serves as a basis for the integrated fifth wheel and acts as a compressed air tank.

The frame itself features a continuous hole pattern of 50 × 50 mm for M16 bolts. This ensures that detachable frame components can be positioned easily and provides bodybuilders with corrosion-protected bolted connections. For the Actros, this means that a wide variety of wheelbases and frame overhangs can be implemented without major difficulty. The challenge inherent in this extremely wide variance is to ensure that components are positioned correctly during assembly. To achieve this, the outlines of detachable frame components, including information about the fasteners to be used, are traced by laser onto the longitudinal frame member. Depending on the wheelbase and vehicle type, the longitudinal frame member is constructed of high-strength steels with low wall thicknesses and local reinforcements. It combines with the optimized topology of the frame cross-members to make a significant contribution to achieving the target weight. In addition to a consistent policy of lightweight construction based on components designed to cope with their respective loads, aluminum and fiberglass-reinforced plastic were also used extensively in large chassis components for the first time.

AXLES AND STEERING

The target for the lateral dynamic properties of the Actros was to achieve stable understeering driving characteristics, which, in conjunction with firmer center alignment of the steering, reliably suppresses any oscillating movement of the semitrailer rig in response to steering inputs by the driver. The decisive breakthrough was achieved with the design of a new rear axle guide, which brings about the desired understeering steering characteristics under the influence of lateral force. This was achieved by replacing the upper strut level, normally configured as a wishbone, with a short arm/long arm design, ❹. This allowed the axle guide's momentary center of rotation to be positioned behind the axle.

This steering characteristic is supported by the stiff frame and improved straight-line stability of the front axle. In addition, the steering mechanism and characteristic curves were completely redesigned. As a result, Mercedes-Benz has managed to achieve a drastic improvement in lateral dynamics and to convey to the driver an impressive safe driving experience without making compromises. However, the axles and steering system also contribute their share to the fuel savings achieved by the new Actros. For example, the newly developed variable power steering pump that regulates the flow of power steering fluid in line with requirements, thus cutting no-load losses when the vehicle is driving straight ahead, or the axles, with their efficiency-optimized gearing and reduced oil churning losses.

ENGINE PERIPHERAL EQUIPMENT

The engine peripheral equipment in the chassis includes the cooling system, the air intake, engine mounting, and the exhaust gas and tank systems. The new Euro VI engine generation and the newly developed secondary water retarder impose stricter requirements on the cooling system in terms of coolant pressure, coolant flow and cooling capacity. In order to meet these requirements in the installation spaces available, a new family of cooling modules was developed. A newly developed and quiet ducted fan with a diameter of 810 mm along with the large coolers and newly adapted fan clutch ensure that the cooling requirements are met at minimum fan speeds, which improves fuel consumption. Further fuel savings were achieved by a continuously regulating water pump.

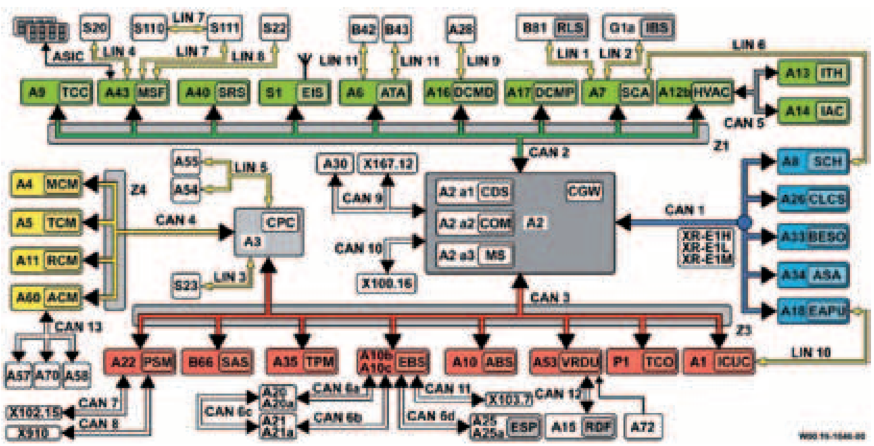
As a result, the chassis of the new Actros offers a high degree of modularity, exceptional variance, improved body mounting ability and low curb weight. It also helps reduce fuel consumption, improve safety and, not least, offers impressive driving dynamics and ride comfort characteristics of the kind that only a completely new design can deliver.

MECHATRONIC SYSTEMS

The challenges that a modern commercial vehicle faces can be successfully overcome only through the use of innovative electronic systems. With innovative electronic/electrical systems and a fully-networked overall architecture, the mechatronic components used in the new Actros make a decisive contribution toward achieving the benchmark position targeted for the vehicle with regard to comfort, driving dynamics and efficiency.

All electronic and electrical functions in the vehicle are based around the electronic/electrical architecture, which was redesigned and developed for the new Actros as a result of the following premises: The safety and availability of the overall system was given top priority in the electronic/electrical design. For instance, the use of redundancy and emergency running concepts enables the vehicle to be operated safely in the event of externally induced malfunctions.

To ensure that the objectives outlined before are fully achieved, the overall architecture shown in ❺ was implemented for the new Actros: the cabin CAN (green) integrated in the cab; the chassis CAN (red) and exterior CAN (blue) in the chassis operate at 500 kBd. The complex control functions in the drivetrain require that the components involved be closely networked. This is taken into account by the introduction of the powertrain CAN running at 667 kBd. The individual subsystems in turn contain local networks for connecting intelligent sensors and actuators, and were implemented using LIN or dedicated CAN networks, depending on the data volume. All bus systems are linked to one another via gateways, which facilitates the implementation of fully networked groups of functions.



❺ Electronic networking topology

ELECTRONIC/ELECTRICAL SYSTEMS AND ELECTRICAL ENERGY MANAGEMENT

The basic task of supplying electrical energy to all systems in the vehicle was achieved by integrating several central components. Central sensor/actuator modules that contain all the basic functions required to distribute and monitor the energy supply were integrated into both the cabin and the chassis. To keep the complexity of individual components at a reasonable level with regard to hardware layout and software, particularly for well-equipped vehicles, and to minimize the necessary cabling expenditure, the functions were deliberately allocated between two components.

If the capacity of the maintenance-free batteries falls to a critical level while the vehicle is not operating, the vehicle automatically switches electrical consumers off or informs the driver so that the vehicle can be restarted without fail. Even though the complex functions of the central electronic/electrical systems are generally unnoticed by the driver, they still make an important contribution to the comfort and safety of the vehicle.

In contrast to the functions described before, the electronic systems at the driver’s seat and in the cabin interact directly with the driver. The centralized display of information takes the form of the newly developed instrument panel equipped with a 4" or 5" TFT display and the innovative Truck Control Center (TCC) in the center console. To ensure optimum haptic operation of the system, the driver is provided with steering wheel buttons, an ergonomically positioned adjustable switch panel and a new rotary pushbutton in the mid and high variant of the TCC, ❻.

All of the displays feature a patented menu layout that allows intuitive navigation throughout all levels of the display. All menu screens are organized in a matrix, and users can recognize where they are within this matrix at all times. The most important status values are constantly displayed in a fixed structure below the matrix so that the driver can see all the necessary information at a glance. The new Actros also marks the debut of an innovative multifunction in the form of the optional Highline vehicle key. In line with the HMI concept in the

❻ Instrument panel, Truck Control Center and multifunction key

vehicle, selected status information can be shown on the high-resolution color display of the key, and various systems can be operated, such as level control, exterior lighting and auxiliary heating and cooling.

CHASSIS CONTROL SYSTEMS AND ELECTROPNEUMATIC BRAKE

On multiple occasions over the past few decades, the Mercedes-Benz Actros has launched new brake and control systems on the market that each represented technological milestones in commercial vehicles. In keeping with this tradition, the new Actros is also equipped with an innovative electropneumatic brake system that guarantees minimum stopping distances and ensures that the vehicle remains stable in critical limit situations. This was accomplished using an efficient pneumatic system that provides the braking energy appropriate to the situation and ensures maximum system availability. Assisted by evolved ESP control algorithms, the intelligent control system intervenes selectively in the braking system if required in order to stabilize the vehicle depending on the load and driving situation. Furthermore, the electronically adjustable brake forms the basis of innovative assistance systems. The air sprung model types of the new Actros are equipped with an electronically controlled chassis that makes an important contribution to ride comfort and vehicle safety. An optional roll stabilization function is also available.

DRIVER ASSISTANCE SYSTEMS

With Active Brake Assist ABA2, the new Actros is equipped with the most innovative and efficient active safety system [3]. With the aid of radar sensors, ABA2 continuously analyzes traffic conditions, warns the driver of the danger of an accident, and, if the driver fails to take action, automatically initiates an emergency stop in response to moving and stationary obstacles. Thanks to this system, serious consequences of accidents are reduced significantly or even avoided altogether. In addition, the vehicle is equipped with a camera-based Lane Assistant, which issues a warning if the driver leaves the lane, and an adaptive cruise control for enhanced ride comfort and safety. The new Actros is also the first commercial vehicle to offer an adaptive cruise control with a stop and go function, ❼.

ELECTRONIC/ELECTRICAL DEVELOPMENT AND VALIDATION PROCESS

The successful implementation of the complex mechatronic functions required a stringent electronic/electrical development and validation process throughout the development period. This is the only way to ensure maximum availability of mechatronic systems in the vehicle for the customer. All development maturity levels of the systems were subjected to extensive testing at component, system and vehicle levels as part of a multi-stage approach with the aim of identifying and eliminating errors as early as possible. The necessary actions identified during this were analyzed, and suitable measures were initiated and validated [4]. As a result, the electronic systems make a significant, reliable and long-term contribution to achieving the vehicle's benchmark status and ultimately to the satisfaction of the customers.

ENGINE AND DRIVE SYSTEM

In addition to the numerous innovations and further developments of the mechatronic systems, the chassis and the cab, it goes without saying that the new Actros also incorporates numerous special features in its powertrain. The new BlueEfficiency Power engine generation was specifically developed for Europe and the Euro VI emission standard and is based on the extensively tested new heavy-duty engine platform of Daimler Trucks. In this case, the OM471 initially covers an output range of 310 to 375 kW with maximum torque of between 2100 and 2500 Nm, thus ensuring superior performance while delivering optimized fuel consumption. The high level of torque available at engine speeds below 1000 rpm is particularly apparent and helps drive down the engine speed range on normal route profiles to 800 to 900 rpm. In combination with the TopTorque functions (a temporary increase of torque by 200 Nm in twelfth gear), a rear axle ratio of 2.611 is offered as standard in the new Actros.

The transmission in the new Actros is handled exclusively by the fully automated Mercedes PowerShift transmissions. Compared with their predecessor variants, these units have been significantly optimized with regard to the shift speed of the twelve gears as well as their control sensitivity. Consequently, it was possible to increase substantially the proportion of EcoRoll phases during normal vehicle operation, which in turn benefits fuel efficiency. In addition to the familiar additional functions such as the rocking and power modes, a crawl function is integrated – for the first time at Mercedes-Benz.

In view of the strict requirements of the Euro VI emissions limit, an exhaust aftertreatment process incorporating selective catalytic reduction (SCR) technology, cooled exhaust gas recirculation and particulate filters was developed. A further highlight of the powertrain is the secondary water retarder (SWR), which replaces the oil retarder used previously. Despite an increase in output from 3200 to 3500 Nm, the weight of the system was reduced by approximately 35 to around 65 kg. This was only made possible by integrating the secondary retarder into the vehicle coolant circuit. In doing so, it was possible to make additional use of the increased cooling required for Euro VI. In addition to the weight reduction previously alluded to, this also ensures significantly improved retarder availability. Coupled with the proven five-stage retarder control system from Mercedes-Benz Trucks, this enhanced availability in particular ensures a degree of vehicle automation that optimizes comfort, saves fuel and conserves the service brake while at the same time providing a higher level of safety.

TESTING

Fully equipped with these innovations and further developments, the new Actros covered some 20 million km of road tests. Added to this are countless hours spent on test stands and simulators, because of which it can be stated without any doubt that no Mercedes-Benz truck has ever been subjected to such intensive validation as the new Actros. At the same time, also the maintenance intervals were increased, resulting in lower life cycle costs for the vehicle operator. All of the technical highlights play their part in achieving the targets set for ride comfort, driving dynamics and economy.

While it will not be possible to verify the exceptional standard achieved, particularly in the areas of ride comfort and driving dynamics, until after initial driver feedback has been received from "live" vehicle trials, Mercedes-Benz has already managed to set a record for the key profitability factor over which the manufacturer has influence – the consumption of diesel and AdBlue: As part of the Record Run 2011, two variants of the new Actros (Euro VI and Euro V) competed against the previous record holder, the Euro V Actros3, in July 2011, ❽. Over a distance of 10,000 km along a typical east/west transport route between Europe's largest industrial port in Rotterdam and Stettin in Poland, consumption of diesel and AdBlue was measured under Dekra supervision. The entire road test took place under normal route, traffic and weather conditions. To ensure that only the effects of evolution of the new Actros over the Actros3 were evaluated, a great deal of effort was devoted to excluding the impact of driving style, the trailers used and technical boundary conditions such as tires. The outcome of the road test came as a surprise even to die-hard critics: The Euro VI version of the new Actros recorded a 4.5 % reduction in diesel consumption and a 44.2 % reduction in AdBlue consumption compared with the Euro V Actros3. The Euro V variant of the new Actros turned in an even more impressive result with 7.6 % lower fuel consumption. If one applies these consumption figures to a moderate average annual long-haul mileage of 130,000 km, this yields an annual saving of approximately 2700 l of diesel per truck. In addition to the environmental benefits, this will also impact significantly on the operating costs of the vehicle operators, particularly in the context of rising fuel prices.

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❼ Stop and go function

❽ The new Actros on Record Run 2011

INNOVATIONS AND TRENDS IN ASSISTANCE SYSTEMS FOR TRUCKS

In accordance with its "Vision Zero" policy, the EU intends to once again halve the number of fatalities in road traffic accidents in Europe by 2020. One of the measures aimed at achieving this is to require all new heavy commercial vehicles to be equipped with an advanced emergency braking system from 2013 on. OnGuardPlus from Wabco is the first system in the commercial vehicle sector in compliance with the expected regulations.

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BACKGROUND

Between 2001 and 2010, annual fatalities related to road traffic accidents in Europe fell by 46 % from 54,000 to 29,000 [1]. Even though these figures closely match the ambitious goal of the European Union to halve the number of road fatalities by 2010, there is still room for improvement, particularly regarding commercial vehicles, for which maintenance condition, driver qualification and international transit present further challenges. It is alarming that each year accidents involving trucks cause approximately 6,500 road deaths in the European Union [2]. Overall, commercial vehicles represent 7 % of all kilometres driven in Europe [2], while in terms of accidents, they are twice as dangerous per kilometre driven as passenger cars.

The European Union has launched several regulatory initiatives to accelerate the broad implementation of more sophisticated safety systems. For example, Electronic Stability Control (ESC) has been mandatory for commercial vehicles since November 2011. In addition, Advanced Emergency Braking Systems (AEBS) will be required on new heavy commercial vehicles starting in November 2013 [3].

DEVELOPMENT OF ACTIVE SAFETY SYSTEMS FOR COMMERCIAL VEHICLES

The first few generations of active safety systems for commercial vehicles helped to stabilise and control the vehicle while braking. They include the industry's first ABS system, which was pioneered by Wabco and Daimler for application on trucks and buses in 1981, as well as EBS, a system launched in 1996 by Wabco, and their extension – ESC – which has been available since 2001, ❶.

❶ Wabco ESC ECU module

❷ Test drive with ABS at the Wabco test track in Jeversen (Germany)

ABS is used to prevent locking of a vehicle's wheels as a result of road friction being lower than the braking forces, ❷. In 1991, the European Union made ABS mandatory for heavy commercial vehicles. Transmitting the driver's actuation of the brake pedal into electronic signals, EBS significantly reduces the braking distance of a commercial vehicle and also greatly improves driving stability and steerability. As an extension of EBS and ABS, ESC helps to correct any possible instability and helps to prevent the vehicle from oversteering or understeering, ❸. Since November 2011, electronic stability control has been mandatory for all new commercial vehicles in Europe.

OVERVIEW OF DRIVER ASSISTANCE SYSTEMS

Examples of advanced driver assistance systems (ADAS) are Collision Warning Systems (CWS) and Adaptive Cruise Control (ACC). They help to control the distance to the vehicle ahead and if necessary warn the driver to react. Furthermore, ACC can automatically adjust the vehicle's speed to maintain a safe following distance [4].

In a further development, Collision Mitigation Systems (CMS) not only warn the driver in collision-imminent situations but will also autonomously apply the brakes to decrease the impact of a collision. Current versions of ACC, CWS and CMS, however, are not ready to react to stationary vehicles ahead in order to address potential accidents.

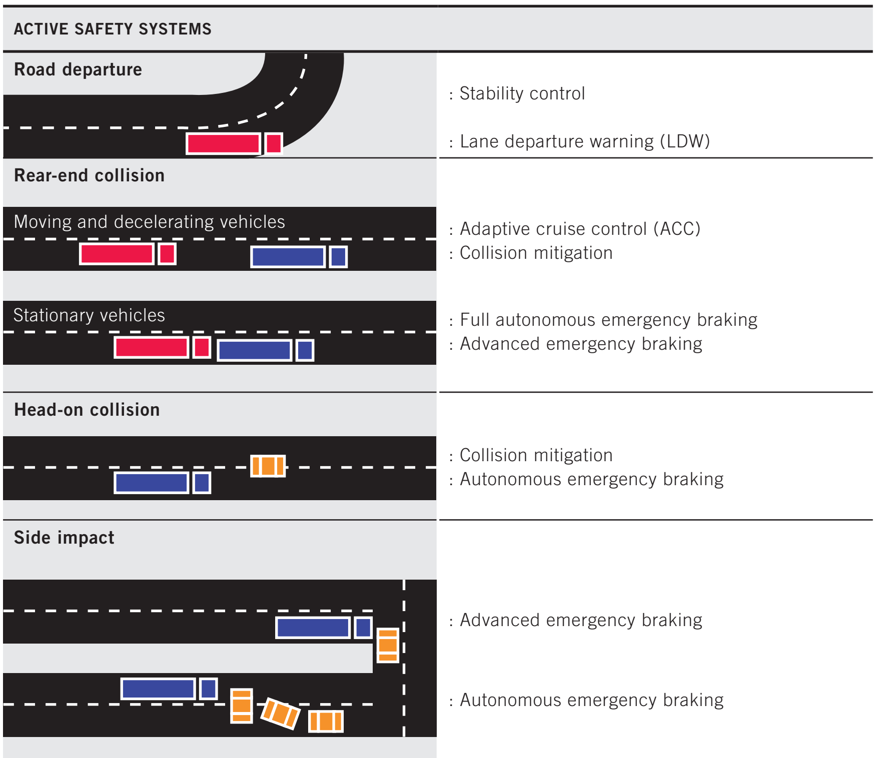
Another kind of ADAS is Lane Departure Warning (LDW). LDW could nearly halve the number of commercial vehicle accidents on highways caused by lane departures simply by alerting drivers who are unintentionally leaving their current lane [5]. ❹ shows an overview of dangerous road situations and safety systems that help to mitigate them.

ONGUARD COLLISION MITIGATION SYSTEM

One example of an advanced safety system that combines ACC technologies with brake application and CMS capabilities is OnGuard from Wabco. It is the first collision mitigation system on the North American market, and was introduced by Meritor Wabco in 2008.

OnGuard can automatically maintain a safe following distance and helps to avoid or reduce the impact of rear-end collisions by monitoring the traffic ahead, recognizing potentially dangerous situations and by braking as needed. Its forward-looking radar sensor uses advanced algorithms to monitor the distance, speed and deceleration of a vehicle ahead. With its internal gyro, the system is also able to select the relevant objects in the radar beam. When detecting that a potential collision with a moving or decelerating object is developing, the system sends a series of audible and visual warnings through an in-cab dashboard display alerting the driver to take the appropriate corrective action. If the driver does not immediately decelerate the vehicle, OnGuard automatically reduces engine speed and provides the necessary braking power by applying the service brakes, which results in a deceleration of up to 3.5 m/s^2, almost 50 % of a full brake application.

❸ Test drive with ESC at the Wabco test track in Jeversen (Germany)



❹ Dangerous road situations and systems that can help to prevent accidents in these situations

Even if an accident is unavoidable, OnGuard's intervention effectively helps to mitigate the impact of a potential collision. On the other hand, if the driver reacts within an appropriate time and starts a braking or steering intervention, the system disengages and allows the driver to take full control of the vehicle. More than 10,000 OnGuard systems have been sold as of March 2011. This technology has proven its effectiveness, as customers have so far collectively driven more than 1.6 billion km protected by OnGuard.

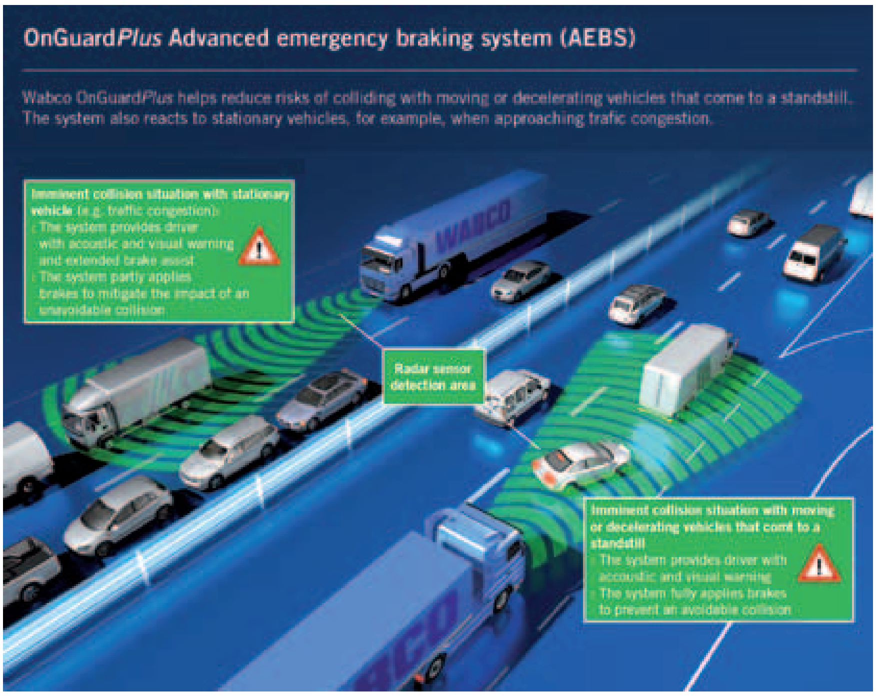
ONGUARDPLUS EMERGENCY BRAKING SYSTEM

OnGuardPlus takes the technology of the OnGuard collision mitigation system to the next level. It is an advanced emergency braking system (AEBS) that was first publicly demonstrated in September 2010 by Wabco. The system extends the OnGuard family's functional range by integrating the latest EBS and ABS technology. Unlike previous systems, OnGuardPlus reacts to moving and decelerating vehicles ahead that come to a standstill, and its collision mitigation function also reacts to stationary vehicles ahead, for example when approaching traffic congestion as shown in ❺. While OnGuard is a collision mitigation system with autonomous partial braking of 35 to 40 % in collision-imminent situations, the OnGuardPlus system fully applies brakes in situations with moving or decelerating vehicles.

It uses a single radar sensor and proprietary algorithms to monitor and analyse vehicles ahead. The sensor's detection area covers the complete width of its own lane, including an area 3 m ahead of the preceding vehicle and both neighbouring lanes ahead.

When a collision-imminent situation is detected, OnGuardPlus initiates several steps of escalation, ❻. At first, a combined audible and visual warning is triggered to get the driver's attention. If the driver does not react to this warning, the system will induce a haptic warning. This indicates the last chance to prevent a crash without the system's intervention. If the driver still does not react, then the system will initiate autonomous braking.

If the brake pedal is even slightly applied during the collision warning, OnGuardPlus will switch to the Extended Brake Assistant (EBA) function, which commands a service brake application to decelerate the vehicle. Under good friction conditions, this step will stop the vehicle

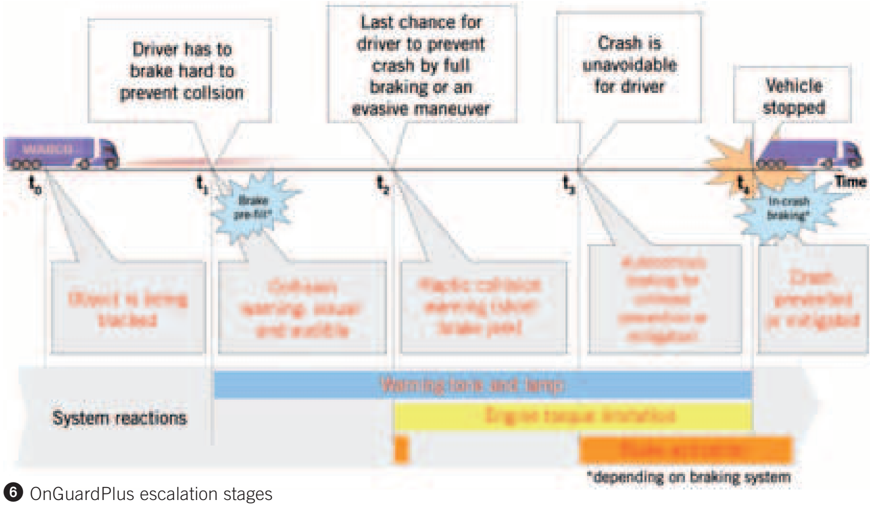


❺ The reaction of OnGuardPlus in collision-imminent situations directly behind the preceding vehicle – regardless of whether or not the driver applies the brake pedal fast and strongly enough.

In combination with a Wabco braking system during the collision warning phase, the AEBS orders the braking system to apply a "response pressure" to prepare the foundation brakes for an upcoming hard braking event. This "pre-fill" reduces the delay time of the brakes when being subsequently actuated by the driver or by the emergency braking system. The time saving that is achieved is between 100 and 300 ms, depending on the vehicle type. The stopping distance reduction for this speed (90 km/h) is 2.5 to 7.5 m.

The system integration also enables "in-crash braking." It helps to improve situations when a crash is unavoidable. This includes, for example, close cut-in manoeuvres of a slower preceding vehicle or low-friction conditions. During in-crash braking, the brake application continues as long as possible. The impact energy can be reduced by utilisation of wheel brakes instead of using the crush zones of the other accident participant.

OnGuardPlus is the commercial vehicle industry's first system to be in compliance with the European Union's expected regulation to make AEBS mandatory on new heavy commercial vehicles for new vehicle type approvals in 2013. The system will be available from 2012 for trucks and buses worldwide, which is timely for original equipment manufacturers to meet the new European regulatory requirements.



❻ OnGuardPlus escalation stages

FURTHER DEVELOPMENTS AND OUTLOOK

OnGuard paved the way for new developments in driver assistance systems – such as OnGuardPlus. Another more advanced system is OnGuardMax, the first system for autonomous emergency braking (AEB) that, together with a full brake application, reacts to moving and stationary vehicles alike and can bring the vehicle to a complete stop to avoid a collision. This system was demonstrated by Wabco at IAA Commercial Vehicles 2008 and will be available to truck and bus manufacturers from 2015 onwards [6].

Other currently developed systems will be ready for market launch in the near future. These include blind spot detection, lane change assistants and systems that monitor the vehicle's immediate surroundings. There are also systems that track information on driver behaviour and allow the timely identification and prevention of risky driving behaviour before accidents are caused.

Policy makers and industry leaders in the European Union and worldwide have made road safety a priority, and commercial vehicle technology leaders are committed to sustaining the pace of development. Legislation will also speed up the implementation of sophisticated electronic safety technologies. Meanwhile, the European Union is issuing directives promoting higher levels of training and education for professional drivers, and it is working on making the infrastructure of roads safer. Altogether, these measures increase the likelihood that the European Union can accomplish its new goal to halve fatal road accidents by 2020.

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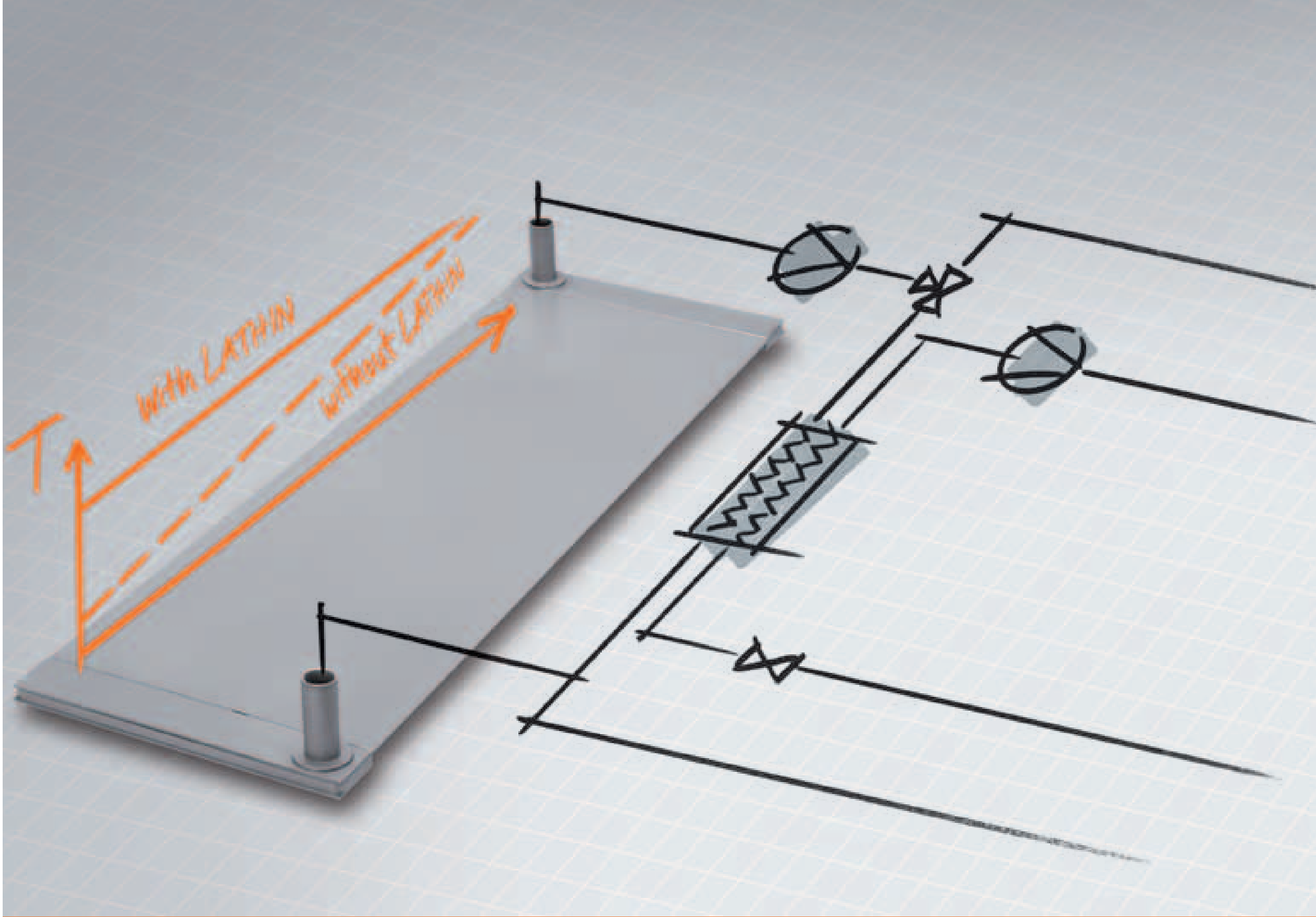

THERMAL MANAGEMENT OF HIGH-PERFORMANCE LITHIUM-ION BATTERIES

A new method permits the optimisation of the temperature control system for lithium-ion traction batteries with regard to cost and weight, while still ensuring the integrity of the cooling function. The greatest cost-reduction potential is afforded by an intelligent coordination of system components and the use of Lathin technology from Behr. This technology makes it possible to use smaller pumps and reduced-power components without adversely affecting the temperature homogeneity of the batteries.

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TASK

In electric and hybrid vehicles, temperature-regulating systems keep traction batteries within a defined temperature range [1]. Here, the design objective is not only to ensure the functional reliability of such sytems but also to optimise them in terms of cost, weight and energy efficiency. ❶ shows an example of a refrigerant circuit, with a chiller – installed parallel to the evaporator – that serves to transfer heat between the refrigerant and the coolant of the secondary circuit. In the coolant circuit, depending on the operating point, either the chiller or the low-temperature radiator (LTR) is swept by coolant in order to cool the battery.

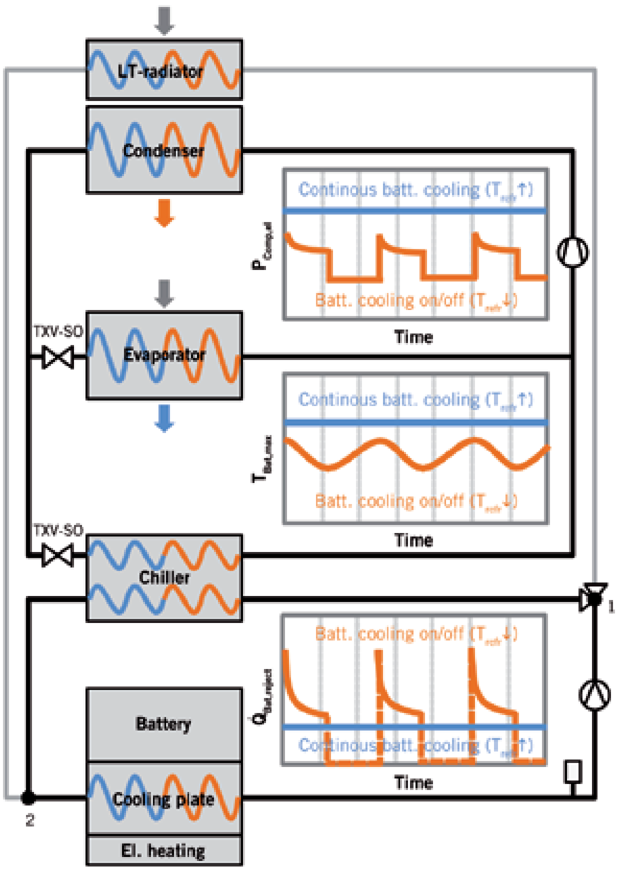
Since the system components are interdependent, an overall system perspective is essential [2]. For optimisation purposes, a thermohydraulic analysis is combined with a cost and weight calculation. By way of example, the following discusses a system optimisation for a base-cooled HV battery of a hybrid vehicle with an energy content of 1.5 kWh.

SYSTEMS AND COMPONENTS CONSIDERED

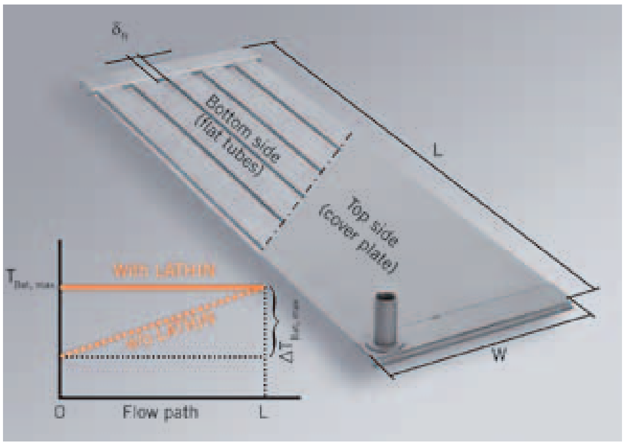
The following considers the combination, as depicted in ①, of a chiller (1-Ch-2-CP-1) and LTR system (1-LTR-2-CP-1) for battery cooling. The chiller subsystem is made up of the following components: cooling plate, chiller, pump, fluid lines and surge tank. The complete system is also supplemented by an LTR with additional coolant lines and a changeover valve. The use of the LTR allows, in the case of low ambient temperatures, energy-efficient cooling of the battery without using the electric compressor.

The battery cells should not exceed a maximum temperature $T_{Bat,max}$, nor should they exceed a maximum temperature spread $\Delta T_{Bat,max}$ among each other.

The system for $T_{Bat,max}$ is designed for a high ambient temperature (→ refrigerant temperature T_{refr} ↑) with the maximum battery dissipation loss to be continuously dissipated. In the case of continuous cooling, the dissipation loss corresponds to the heat rejection (here: $Q_{Bat,reject}$ = 800 W, ① blue



❶ Coolant and refrigerant circuit



❷ Behr modular tube cooling plate

line), so that the maximum permissible battery temperature is maintained.

Transient conditions affect the efficiency and response of the system. ① shows that, at the same battery dissipation loss as for the $T_{Bat,max}$ configuration and at a low ambient temperature (→ T_{refr} ↓), continuous cooling is not required (orange line). After exceeding the (in this case, lower) battery maximum temperature, and after the opening of the chiller expansion valve, the heat rejected into the coolant circuit is greater than the battery dissipation loss.

In order to maintain a comfortable climate and cool the battery at the same time, a higher electric compressor power is required, which, as can be seen in ①, is reduced as the quantity of battery waste heat to be rejected decreases. In the case of an on-off control, the battery cooling is switched off as soon as the battery cell temperature falls below a specific temperature. Consequently, the chiller is no longer swept by refrigerant, the compressor speed is reduced and the battery heats up.

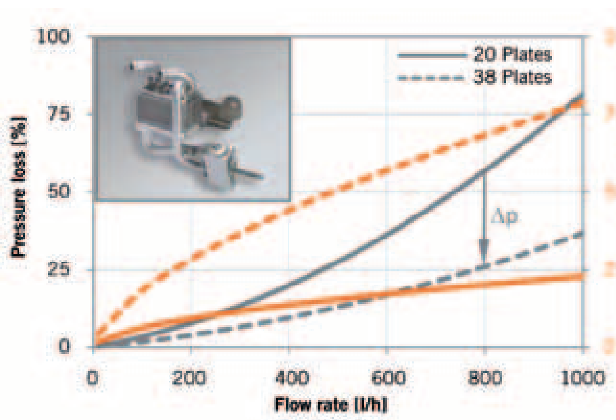
The greater power that is dissipated directly after cooling has been switched on results in greater coolant heating between the inlet and the outlet of the cooling plate than in the steady-state situation. In order to limit the temperature spread between the battery cells (e. g.: $\Delta T_{Bat,max} \geq 4$ K), additional optimisation calculations are carried out. For this purpose, a larger heat rejection is used (here: $Q_{Bat,reject} = 1200$ W).

BATTERY COOLING PLATE AND LATHIN

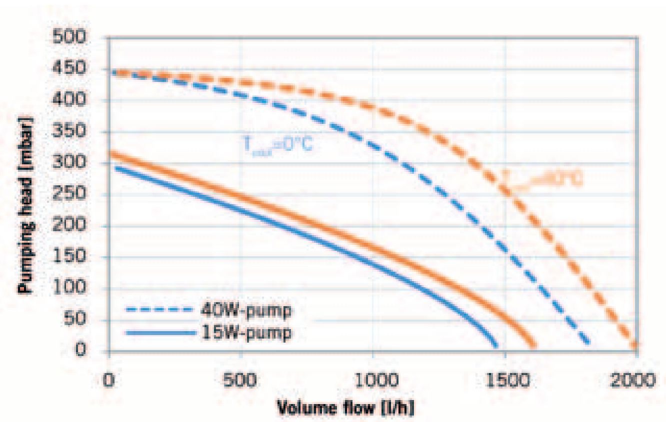
The study investigates a cooling plate consisting of extruded flat tubes and corresponding manifolds with the following dimensions: 500 mm × 250 mm × 5 mm, ❷. In order to adjust the heat transfer and pressure loss in the cooling plate, the tube pitch (δ_{ft}) is adjusted by small increments. The cost function used for the optimisation will depend, among other things, on the materials used and the number of flat tubes.

The battery power and lifetime depend to a large extent on homogeneous cooling. To prevent extreme heating of the fluid with an increasing flow path length, the temperature gradient in the coolant (ΔT_{cool}) is usually reduced using a high volumetric flow rate. Lathin technology from Behr ensures efficient temperature homogenisation (locally adapted thermal interface). The thermal interface between the cooling plate and battery cells, which is in any event required for tolerance compensation and for electrical insulation, is locally modified in such a way that, even with small volumetric flow rates, temperature differences between the cells are compensated for. In cases where homogeneity is less critical, the thermal interface can be realised without local adaption. In both cases, the costs are largely dictated by the quantity of thermally conductive material required.

The chiller is a compact heat exchanger made of thermally and hydraulically optimised stacked plates (Behr standard: 20, 38 and 56 plates). The power increases with the difference in temperature between the refrigerant and the coolant, and the coolant volumetric flow rate, ❸. The coolant-side pressure loss increases in accordance with the volumetric flow rate, and decreases with an increasing number of stacked plates exposed to the flow.



❸ Chiller pressure loss and chiller performance at coolant temperature T_{cool} = 25 °C and refrigerant temperature T_{refr} = 11 °C



❹ Pumping head as a function of volume flow and coolant temperature

Property	Pump	Chiller	δ_{Ft}	A_{LTK}	d_{2KP1}	d_{1Ch2}	d_{1NTK2}
			[mm]	[dm²]	[mm]	[mm]	[mm]
Chiller/LTK system	15W; 40W	20; 38; 56	0…28	5…12	8…15	8…15	8…15

❺ Variation of components and component properties

The air flow surface A_{LTR} of the 26 mm-deep LTR considered for the system optimisation changes within a range from 5 to 12 dm² – at a constant air mass flow density of 3 kg/(m²s). The optimisation tool includes correlations for heat transfer and pressure loss. The costs consist of a fixed amount and an amount dependent on the size of the LTR.

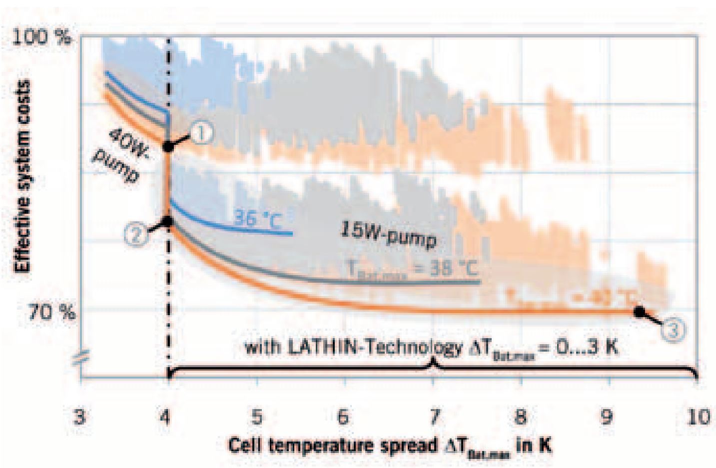
The study uses two pumps with 15 and 40 W nominal capacity – with pumping heads for a maximum of 300 and 450 mbar. The pump characteristics depend on the coolant temperature, ❹. The weight and costs of the pumps correspond approximately to their respective capacity.

The lines selected (internal diameter 8 to 15 mm) vary depending on the individual section. The wall thickness of the plastic lines is considered to be constant at 3.5 mm. A larger line cross section may reduce the pressure drop; however, it involves an increase in materials used and in the cooling water charge, and a corresponding increase in weight and costs.

CALCULATION METHOD

Selecting a cost-optimised system involves, in the first instance, calculation of the thermal properties and also of the manufacturing costs and the weight of each cooling system that can be created by variation of the components. To this end, a cost and weight calculation is added to the thermohydraulic calculation method BISS (Behr Integrated System Simulation [3]). The validated models of the individual components form the basis for the method. For each system, four steady-state calculations must be made in order to determine both of the modes "LTR mode" ($T_{Amb} < T_{LTR/Ch}$) and "Chiller mode" ($T_{Amb} \geq T_{LTR/Ch}$) under the respective critical conditions of maximum battery temperature and maximum battery temperature spread.

In this study, by way of example, the most important components and system properties are adapted by making small adjustments, ❺, and this results in several hundred thousand variants. Owing to the efficient calculation method, the calculations can be used for every variant and there is no need to use an optimisation algorithm. Lighter systems should be favoured in the overall system assessment. Thus, the system weight is converted into a cost equivalent using a factor of 5 Euro/kg, and the effective system costs are calculated by this means.



❻ Effective system costs as a function of thermal properties (switching temperature chiller/LTR = 15 °C)

RESULTS

❻ shows the actual costs based on the thermal variables, for a system that switches from the LTR to the chiller at an ambient temperature of 15 °C. It is possible to observe two sections, each of which can be linked to a pump. The significantly higher costs and the greater weight of the 40 W pump cannot be compensated for even by a reduction in the weight and the cost of the other components. The lines represent the most cost-effective system for each pair of the variables $T_{Bat,max}$ and $\Delta T_{Bat,max}$. It is immediately apparent that higher permissible battery temperatures and temperature spreads allow for more cost-effective and lighter systems.

Consideration of three selected systems, ❼, with comparable thermal properties ($T_{Bat,max}$ and $\Delta T_{Bat,max}$) clearly reveals the potential for reducing weight and costs.

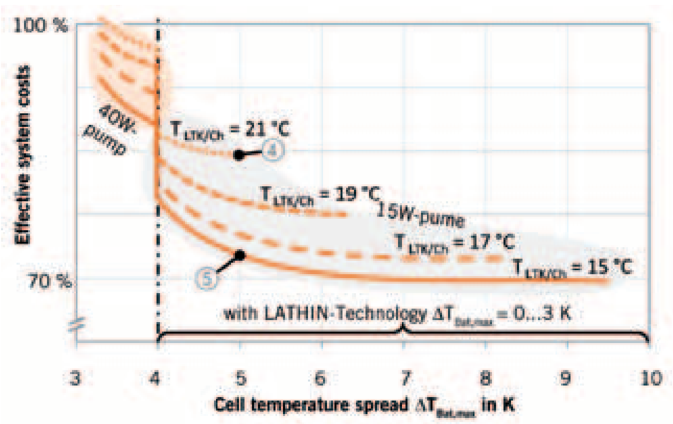
System 1 is the most cost-effective 40 W pump system that can still cool the battery to 40 °C under critical conditions. By changing to a 15 W pump and making corresponding adjustments to the other components, a 15 % cost reduction can be easily achieved with the same temperature spread (System 2). However, the system weight then increases by almost 5 %, to 6.4 kg, in spite of the lighter pump. In System 3, a further cost reduction of 6 % together with a reduction in weight of 20 % can be achieved without increasing the temperature spread, thanks to the use of Lathin technology (without Lathin, there would be a $\Delta T_{Bat,max}$ of 9.3 K).

To ensure the greatest energy efficiency of the temperature control system, it makes sense to change from the LTR to the chiller only in the case of high ambient temperatures. However, to permit sufficient battery cooling, it is necessary for the LTR, the lines and in some cases even the pump to have larger dimensions. Since this increases the system weight, the energy efficiency should be taken into account when selecting the changeover temperature; however, this step is not covered in this study.

❽ represents the effect of the changeover temperature $T_{LTR/Ch}$ for systems with a maximum battery temperature of 40 °C. The main links between temperature spread and actual system costs correspond to those described above. This figure also shows that the costs rise significantly as the changeover tempera-

PARAMETER	SELECTED SYSTEMS				
	①	②	③	④	⑤
P_{Pump} [W]	40	15	15	15	15
Chiller	20	56	38	38	20
A_{LTK} [dm²]	5	5	10	12	5
d_{1Ch2} [mm]	10	15	12	8	13
d_{1NTK2} [mm]	10	15	8	15	12
d_{2KP1} [mm]	12	15	8	14	11
δ_{Ft} [mm]	0	0	28	0	0
V_{min} [l/h]	510	495	203	364	350
m [kg]	6.1	6.4	5.3	6.8	5.5
$T_{Bat,max}$ [°C]	40	40	40	40	40
$\Delta T_{Bat,max}$ [K]	4	4	<3*)	<3*)	<3*)

❼ Properties of selected system configurations (*with Lathin)



❽ Effect of switching temperature chiller/LTR on effective system costs ($T_{Bat,max}$ = 40 °C)

ture increases. Cooling systems with a changeover temperature of up to 21 °C can still be realised with the components considered here. However, owing to the limited heat conduction in battery cells and the thermal interface, cooling with an LTR is no longer possible from an ambient temperature of approximately 22 °C.

Systems 4 and 5 in ⑦ show the increase in costs when the changeover temperature is raised while maintaining the maximum battery temperature and temperature spread. This means that a system with a changeover temperature of $T_{LTR/Ch}$ = 21 °C is approximately 23 % heavier and 11 % more expensive than a system with a changeover temperature of $T_{LTR/Ch}$ = 15 °C.

SUMMARY AND CONCLUSION

A new method of optimising the costs and weight of cooling systems with a secondary circuit for traction batteries in electric and hybrid vehicles is presented. An example of a system is provided to demonstrate what kind of savings are achieved simply through optimum coordination of the components. The use of Lathin technology from Behr offers additional savings opportunities that would allow significant cost and weight reductions compared to conventional system configurations.

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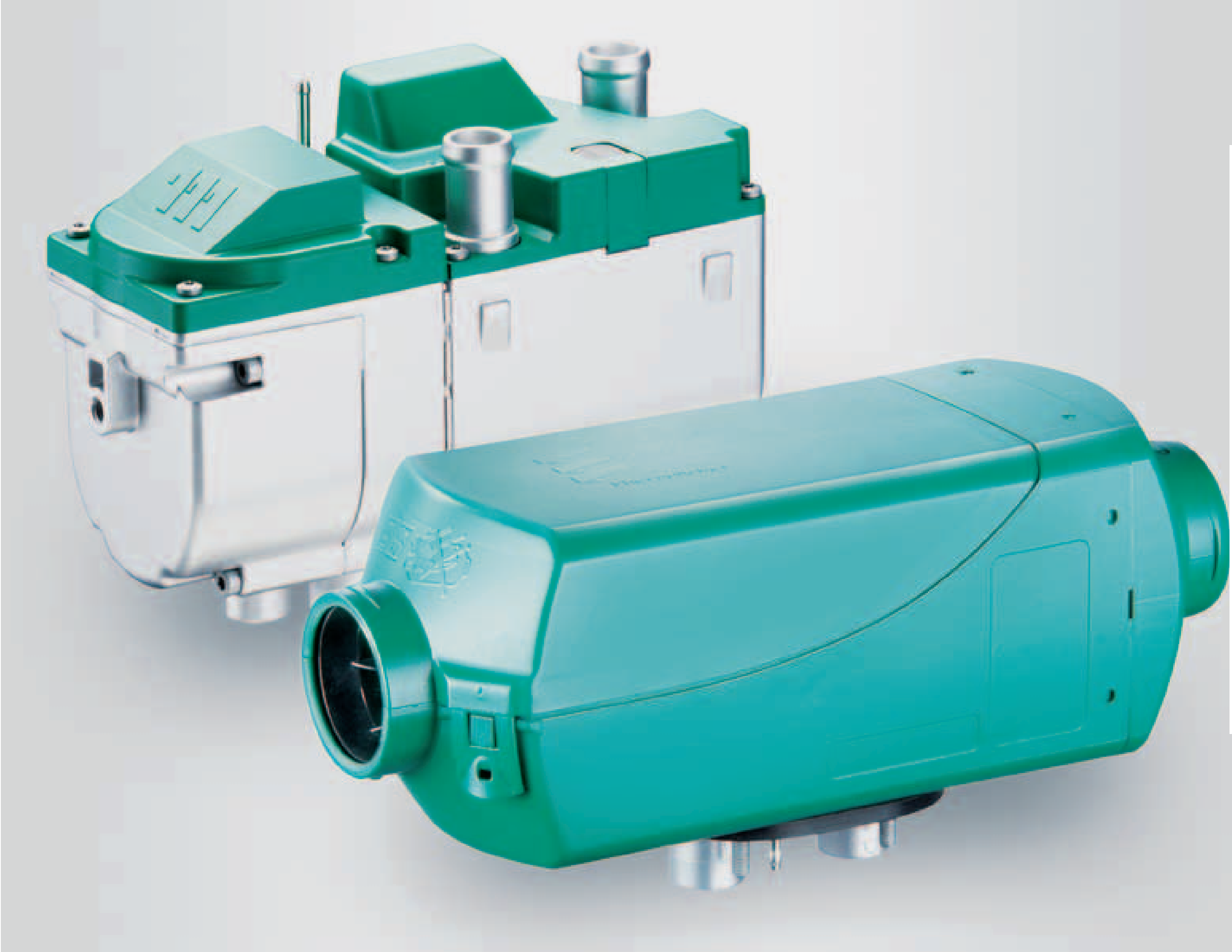

BIOETHANOL HEATER FOR THE PASSENGER COMPARTMENTS OF ELECTRIC CARS

The paradigm shift in powertrain technology is resulting in new challenges for passenger compartment heating systems. As an alternative to electric heating systems, which reduce the driving range of electric vehicles, Eberspächer has developed a heater that runs on bioethanol, thus providing a CO_2-friendly solution.

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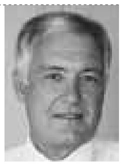

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TASK

In response to environmental challenges, many manufacturers are currently developing and testing vehicles that can be powered by electricity alone, and some of these have already been launched onto the market in series production. During the testing phase, the main focus is on validating the road capability of these vehicles. This also includes the use of vehicles in climatically difficult situations, which frequently occur in autumn and winter. At these times of the year, electric energy is also required to operate vehicle fans, rear window heaters and, above all, to heat the passenger compartment [1].

When electric heating systems are used, these are operated by the same source of energy as the engine. As a result, according to the vehicle manufacturers, the driving range will be reduced by up to 50 %, depending on the heat requirement and operating mode. Therefore, a large number of alternatives to the heating of electric vehicles are being investigated. Some of these are a combination of known solutions [2]. However, completely new approaches which, for example, regulate the temperature only in the vicinity of the vehicle passengers are also being discussed [3].

A technical solution for such systems is certainly possible. However, in all probability it will be complicated and therefore costly. Traditional pre-heating and auxiliary heating systems with fuel-operated heating devices are therefore the obvious choice for alleviating the driving range problem. In this context, it is necessary to consider the question of the usability of alternative and, above all, more environmentally friendly fuels than diesel or petrol with comparable energy densities. Eberspächer, as a manufacturer of engine-independent fuel-operated vehicle heaters, among other things, has already asked this question and can offer CO_2-friendly solutions with its bioethanol devices.

FUEL PROPERTIES

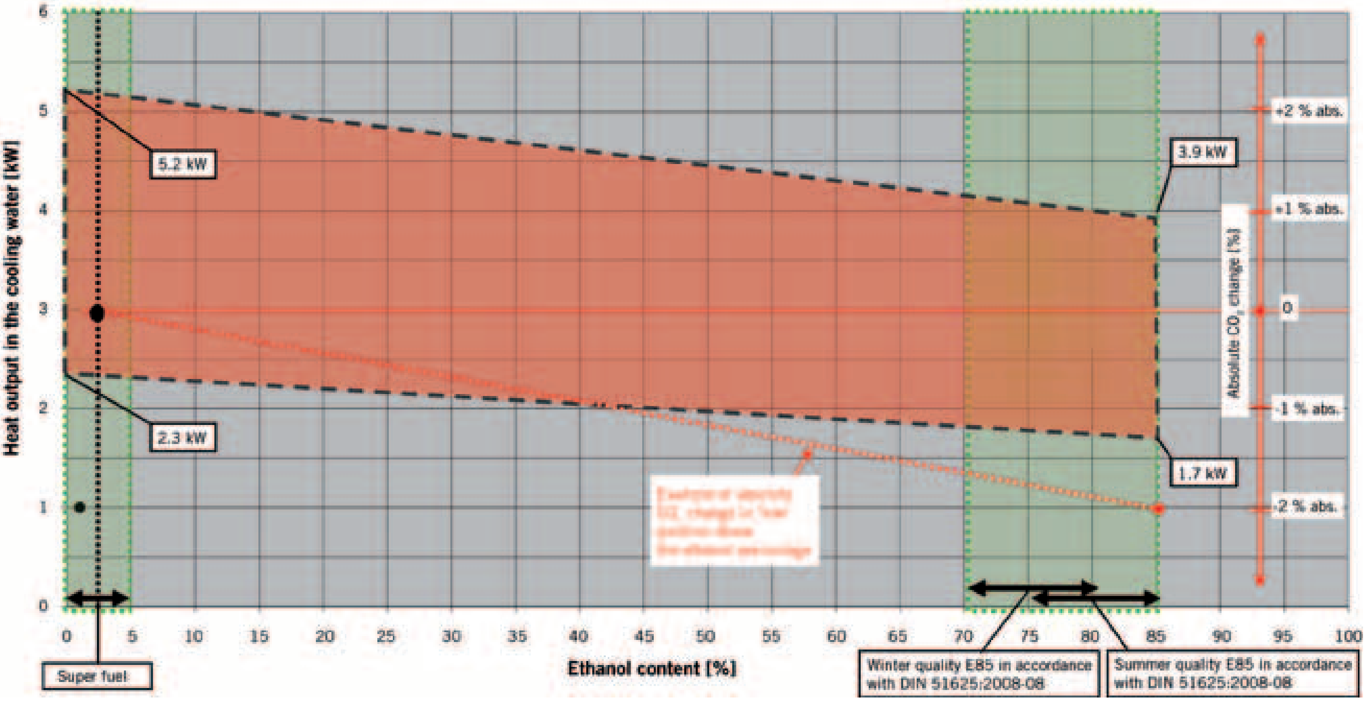
Bioethanol is currently the favourite fuel for heating electric vehicles, as its CO_2 load is up to 70 % lower than petrol. The most important material property for heating is the calorific value of ethanol, which, at 26.8 MJ/kg, is approximately 38 % lower than that of petrol, but the energy density of ethanol is still approximately 57 times greater than that of a lithium-ion battery [4]. This represents a significant advantage for ethanol. However, other factors such as evaporation heat, boiling temperature range and the percentage of carbon in the compound are important for the operation of fuel-operated heating devices, ❶.

When ethanol or petrol containing ethanol is used, this affects both the burner design and the parameterization of the heating device. If alcohol-based fuels are used, the air requirement and the calorific value are reduced, as the percentage of

❶ Properties of different fuels

PROPERTIES	GASOLINE	ETHANOL 100 %	E85 (85 %)*	METHANOL 100 %	M15 (15 %)**	DIESEL	B100
STRUCTURAL FORMULA	C6H14	C2H5OH		CH3OH		C16H34	
CALORIFIC VALUE [MJ/kg]	41	26.8	29.2	19.9	39.45	42.5	37
CALORIFIC VALUE [MJ/l]	32.2	21.2	22.8	15.7	29.725	35.27	32.56
DENSITY [kg/l]	0.75	0.79	0.78	0.79	0.75	0.83	0.88
AIR REQUIREMENT [kg/kg]	14.7	9	9.9	6,4	13.45	14.5	12.4
HEAT OF EVAPORATION [kJ/kg]	380…500	844	730…775	1175	499…601	250	
AVERAGE HEAT OF EVAP. [kJ/kg]	440	844	750	1175	550	250	
BOILING TEMPERATURE [°C]	30…210	78.3	30…210	65	30…210	175…390	176…350
SPECIFIC THERMAL CAPACITY CP [kJ/kg*K]	2	2.44	2.37			2	
BLEND C [% BY WEIGHT]	72	24	22.7	12	63	192	
BLEND H [% BY WEIGHT]	14	6	7.2	4	12.5	34	
BLEND O [% BY WEIGHT]	0	16	13.6	16	2.4	0	
RATIO C/H [1/ …]	5.14	4	3.15	3	5.04	5.64	
MOLECULAR WEIGHT [g]***	86	46	43.5	32	77.9	226	

* calculated from values of gasoline and ethanol / ** calculated from values of gasoline and methanol /
*** C-carbon = 12 g, H-hydrogen = 1 g, O-oxygen = 16 g



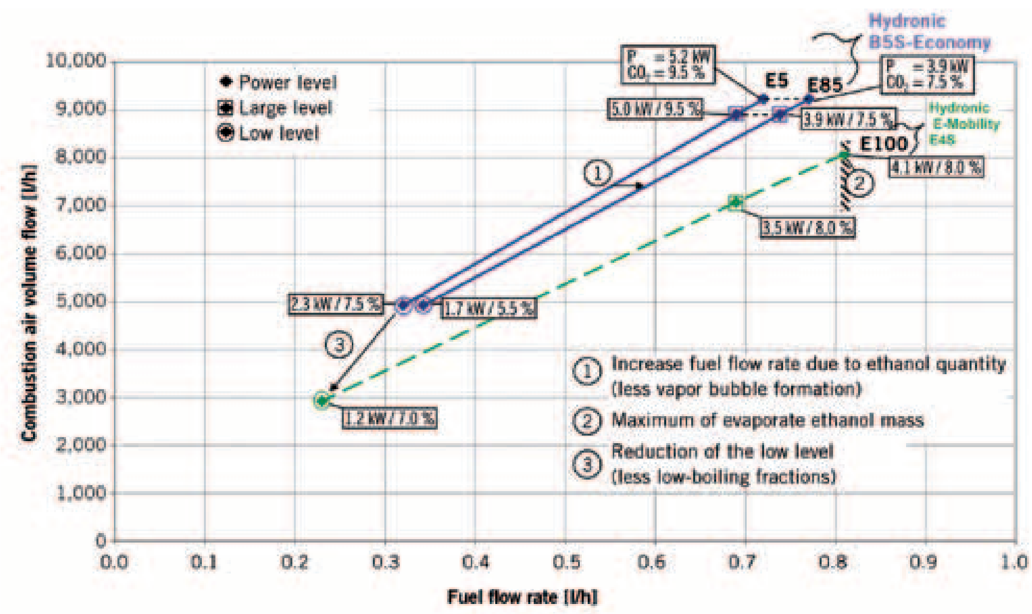
❷ Change in heat output and lambda as a function of the percentage of ethanol

alcohol increases at a constant volumetric fuel delivery. At the same time, the demand for evaporation heat increases. Therefore, the heating devices may have to be adjusted, especially at low ambient temperatures, in conjunction with these new fuels and tested with regard to functionality and durability. In principle, the inherently low-soot combustion becomes completely soot-free as the alcohol percentage increases.

INFLUENCING VARIABLES ON THE BURNER OUTPUT

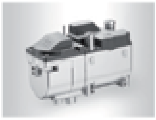
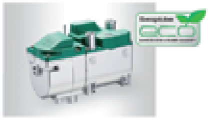
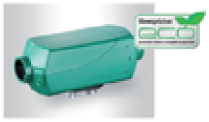
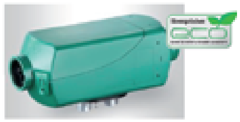
If a petrol-powered device is operated with an unchanged parameter setting, using a fuel with an increasing percentage of ethanol, the heat output is reduced and the working point is shifted, as illustrated in ❷, due to the lower calorific value of ethanol.

If the ethanol blend is up to 85 %, the heat output is reduced by up to 25 %, and the working point at which the CO_2 value shifts absolutely by 2 % changes simultaneously, in other words combustion runs more leanly. The statutory requirements for emissions are nevertheless fulfilled. However, if a device is to be designed for 100 % ethanol, the parameterization must be adjusted accordingly. This means currently for the Hydronic II water devices from Eberspächer that the combustion air must be reduced and adjusted to the fuel



❸ Working points as a function of the device design

❹ Overview of the ethanol heating devices currently available from Eberspächer

	Hydronic B5S-ECONOMY 5.2 / 2.3 kW with E5	Hydronic E-Mobility E4S 4.1 / 1.2 kW with E100	Airtronic E2 0.85... 2.2 kW with E100	Airtronic E4 0.9 ... 3.8 kW with E100
				
	Permitted fuels: E0, E5, E10, E25*, E85** and mixtures of these	Permitted fuels: E85*, **E100*** and mixtures of these	Permitted fuels: E85*, **E100*** and mixtures of these	Permitted fuels: E85*, **E100*** and mixtures of these
	* typ. fuel in Brazil **with E85 (DIN 51625) approx. 30 % Heat output reduction **Burning sequences not adjusted to fuel E85**	***Burning sequences adjusted to fuel E85/E100**	***Burning sequences adjusted to fuel E85/E100**	***Burning sequences adjusted to fuel E85/E100**
	Basic device 5 kW = Multifuel device	**Ethanol 4.1kW Monofuel device**	**Ethanol 2.2kW Monofuel device**	**Ethanol 3.8kW Monofuel device**
Exhaustgas catalytic Converter (Series)	**Installation is recommended**	**Installation is recommended**	**Installation is recommended**	**Installation is recommended**
Low-frequency muffler (tailored to customer requirement)		**Installation is recommended**	**Installation is recommended**	**Installation is recommended**

delivery in order to counteract the combustion leanness.

Another advantage in functionality lies in the fact that, as the percentage of ethanol increases, the percentage of low boilers in the fuel is reduced and, as a result, the low power of the burner may be reduced further. This has a positive effect on the control quality, particularly between seasons when less heat output is required.

In the case of the Airtronic air devices, the amount of fuel can be raised accordingly and the heat output retained as a result of the different evaporator design and, as a result, the slightly more favourable temperature regulation of the combustion chamber for ethanol. The example shown in ❸ shows the correlation between types of fuel (petrol, ethanol and appropriate mixtures), potential heat output and fuel or air requirement for the Hydronic water heating devices B5S-Economy and E-Mobility E4S.

Due to the operating principle of fuel-operated heating devices, the combustion air and amount of fuel are conveyed volumetrically. If E85 is used as the energy carrier at an unchanged device setting (displacement according to 1 in ③), the stoichiometry is affected on account of the different material properties. Owing to the lower tendency of ethanol to form vapour bubbles, the amount of fuel increases slightly. However, because of the lower calorific value and the different C-H ratio, the heat output and CO_2 working point are reduced.

If the heating device is designed optimally for 100 % ethanol, the amount of fuel can be increased to the maximum amount that can be evaporated by the evaporator. This limit is specified by the type and therefore by the temperature conditions on the evaporator (displacement according to 2 in ③). Moreover, the "low" power can be further reduced with 100 % ethanol in comparison with petrol, as ethanol, a so-called point boiler at 78.3 °C, has no low-boiling constituents (displacement according to 3 in ③).

MODELS

Eberspächer has various devices available for use in different applications. From the Hydronic family, the 5 kW petrol model can be installed unchanged as a flexfuel device with an ethanol blend of up to 85 %. Furthermore, a so-called monofuel device, Hydronic E-Mobility E4S, is available especially for electric vehicles and, with regard to its working points, is designed for an ethanol blend of 70 to 100 %, ❹.

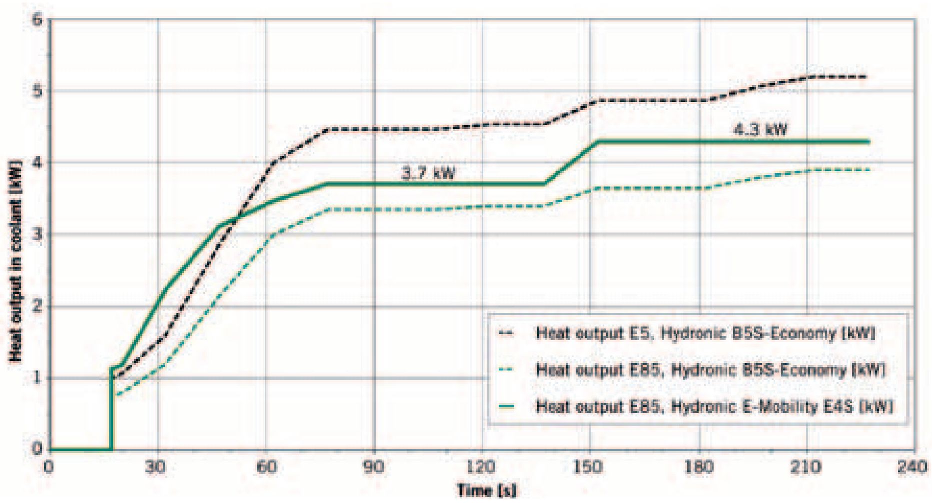
Therefore, both pure ethanol and E85 fuel, available at petrol stations for flexfuel vehicles, can also be used in winter quality (as E70 fuel with 30 % petrol blend).

The ethanol devices from the Airtronic family have been designed as monofuel devices Airtronic E-Mobility E2/E4 and can be operated with pure ethanol (E100) and with up to 30 % petrol admixture (E70) without any reduction in the performance features.

If a flexfuel device is operated with E85, the functional sequences for operation with petrol are identical. Only the heat output is reduced during the starting sequence and in the working points due to the lower calorific value according to the ethanol blend, ❺.

In the case of a Hydronic device adjusted especially to E70 to E100, the starting sequence has been slightly accelerated and the working points have been optimally designed. This is also reflected in the characteristics of the device, ❻.

On account of the adjustment of the combustion air values, the CO_2 values in the working points are shifted again to higher values. At the same time, the power consumption of the device is reduced and the power spread can be increased by 50 %, as the value of the



❺ Starting sequences – heat output development at -5 °C

	HYDRONIC B5S-ECONOMY			HYDRONIC E-MOBILITY E4S		
FUEL	E85 (85 % Ethanol)					
	Operating position horizontally and perpendicular					
POWER STAGE	POWER	LARGE	LOW	POWER	LARGE	LOW
POWER [kW] AT -5 °C	3.9	3.8	1.7	4.3	3.7	1.3
FUEL CONSUMPTION [l/h] AT -5 °C	0.77	0.74	0.34	0.81	0.69	0.23
CO_2 OPERATING POINT [%] AT -5 °C	7.5	7.5	5.5	8.5	8.5	7.5
ELECTRIC POWER CONSUMPTION	40	37	12	27	20	7

❻ Device characteristics

low position in particular can drop from 1.7 to 1.3 kW. A further side effect of this is that the power consumption of the heating device drops between 32 and 45 % depending on the working point.

VEHICLE COMPARISON TEST

In order to compare the effect of an ethanol-operated fuel heater with an electric heater, a comparative test was conducted using an electric vehicle of the small car class with four adequate seats at -7 °C in accordance with TÜV Süd TSECC (= TÜV Süd Electric Car Cycle) [5]. The Hydronic E-Mobility E4S used was operated with 100 % ethanol. The TSECC cycle lasts 60 min for each run. A distance of 60 km is covered.

The test contains three different driving profiles: city traffic, country road and highway. When the test was conducted with the ethanol heating device, the test cycle could be run just once, at the end of which the battery warning light lit up, indicating discharge. The electric vehicle used in the test features an electric heater as standard. As this heater has a lower heat output than the fuel heater, a direct range comparison cannot be tested.

Therefore, the range gain of the fuel heater in comparison with the electric heater was determined arithmetically via the energy consumption. The total electrical energy consumption during the TSECC cycle was 15.72 kWh. During this time, an average thermal heat output of 3.17 kWh was introduced into the water cycle by the ethanol heating device. Had this energy been taken from the vehicle battery, based on an electric water heater in consideration of its thermal efficiency of approximately 85 %, 3.7 kWh would have to be applied. When an electric heater is used, the battery capacity available for locomotion would be reduced by just this amount to 12.02 kWh. As a result, a range of just 45.88 km would be reached, equivalent to a range reduction of approximately 30 %.

OUTLOOK

Fuel-operated heating devices, in conjunction with environmentally friendly fuels, are an efficient solution for heating electric vehicles. Safety and comfort can be implemented in the same way without affecting the use of the vehicle. The developing market of electric vehicles will show which systems are best suited under which boundary conditions. The energy requirement, the storage density of the energy form and the costs and availability will be crucial for the technical solution for vehicle heating or air-conditioning systems.

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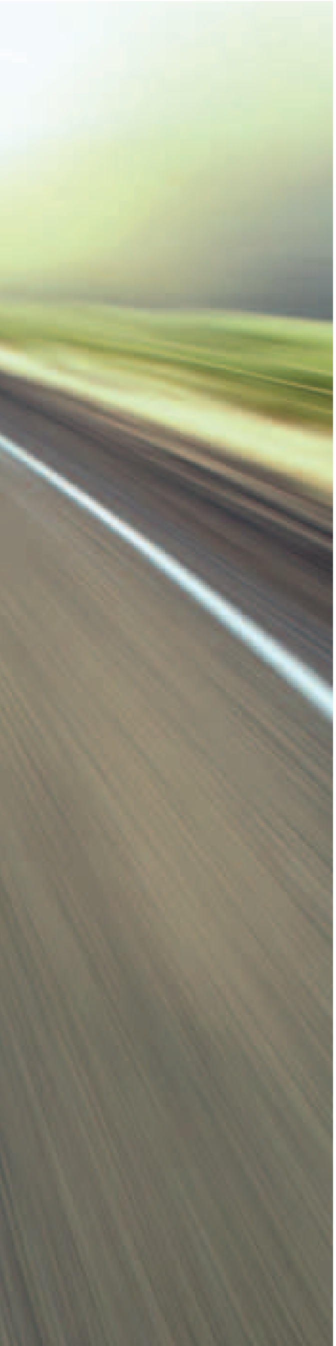
CLUTCH DISC WITH FREQUENCY DAMPER TO PREVENT JUDDER VIBRATIONS

Noticeable vibrations of the vehicle during the clutch's slippage phase are a well-known phenomenon. These vibrations are generally known as judder and, depending on their severity, can lead to a considerable loss of comfort that must be avoided in modern vehicles. LuK has developed a clutch disc with a frequency damper that provides a particularly effective remedy and can be used for both manual and double-clutch transmissions.



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DEFINITION

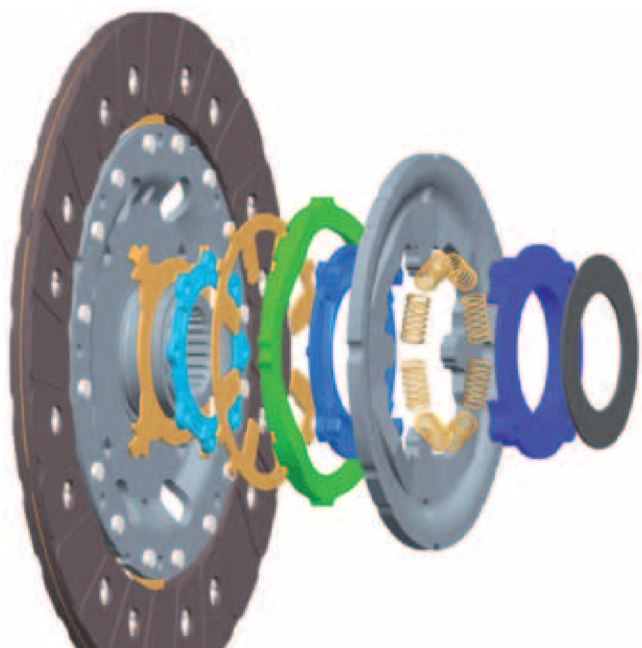
Judder vibrations are produced by a variety of things. The term judder generally refers to an alternating torque that is superimposed on the mean slip torque of the clutch. This definition alone is not sufficient, however, because in reality, all frictionally engaged clutch systems produce alternating torques. Judder only applies when the excitation causes vibrations that can be felt by the driver. This is generally only possible when natural frequencies of the drive train and the vehicle as a whole are excited with sufficiently high amplitude.

Like many NVH problems also for judder the requirements increase in the entire chain of effects. The excitation potential increases as a result of the higher performance density in the vicinity of the clutch assembly, the development of more efficient drive trains causes increased sensitivity to alternative torques, and customer expectations become higher with every new generation of vehicle models.

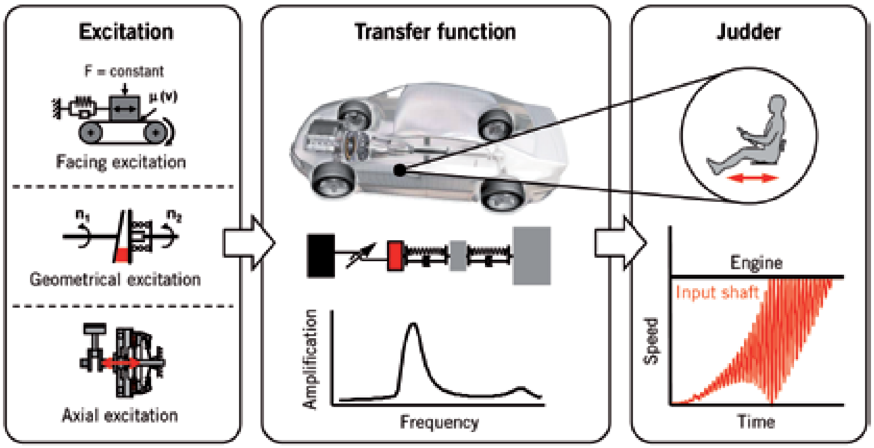
These are positive developments in terms of fuel economy and driving enjoyment, but they may mean that the state of the art is no longer sufficient to fulfill comfort requirements with regard to judder in certain vehicle applications, and that special measures must therefore be taken. One solution could be clutch discs with frequency damper from LuK, ❶.

INITIAL SITUATION

Knowledge of both the causes and the transfer behavior all the way up to the driver is needed in order to develop solutions to prevent judder, ❷, and to be able to evaluate their areas of application and performance. Causes can be divided into three categories. The first category includes the mechanisms for which the clutch system is the decisive source of excitation. This includes



❶ Exploded drawing of the clutch disc with frequency damper



❷ Judder – cause and effect

self-excitation and geometrical excitation. Self-excitation, also known as facing judder, is the most well-known and most unpleasant type of judder. This is caused when the friction coefficient of the clutch's frictional contact decreases along with the sliding speed, which can make the drive train unstable. Basic geometrical excitation cannot be completely avoided. This is caused by geometrical defects of the clutch and its surrounding components.

The second category includes mechanisms in which the clutch system is modulated or excited by crankshaft vibrations, that means in which the clutch system is not the source of excitation. With crankshaft vibrations, a differentiation must be made between torsional and axial motion. Torsional vibrations play an insignificant role in conjunction with judder, and can easily be kept in check. Axial vibrations, on the other hand, are an increasingly frequent cause of judder.

The third category comprises all pseudo-judder phenomena, which feel like judder to the driver but on which the clutch system has little or no influence at all. Examples of this are excitations in the transmission and torsional engine block vibrations caused by the periodic ignition and combustion processes.

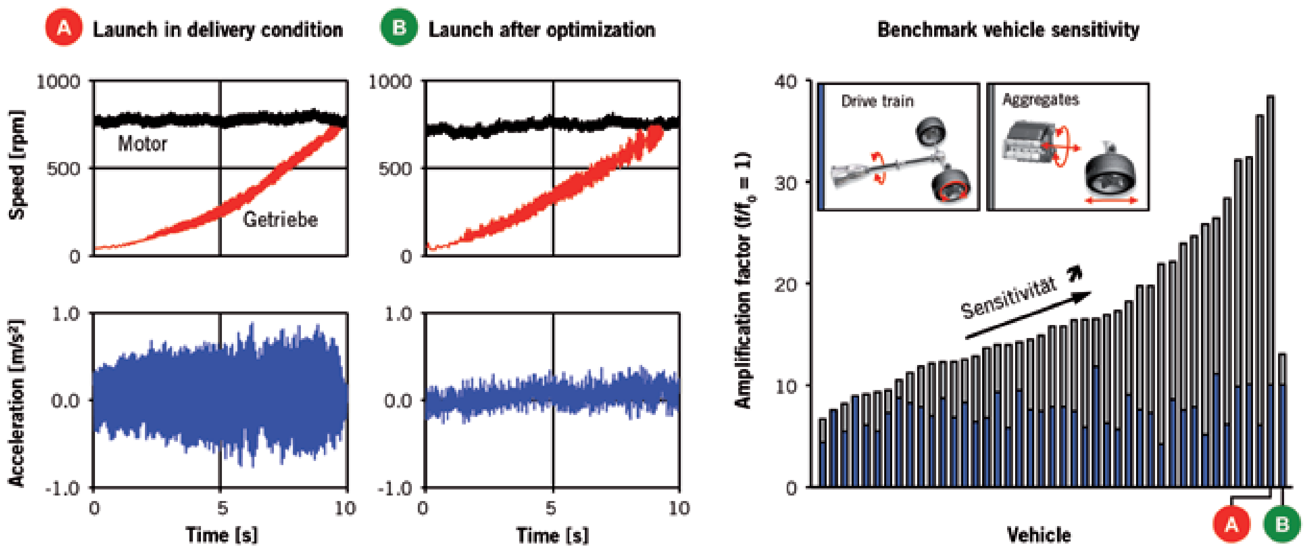
The best way to avoid judder is to keep the level of excitation low. However, if even small excitation amplitudes lead to noticeable vibrations, the cause is excessively high sensitivity of the drive train. For this reason, evaluation of the transfer path has now become a central part of the process. Previously, the rotary components of the drive train were almost the only things taken into consideration, while modeling today also includes aggregates that can have a significant influence on the vibratory behavior.

This increase in the number of factors considered was triggered by the observation that the vibrations measured in the drive train often did not correlate with those in the vehicle. The discrepancy could not be explained with purely rotational models as it was caused by degrees of freedom of the wheel suspension and engine block. An example is shown in ❸. The vibrations measured in the vehicle are higher than those in the drive train by a factor of 5. The rigidities of the drive shafts and the engine block suspension were redefined using simulation-based optimization. The subsequent vehicle test confirmed a predicted reduction in judder sensitivity by the factor 3. This improvement would not have been possible by optimization of the clutch system alone.

Optimization of the drive train is one way to reduce judder. The associated modifications to the vehicle, however, can only be implemented in infrequent cases. The challenge is to also create solutions at component level for cases such as this.

REDUCTION OPTIONS

Modern state-of-the-art clutch systems already boast high levels of quality in terms of judder excitation, and are subject



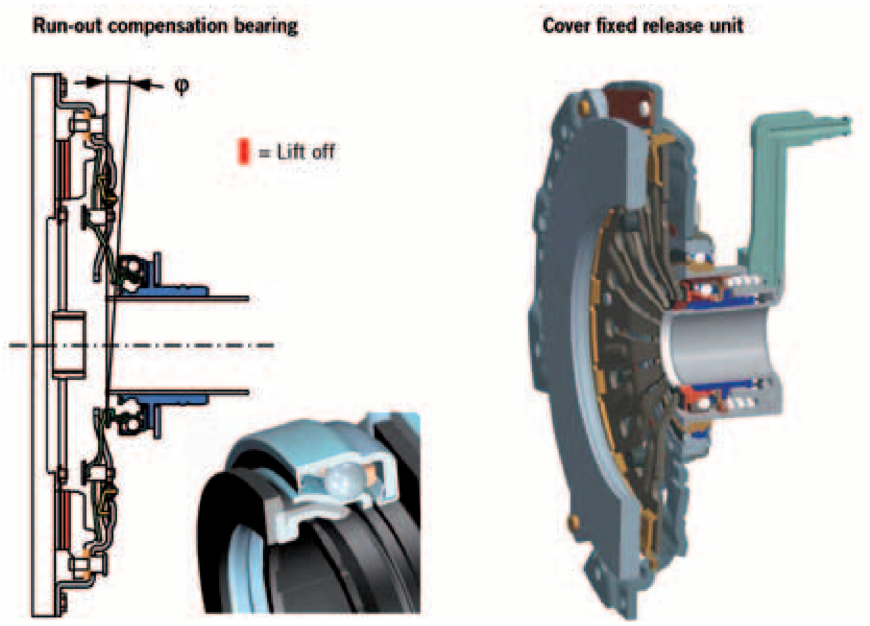
❸ Optimization of launch and vehicle sensitivity to the limits of what is possible and to conflicting objectives when it comes to other criteria.

Active and passive secondary measures offer additional potential. These can be divided into measures that compensate the excitation mechanism and measures that influence the transfer behavior (shifting natural frequencies or damping resonances). Compensating the excitation is only helpful in the case of a specific cause whereas active measures or modifications affect the transfer behavior independently of the cause.

A special release bearing, named axial run-out compensation bearing, ❹, that compensates geometrical defects between the clutch and the release system has been used in volume production for years and, until recently, was the only secondary measure. The basic principle is simple and efficient: A cup ring adjusts to possible axial runout of the individual diaphragm spring fingers and thus reduces slanted lifting of the pressure plate – an effective method for reducing geometric judder [3].

Judder caused by axial vibrations of the crankshaft can be completely prevented using a release unit, ④, affixed to the clutch cover, as modulation of the clutch is prevented by the crankshaft. This type of system also prevents vibrations of the clutch pedal and rattling noises during the slippage phase [1, 3, 5].

An anti-judder control is a universal solution to prevent judder [4]. Sensors detect judder vibrations that take place and an actuator produces a counter torque in the clutch. Ideally, this allows the excitation to be almost completely compensated. The requirements placed on the control strategy and actuator system are high, as the counter torque must be produced with the correct phase and amplitude. Anti-judder controls are a possible solution for double-clutch transmissions since these are already equipped with the necessary hardware, whereas the outlay for implementing them in manual transmissions seems too great.

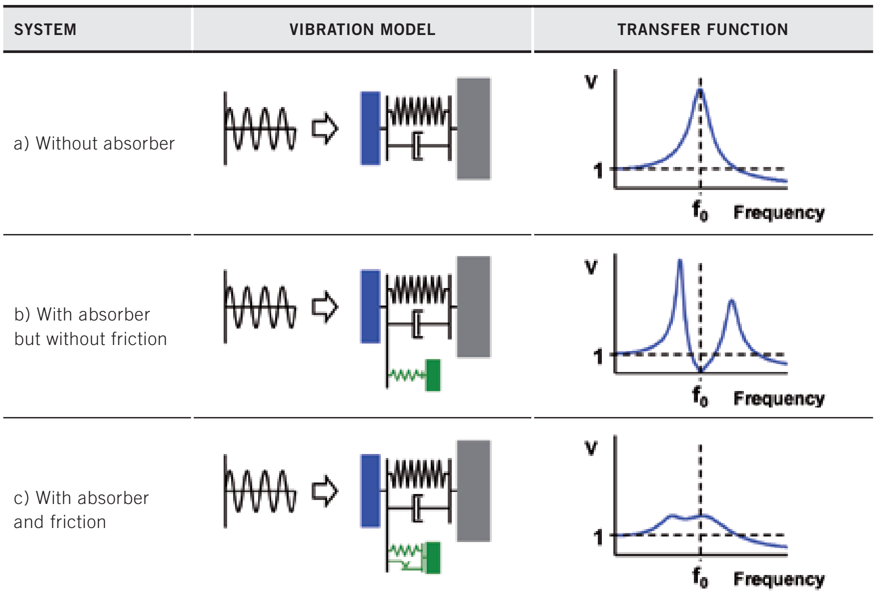


❹ Avoiding judder with axial run-out compensation bearing (left) and release unit affixed to the clutch cover (right)

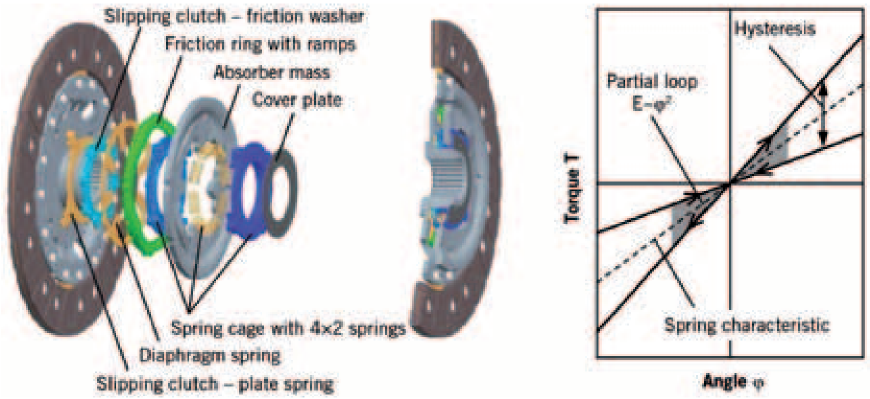
FREQUENCY DAMPER

During the search for other solutions to prevent judder, which produced numerous ideas, a frequency damper was always assessed as being an efficient and comparatively simple principle. The basic requirement for a frequency damper to be used effectively is fulfilled because, in most cases, judder only occurs with a certain dominant frequency (for example 10 Hz in a car in first gear). The obvious course of action is therefore to rectify the problem by damping these frequencies.

The basic principle is shown in ❺, which shows a simplified depiction of the drive train as a two-mass oscillator, ⑤ a). If this system is expanded to include an ideal (that means frictionless) damper, ⑤ b), the original resonance can be completely eliminated. The system, which includes one additional degree of freedom, now has two resonance points, however. A frictionless damper can therefore not be used, as the speeds of the engine and transmission, and thus also the excitation frequency, are variable. Energy has to be removed from the system in order to prevent pronounced



❺ Functional principle of a frequency damper with and without friction



❻ Design (left) and characteristic curve (right) of the judder absorber with a more stable and more reliable reduction rate

resonance magnification over the entire speed and frequency range. Theoretically, damping via friction that is proportional to the speed and aligned parallel to the spring, ⑤ c), would be ideal here, but implementing this design is complicated.

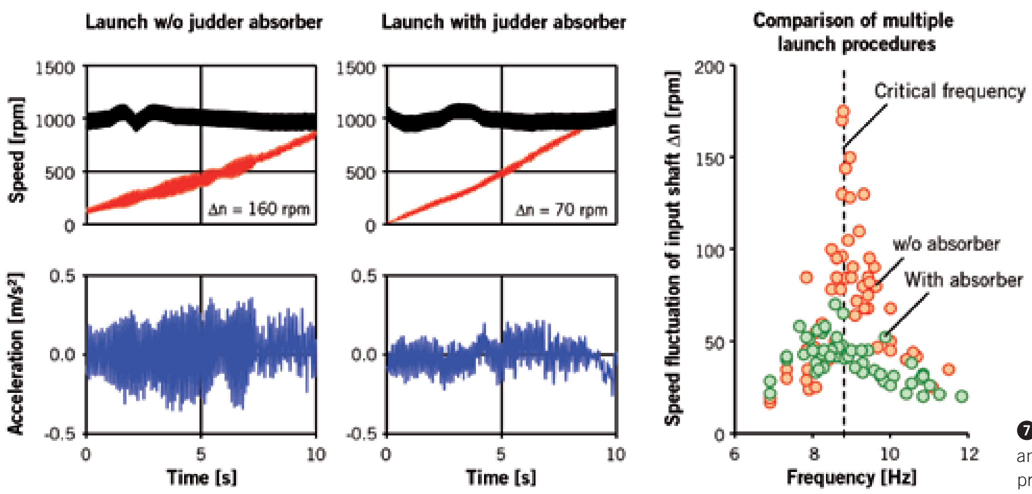
Therefore, the damper was originally developed with constant friction which acts in parallel. This arrangement involves making a compromise, namely that optimum damper performance is only achieved with a specific ratio of excitation amplitude to friction. When the ratio is higher than this, the system tends towards frictionless behavior, and when it is lower, the system tends towards adhesion. In both cases, the damper is not able to remove enough energy. For this reason, numerous tests with this principle showed no sufficient or reliable results.

The required energy that has to be removed from the system increases quadratically with the excitation amplitude. The damper can fulfill this requirement if its friction increases proportionally to its vibration angle. This development objective brought about the breakthrough for the design of a judder absorber with a more stable and more reliable reduction rate. Its design is shown in ❻.

The friction device consists of a diaphragm spring for producing the clamp load and a friction ring with ramps. In normal operation, both parts are rotationally rigid in relation to the clutch disc. The damper mass also features integrated ramps that act as a friction surface to counter the friction ring with ramps. If the damper mass rotates in relation to the clutch disc, the friction ring with ramps executes an axial movement and thereby tensions the diaphragm spring. This increases the clamp load and thus the friction between the clutch disc and the absorber mass. Pairs of compression springs clamped against each other are used to define the damper frequency. This arrangement has the advantage that the damper mass is centered in relation to its bearing support, which allows the level of extraneous friction to be kept low. The entire judder absorber is mounted on the clutch disc using a slipping clutch in order to protect the spring cage from impacts.

With this design, reduction rates of over 60 % at the design point can be achieved, irrespective of the excitation amplitude. Theoretically, a very small damper mass would be sufficient for this purpose. However, in order to present a sufficient capacity in the case of vibration angles that can be implemented in design and to keep tolerance influences low, the damper mass should be approximately 10 % of the reduced drive train mass. It must be taken into consideration that there is a corresponding increase in the mass to be synchronized and in the axial space requirement.

Vehicle testing has already confirmed the performance of this judder absorber many times. The left section of ❼ shows two representative launches of a test vehicle. The absorber reduces the maximum speed fluctuations by > 50 %, which improves the subjective assessment grade by 1.5. The right section of ⑦ is a summary of several individual launch procedures. The maximum acceleration fluctuations depending on the vibration fre-



❼ Two representative launches (left) and comparison of multiple launch procedures during vehicle testing (right) quency are shown. In the case in which the judder absorber was used, a pronounced resonance magnification was prevented in the 8 to 10 Hz range of the critical frequency. The judder absorber presented here has already been fully developed and tested, and went into series production in 2011.

AREAS OF APPLICATION FOR THE JUDDER ABSORBER

The judder absorber can be used to remedy all judder and vibration problems in which the frequency remains largely constant. In the case of extraneous excitation, the vibrations are significantly reduced. In the case of self-excitation (facing judder), vibrations can even be completely prevented, provided that the capacity of the absorber is sufficient. With a absorber, negative friction value gradients that are approximately three times higher are permissible, depending on the vehicle application.

The development process was based on manual transmissions for passenger cars. However, the judder absorber can also be used in all other types of transmission technology and vehicle categories, for example in innovative wet and dry double-clutch transmissions and in truck applications.

SUMMARY

Judder remains an intrinsic comfort problem in drive trains with frictionally engaged clutches. Developments in the drive train area mean that higher requirements are placed on the permissible excitation levels. The judder absorber developed by LuK provides sufficient potential to prevent loss of comfort for the driver. It reduces the maximum speed fluctuations by more than 50 %.

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SAFETY AND STYLING OF FUTURE REAR LIGHTS

New light sources such as LEDs make it possible to further develop lighting systems while at the same time offering a wide spectrum of styling and design opportunities. Lighting engineers and designers at Hella are using these possibilities in the design of rear lamps for future vehicle generations.

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FUNDAMENTALS

Combination rear lamps improve safety on the road throughout the world. Statutory regulations such as ECE or FMVSS108 are the reason that this works, as regulations provide the recognised framework and a definition of a standard signal image.

Tail lights, stop lights and direction indicators are the most common signal functions. Signal functions also include back-up lights, which are activated when a vehicle is reversing, and rear fog lights for visibility below 50 m, which both provide safety functions. The development of a combination rear lamp ends with a review of the statutory specifications to obtain general vehicle certification.

However, as combination rear lamps are very different from one to the next and function increasingly as a design element, car manufacturers are looking for distinct and contrasting designs. Night-time appearance is particularly important in this case. Car manufacturers want striking tail light graphics with a homogeneously bright surface to meet branding and quality requirements. A matching stop light and direction indicator will strengthen the appearance. However, combination rear lamps also have to look good during the day when signal functions are inactive, and they have to fit harmoniously into the vehicle design. Design and technology-driven development by suppliers focuses on offering vehicle manufacturers as many innovative combination rear lamp variants as possible. Current designs of combination rear lamps are the result of the technical development of light sources and optical analysis in the 1990s that paved the way for the design of new lighting systems.

DEVELOPMENT OF LIGHTING TECHNOLOGY

Combination rear lamps were technically underdeveloped until the mid-1990s. The basic variant is made up of a lamp housing with reflectors, a bulb holder with bulbs and a cover lens with dispersion optics. The bulbs used and the temperatures in the combination rear lamp when the bulbs are in use determine the size and the configuration of the individual functions. Vehicle designers have had an influence on the shape and size of combination rear lamps, their integration into the vehicle and the colouring of the lens in terms of the configuration of the functions. Typically, the reverse light and the direction indicator have been integrated into a clear area of the cover lens; the other signal functions have been implemented in red.

The first stage of development on the way to today's lighting systems was the use of a non-patterned cover lens in the late 1990s in the Jaguar S-Type. The S-Type combination rear lamp set new accents with its brilliant reflector optics. The insight provided into the lamp and the ability to design its interior components is still considered pioneering among lighting developers. For the first time, designers could actively design the optical systems and influence the overall appearance, ❶.

New software tools and algorithms to calculate optical components were developed to support lighting engineers in their work.

A second development, in hindsight, was not so much a step as a leap. The LED (Light Emitting Diode) began its rise to dominance in automotive lighting technology. With a long service life, high fail-safe performance, compact size and low energy consumption, the LED is increasingly replacing the light bulb. The continuously functioning tail light and the stop light can both benefit from the advantages of the LED, such as its faster, safer switch-on behaviour. The LED lights up to full brightness immediately after it is switched

❶ The world's first rear combination lamp with a non-patterned cover lens

❷ Combination of the light curtain and EgdeLight systems

❸ Overlapping of flat light guide elements

on, whereas a light bulb only reaches full brightness a fraction of a second later. The braking signal is then recognised more quickly, triggering a swifter reaction that may be decisive in a dangerous situation.

CURRENT OPTICAL SYSTEMS

The LED is the ideal light source for light guide optics – optical components into which light is beamed from a light source and redirected by total reflection on the outer surfaces of the material until it is re-emitted at defined areas of dispersion. Rod-shaped light guides with linear illumination originally provided the functionality in this case. The design of modern combination rear lamps is characterised by the symbiosis of light guide optics and LED technology, jointly leading to new, innovative lighting systems. For lighting engineers, this has meant a rethink away from the purely functional fulfilment of statutory regulations towards high-quality design of signal functionality.

Discussions are increasingly focused on the night-time appearance and the homogeneity of illumination and less on the statutory approval criteria. In advance lighting technology development, lighting engineers and designers now work closely together to develop future lighting systems, introducing them as styling templates. Thanks to technological advances, it is now possible to implement what designers are looking for in terms of flat illumination, the creation of signatures and a greater appearance of depth. The light curtain, for example, is a flat light guide lens with light from an LED at one edge – light that is broken, reflected and radiated at the structures on the surface. Other signal functions, such as the stop light, can be positioned behind the light curtain. They can then shine through the transparent light curtain. As a result, combination rear lamps with lighting systems staggered in depth are now an option.

An EdgeLight light guide is an element with an illuminated front edge that can be used as a striking signature. The EdgeLight system can be implemented for all signal functions and can add the appearance of depth with the addition of surface structuring.

The combination of the two systems creates a clear tail light signature that overflows into a flat light curtain to the sides. The combination rear lamp of the Ford S-Max is a good example, ❷.

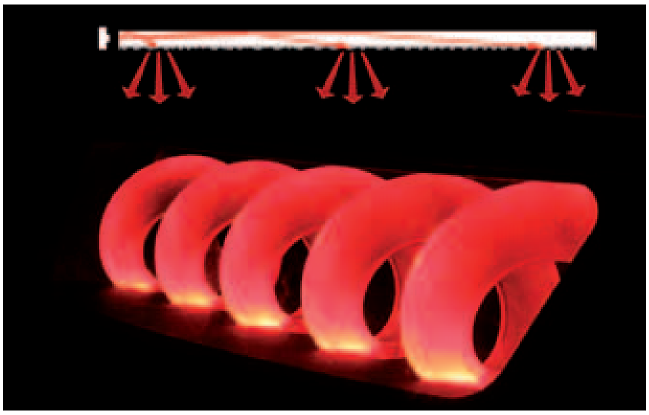
The quality of a signal function is defined by the homogeneity of its illumination, something that is only clearly visible at night. Lighting systems that provide homogeneously illuminated functions with the appearance of a glowing piece of steel – glowing body systems – make it possible to use tail light graphics with high-quality light design. Only the surface is visible, illuminated with homogeneous light. The optical system hidden behind it that provides the illumination is not visible. Backlighting is provided by LED light sources using various optical systems, or alternatively the glowing body is shaped as a solid light guide. The glowing body has established itself on the market and is a significant characteristic of tail light functionality for a number of vehicle manufacturers.

THREE-DIMENSIONAL LIGHTING SYSTEMS

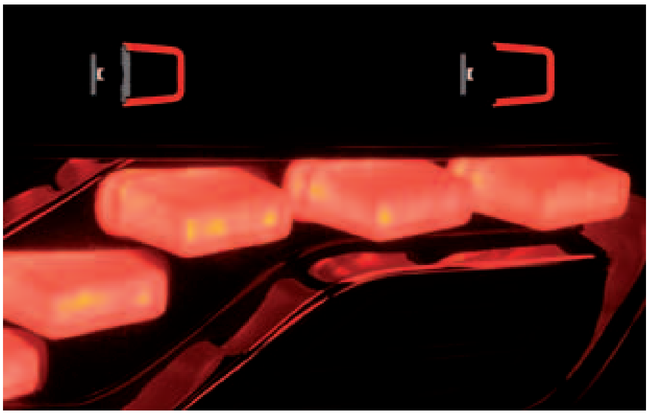
The future of lighting systems will be designs with bold geometries and clear depth effects. Light is becoming three-dimensional. Such lighting systems with a visible appearance of depth must nonetheless be designed flat so that they can be integrated into the limited installation spaces of the chassis. There are various approaches to solving this contradiction. Firstly, several flat light guides can be installed in a combination rear lamp in three dimensions, overlapping in some areas, to create the appearance of depth. They then require only a slim design. Other functions can be positioned behind the light guides. The light guide profile, the optical design and the number of light guides can be adapted to design requirements and offer a high degree of variation for a differentiated, brand-typical design, ❸.

The future development of flat, contoured light guides will produce a three-dimensional light guide. Entirely new light guide designs will be possible with three-dimensional profiles. As complex 3D light guides present a geometry that partially overlaps, they cannot be manufactured as a single piece via plastic injection moulding. A modular approach is used to create 3D light guides.

Any desired light guide profile is achieved with a set of single modules that are only incorporated into a three-dimensional light guide in the combination rear lamp. The required light intensity and the illumination of the signal function are controlled by a light feed into each module and by the optical design of the light



❹ A modular three-dimensional light guide helix



❺ Design with freestanding glowing bodies

guide. 3D light guides offer the observer a dynamic appearance uniformly from different perspectives, day and night, thanks to their spatial and sculptural design, ❹.

glowing bodies will develop further in two ways. The geometries are becoming more substantial so that, instead of flat elements, three-dimensional bodies will be used in the future. The optical system is also being analysed in terms of function, so that signal functions such as stop lights and direction indicators can be designed with greater light intensity. The optical structure uses the wall of the glowing body as a light guide and an additional, central source of illumination. The same LED is used for the two illumination effects, or separate groups of LEDs are used. The three-dimensional glowing bodies come in different shapes and sizes. Smaller, modular glowing bodies can be positioned freely and support a range of different design criteria optimally, ❺.

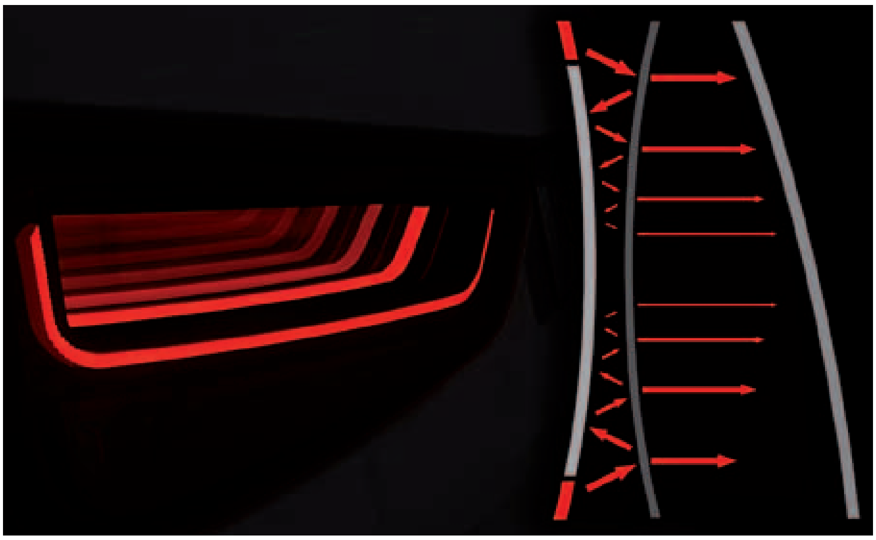
Besides three-dimensional lighting systems, virtual 3D effects are also used, for example, by emitting light between two mirrors. The front mirror is semi-transparent, while the rear mirror is a full mirror. Some of the light is emitted from the front mirror and the rest of the light is reflected. This creates continuous reflections between the two mirror surfaces with partial emission of light in each case, creating a highly characteristic visual appearance of depth – the tunnel effect.

The system, known as the mirror tunnel or tunnel light, was previously used only for general purpose lighting effects, but has now been adapted for innovative 3D vehicle illumination lighting systems. The transparency and the degree of reflection of the front half-mirror are determined precisely by the coating process. The profile of the reflections is defined by the geometries of the mirror surfaces and by the spacing between the mirrors. The mirror structure requires only a slim design, although a significantly deeper light tunnel is presented, ❻.

OUTLOOK

Signal functions leave a lasting impression due to their innovative, three-dimensional lighting systems for night-time appearance and their high potential in terms of brand-specific designs. Implementation of such customisation options is the task of lighting engineers and designers. The focus of development, however, should remain on the effects and perception of lighting systems to investigate and assess the psychological and physiological effects of lighting systems. In this field, Hella is working closely with L-Lab, a light technology research institute supported by the University of Paderborn and Hella. Materials and process development is also closely related to lighting technology and design, as development in materials and processes allow innovations to be manufactured on an industrial scale quickly.

New light sources, such as OLED and laser diodes, are leading to innovative approaches to lighting systems. The use of new materials and components for lighting effects, such as textile fabrics, is paving the way for further, exciting design possibilities. Hella lighting engineers and designers work in all areas to offer car manufacturers a broad range of innovative solutions for the design of combination rear lamps.



❻ Tunnel effect caused by reflection of light in a mirror system

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CFD STUDY TO OPTIMIZE THE MOVING BELT TECHNOLOGY IN THE 1:1 AEROACOUSTICS VEHICLE WIND TUNNEL

A novel interchangeable 3-/5-belt system shall further optimize the simulation of road conditions in the 1:1 aeroacoustics vehicle wind tunnel at the University of Stuttgart. CFD results show an aerodynamic simulation quality comparable to a wide single belt system. But concerning operation reliability and maintainability the new system is clearly more convenient.

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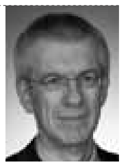

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1 INTRODUCTION

Compared to the situation on the road, the vehicle is fixed in the wind tunnel while the air is moving relative to it. Therefore, suitable measures have to be applied in the wind tunnel to remove the ground boundary layer and to simulate the relative motion between the road and the vehicle. If this ground boundary layer is not removed, measured aerodynamic drag coefficients will tend to be too small and lift coefficients too high [1 – 3]. These differences are even getting higher with lower vehicle ground clearance. In addition to the simulation of the relative motion between the road and the vehicle, also the rotation of the wheels must be simulated according to the situation on the road, because this will change the flow through and behind the wheels and wheel houses significantly.

Presently, a 5-belt system is installed in the full scale aeroacoustics vehicle wind tunnel to simulate road conditions [4]. In case of the 5-belt system, a centerbelt is located between the wheel tracks. The wheels are driven by four independent wheel rotation units. The vehicle is fixed with a 4-point mounting system which is connected to the subfloor balance together with the wheel rotation units to measure aerodynamic forces. A boundary layer pre-suction at the nozzle exit in conjunction with a tangential blowing unit directly in front of the centerbelt are used for boundary layer conditioning in front of the moving belt system. Furthermore, a distributed suction system next to the centerbelt prevents boundary layer growing over the test section floor.

However, certain on-road driving effects cannot be simulated using only a distributed suction system, since the relative motion between road and vehicle is not replicated. Consequently, from an aerodynamic point of view, a single moving belt, which is longer and wider than the vehicle itself, features an optimal aerodynamic simulation quality. But, besides limited test section dimensions and vehicle fixation problems, such a single belt system cannot provide the measurement accuracy that can be reached with contemporary 5-belt system because the measurements will always be influenced by parasitic forces. To cope with that problem, either the wheels can be detached from the chassis which will require major modifications to the vehicle structure or a sophisticated vertical force measurement through the moving belt has to be applied. Longitudinal and lateral forces can be measured via instrumented restraints. Additionally, it is possible to couple the whole moving belt with the force measurement platform, similar to the wheel rotation units of a 5-belt system, so that aerodynamic forces are measured without being influenced by the tire rolling resistance. Details of that approach can be found in [5].

The broad utilization-profile of wind tunnel test vehicles with a large variety of different sizes and types – from conventional passenger cars and vans up to race cars – as well as frequent vehicle changes requires the implementation of a universal moving belt system. Therefore, an interchangeable 3-/5-belt system will be installed into the aeroacoustics vehicle wind tunnel. With such a 3-belt system, which replaces the four wheel rotation units with two long sidebelts, it is possible to change easily between a wind tunnel setup for high aerodynamic simulation quality using a wide moving belt system and a high measurement accuracy setup by use of a 5-belt system.

Following, a CFD study is presented to assess the possible aerodynamic simulation quality of such a 3-belt system in detail.

2 THE NEW 3-/5-BELT SYSTEM FOR THE AEROACOUSTICS VEHICLE WIND TUNNEL

The new moving belt system commissioned at MTS, Minneapolis, USA will replace the existing 5-belt system from 2001. The installation and commissioning in combination with a new 6-component subfloor balance is scheduled for the first half of 2014.

The new system is an interchangeable multi belt system, which can be operated in 5-belt mode (4 wheel rotation units and 1 centerbelt) as well as in 3-belt mode (2 long sidebelts and 1 centerbelt). In 5-belt mode each side consists of two wheel rotation units and two rocker panel struts on a common framework. In 3-belt mode each framework is replaced by a long sidebelt. Any peripheral devices are available on any framework to realize short conversion periods. Thus, for conversion only quick connectors for media and data communication have to be disconnected and relocked with the new system.

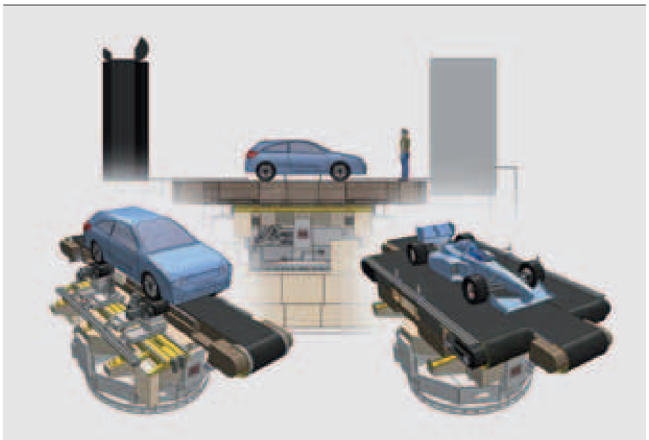
After conversion the two sidebelts are coupled to the subfloor balance. This leads to a significantly improved measurement accuracy of longitudinal and lateral force (i. e. aerodynamic drag and side force) measurements compared to single belt systems. Additionally, parasitic forces are reduced significantly. Vertical forces are measured via contact patches through the moving belt.

In 3-belt mode the vehicle fixation is realized by two different restraint systems located at the outer part of the sidebelts. Race cars as well as passenger cars can be mounted to the measurement system with a variable restraint angle. In 5-belt mode particularly passenger cars can be restrained and vertical positioned conventionally using rocker panel struts. Furthermore, ground clearance can be adjusted using a vehicle internal lift system. If this is not available, ground clearance can be reduced alternatively using tare weights.

❶ shows a scheme of the interchangeable 3-/5-belt system. In ❷ major dimensions of the moving belt systems are summarized.

3 CFD STUDY

In line with the preliminary design of the 3-belt system numerical simulations with Exa PowerFlow were carried out to investigate the aerodynamic simulation quality of such a moving belt system. Therefore, several vehicle models were simulated in conjunction with different moving belt systems. The objectives of such an investigation are to identify and evaluate aerodynamic effects and trends to get a sophisticated assessment of the aerodynamic simulation quality of prospective moving belt concepts. In the following a summary of simulation results is presented.



❶ Interchangeable 3-/5-belt system for the 1:1 aeroacoustics vehicle wind tunnel

LENGTH CENTERBELT	7800 mm
WIDTH CENTERBELT	900 mm / 1100 mm
LENGTH SIDEBELTS	5700 mm
WIDTH SIDEBELTS	1100 mm
WIDTH WHEEL ROTATION UNIT	280 mm / 360 mm
WIDTH AIR BEARINGS (THROUGH THE BELT MEAS.)	260 mm / 360 mm / 410 mm

❷ Dimensions of the moving belt systems

3.1 NUMERICAL MODEL

Each moving belt concept was simulated using the same CFD setup and the same digital vehicle models. A typical numerical setup was chosen, setting the boundary conditions far enough away from model position to have no influence on the flow around the model. This approach is referred to as the PowerFlow Digital Wind Tunnel (DWT). Comparisons between interference corrected wind tunnel data (using the Mercker/Wiedemann correction method described in [6]) and DWT simulation results have been published by Fischer et al. [7, 8].

The floor boundary condition was set to provide a development of the boundary layer to match an idealized boundary layer conditioning resulting in a rectangular velocity profile at the beginning of the belt system. Friction was applied to the floor alongside and behind the moving belt system. The vehicles were centered on the 7.8 m long belt systems. The single and 3-belt system have an overall width of 3.4 m. Each centerbelt is 1.1 m wide. For all moving belt surfaces a surface roughness of 0.05 mm (equivalent sand roughness) was assumed.

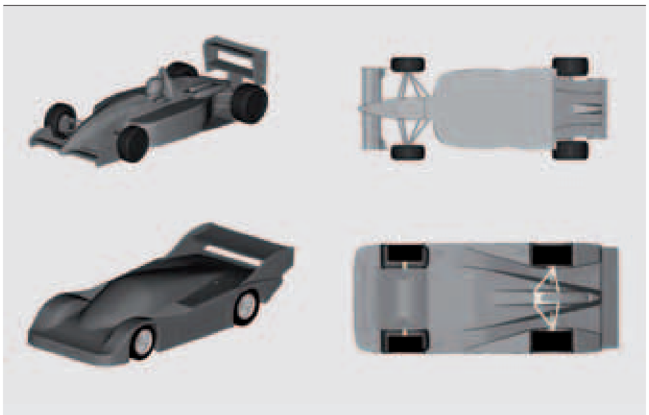
A fundamental advantage of PowerFlow is the automated discretization of the simulated fluid volume using different levels of variable resolutions. This leads to a reduced overall setup time. The computational mesh utilized to discretize the simulation volume consists of approximately 70 million cubic cells (voxels) and 10 million surface elements (surfels).

Two simulated vehicle models are presented in ❸. The selection of the models was on the one hand based on a desirable large sensitivity concerning the chosen moving belt system and on the other hand the models should be kept geometrical simple to reduce numerical errors. Therefore, two generic race car models were designed – a Formula-3 model and a model of a Le-Mans Prototype (LMP) race car. Additionally, a detailed model of a sedan passenger car has been simulated.

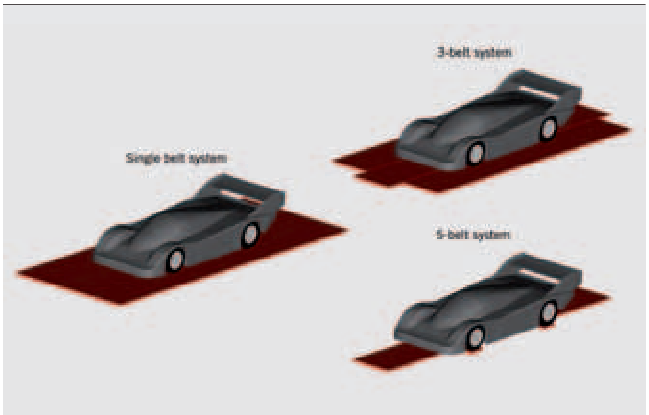
A summary of the simulated moving belt systems is shown in ❹. The 3- and 5-belt systems described above are compared to a conventional single belt system of similar dimensions. All moving belt concepts are referenced to the so-called full road simulation (FRS). In this case the complete floor of the simulation volume has a sliding wall boundary condition. Hence, the relative motion between the road and the vehicle is represented correctly for the whole simulation volume. This numerical setup is generally regarded as reference case for an idealized simulation of road conditions.

3.2 SIMULATION RESULTS

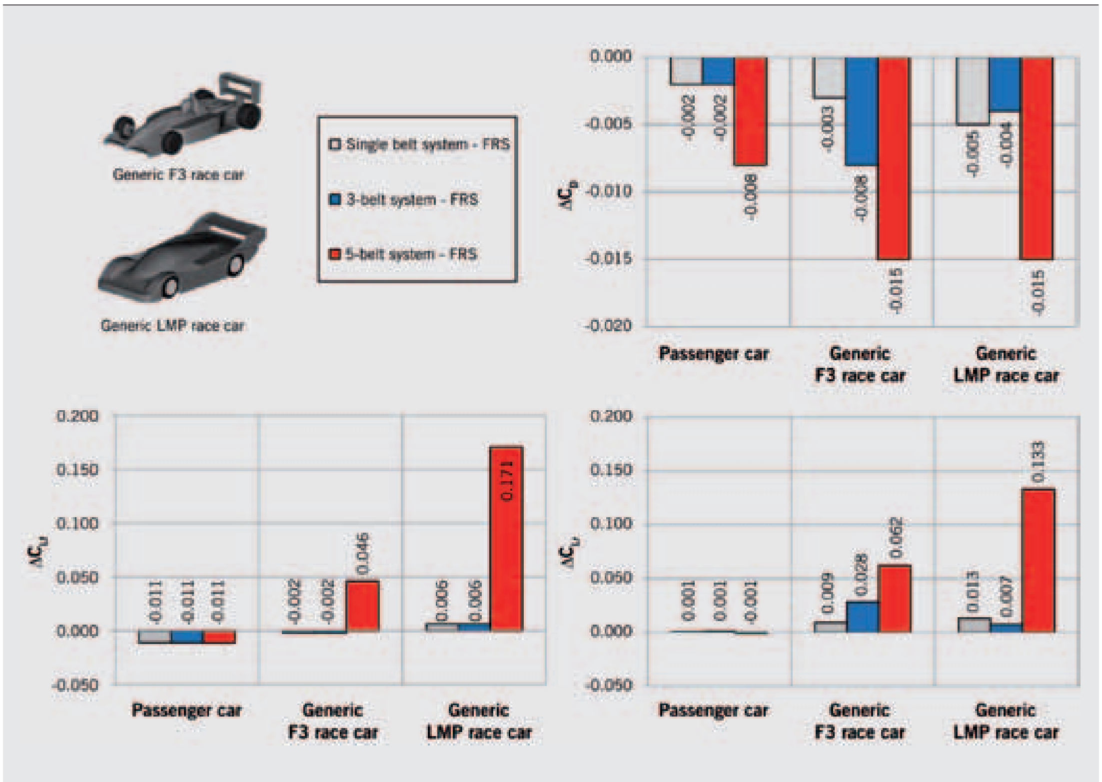
The deltas of the aerodynamic coefficients (Δc_D, Δc_{Lf}, Δc_{Lr}) compared to the FRS are summarized in ❺. According to the experience in wind tunnel testing, the simulation results confirm the trend that less moving belt surface usually decreases drag. For the 5-belt system drag coefficients are consistently lower than for the single or the 3-belt system. For the LMP race car the single and 3-belt system are on a similar drag level. The F3 race car is very sensitive to changes to the road simulation under the sidepods.



❸ Top: Generic Formula 3 race car; bottom: Generic LMP race car; left: isometric view; right: view on underbody geometry



❹ Simulated moving belt systems



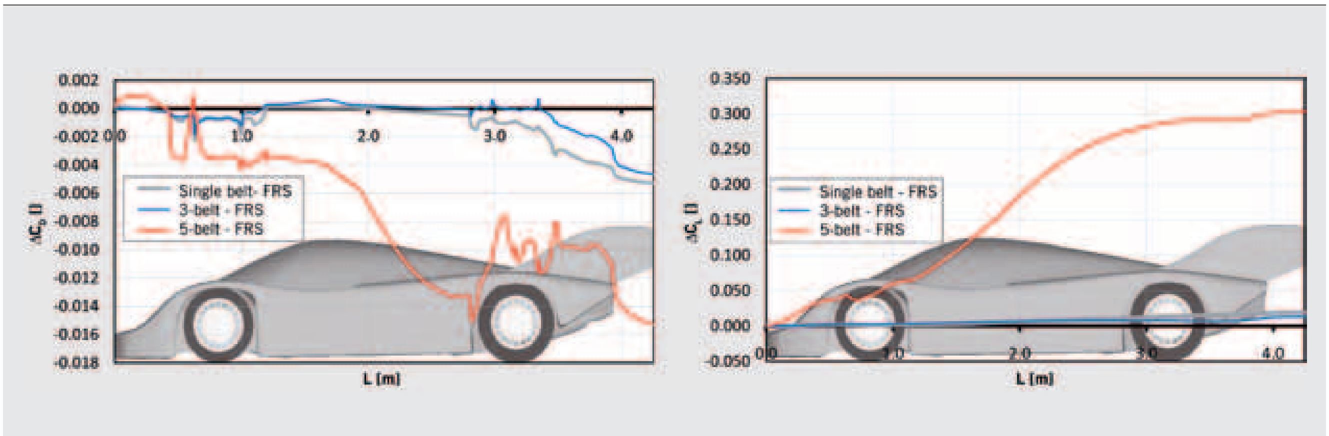
❺ Deviation of aerodynamic force coefficients relative to the FRS

Due to the long narrow gaps between the sidebelts and the centerbelt the 3-belt system does not reach the drag level of the single belt system.

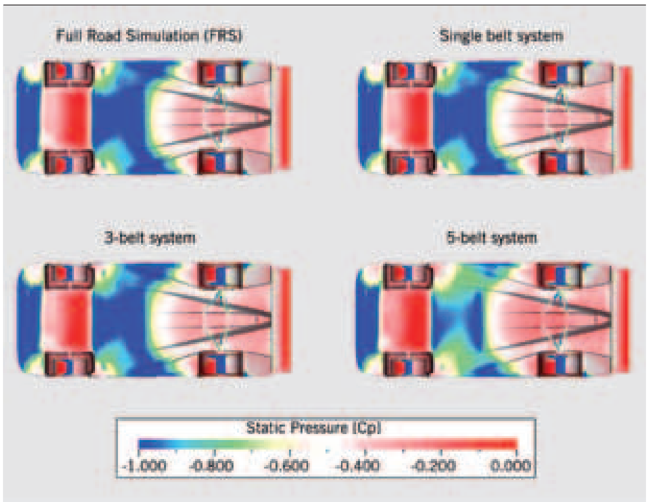
The lift results are strongly vehicle dependent. For the passenger car only small deviations in lift and, thus, only a small dependence from the chosen belt system can be observed, contrary to both generic race cars. The single as well as the 3-belt system results are similar to the reference case, but the above mentioned effect of the 3-belt system in conjunction with the F3 race car leads to increased rear lift. For the 5-belt system very large overall lift deltas of more than 100 counts for both race cars are not acceptable for a sophisticated aerodynamic development.

Below the data of the LMP race car are surveyed in detail. ❻ shows force development graphs for the delta in drag and lift compared to the FRS plotted against the vehicle length. At each point of the abscissa, the graph value is the integration of drag, respectively lift, delta from the vehicle front to the respective vehicle coordinate.

Due to the limited moving belt dimensions of the single and 3-belt system compared to the FRS, small deviations in drag and lift can be observed at the vehicle end. For the 5-belt system deltas are larger and already visible at the vehicle center where the large diffuser channels start to rise up (see also ③). This is due to significantly lower flow velocities inside of these diffuser channels.



❻ Force development deltas for the LMP race car relative to the FRS



❼ Underbody static pressure distribution for the generic LMP race car

In ❼ the corresponding static pressure distribution on the underbody of the LMP race car is shown. Here, the aerodynamic effects of the diffuser channels for the 5-belt system can also be observed clearly. These systems that cover almost the complete test section floor (single belt and 3-belt system) only show very small differences in the underbody surface pressure distribution compared to the FRS. But for the 5-belt case static pressures on the underbody are higher than for the FRS due to the relatively small moving belt area underneath the vehicle. In this case significantly less volume flow is fed into the rising diffuser channels resulting in lower flow velocities and consequently in higher static pressures on the complete underbody.

4 SUMMARY AND OUTLOOK

The complex requirements on a prospective moving belt system in the aeroacoustics vehicle wind tunnel account for a universal approach. On the one hand such an approach must be able to cope with a variety of different vehicle types, frequent vehicle changes and an optimal maintainability in the aerodynamic development of passenger cars. And on the other hand it must also meet the high aerodynamic simulation quality demands in the development of race cars and modern passenger cars. The operating experience with the present 5-belt system has shown that, especially in race car development, direct data transfer from wind tunnel results to on-road conditions is challenging. Especially regarding static pressure distributions on the underbody of race cars, differences between wind tunnel measurements and data obtained on the race track are obvious.

In the last years achievements in measurement techniques have enabled new possibilities like force measurements through the moving belt and, consequently, the implementation of single and 3-belt systems. A 3-belt system combines the high aerodynamic simulation quality of single belt systems with increased measurement accuracy and a significantly improved reliability of operation. CFD simulations have shown that such a 3-belt system provides an aerodynamic simulation quality comparable to conventional single belt systems. The observed aerodynamic trends are consistent with experimental experience gained in many wind tunnel tests. The demands in the aerodynamic development of passenger cars concerning maintainability and measurement accuracy are fulfilled in an optimal way by using the 5-belt mode of the new system.

With innovative measurement techniques as well as a universal application spectrum the new interchangeable 3-/5-belt system in the full scale aeroacoustics vehicle wind tunnel features perfect conditions for an efficient aerodynamic vehicle development not only for race cars, but also for the demands of future drag optimized passenger cars.

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ENTERING THE ELECTRIC MOBILITY MARKET

In its National Electromobility Development Plan the Government of the Federal Republic of Germany posts an ambitious aim: up to 2020 one million electric cars shall be driving on German roads, among them battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV), which are powered by energy from the grid. At present, electric cars still suffer from various restrictions. Therefore, it is necessary to identify potential target groups for the first generation of series-production electric vehicles with regard to possible and reasonable implementation strategies.

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1 OBJECTIVE

Compared to conventional gasoline or diesel vehicles, pure electric cars have some inherent disadvantages: due to its specific storage capacity of about 10 kg/kWh the battery is heavy and voluminous but significantly defines the BEV package. Hence, it has to be designed as small as possible to just fulfil its operation purpose. The same conclusion can be made from the current battery costs of about 1000 €/kWh [2]. A small battery comes along with a limited range (of about 150 km in case of compact cars) which additionally depends on the driving performance and the use of active auxiliary equipment such as air-conditioning and heating. The maximum charging power is controlled by battery design, power supply and charging set. Even though most of the private trips can be covered by such a BEV [7], they do not necessarily match the customer's requirements: Longer trips can only be realised with time-consuming intermediate charging. The large initial costs of BEV can only be amortised after many years – presuming an optimistic development of consumption and battery life, electricity tariff and taxation. Paradoxically, this means that BEV can only be cost-efficient if being operated at lowermost battery size routinely exhausting the maximum range.

Consequently, the economic advantages of BEV usage are larger for commercial fleets than for private users: many fleets have a defined operational schedule with fixed routes or at least a limited cruising radius. Reach capacity has not necessarily be reserved for unexpected longer trips. It is easier to adjust the battery dimension to the concrete operation purpose. The fleet management's attitude to the vehicles is less emotional. Its cost calculations generally take into account the entire life time of the vehicle. For a customised vehicle dimensioning low operating costs may lead to a sufficiently quick payback.

2 CHARACTERISTICS OF COMMERCIAL FLEETS

It is necessary to classify the variety of commercial fleets in order to identify those with large electrification potential. In a first step classification characteristics have been gathered which are relevant due to the following reasons.

2.1 FLEET SIZE

The potential degree of electrification in a fleet strongly increases with the fleet size. A large fleet allows for a satisfying mixture of conventional and alternative drive trains, so that restrictions due to the use of electric vehicles (e. g. limited range) can be overcome by vehicles with conventional engines. In addition, it is easier to re-use already weakened batteries (by age or cycle).

2.2 RADIUS OF ACTION

Diurnal and annual driving performances are as essential as the operation frequency when deciding for a certain drive train design. Moreover, the ratio of city driving, rural road driving and motorway trips is taken into account.

2.3 ROUTE SCHEDULING

The scheduling of routes and the predictability of the driven distances enable a user-optimised drive train design, especially the battery dimensioning.

2.4 PARKING AND CHARGING TIMES

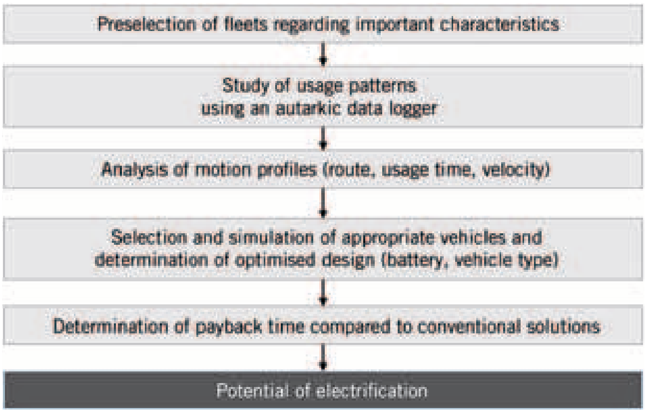
In contrast to private users, many commercial fleets can reliably predict times that can be used for charging. A determined parking space allows for easy installation of needed infrastructure (charging station/charger).

2.5 VEHICLES

Range, driving performance, the required load capacity and payload have to be regarded.

2.6 USAGE STRATEGY

The fleet's car pool mixture is controlled by criteria like vehicle life time or required flexibility. According to a pan-European survey [5] the average usage time of commercial cars amounts to five years. Light commercial vehicles are replaced after six years. Expensive vehicles such as post vans with walk-in access remain in business for more than ten years.



❶ Methodology to derive the potential of electrification

FLEET SIZE	7 vehicles (2 delivery vans, 5 minivans)
RADIUS OF ACTION	Berlin and outer conurbation area
PREDICTABLE ROUTES	yes
PARKING SPACE	not fixed (vans also used for private concerns)
LOADING TIME	at night > 11h, until 6 AM (CEP 1), until 8 AM (CEP 2)
COMPANY'S INTEREST	driving into Green Zone, environmentally friendly image, private use of vehicles*

*The permission for private use is part of the parcel service's remuneration strategy.

❷ Characteristics of the researched parcel service

2.7 REMARKETING

The resale value is included in a fleet management's cost calculation. It affects selection criteria like colour and motorisation. Depending on vehicle type and industrial sector, a part of the vehicles is returned to the business market, another part is sold to Eastern Europe, the Middle East or Northern Africa. Rarely, the vehicles are given to private users [6].

2.8 ADDITIONAL COMPANY INTERESTS

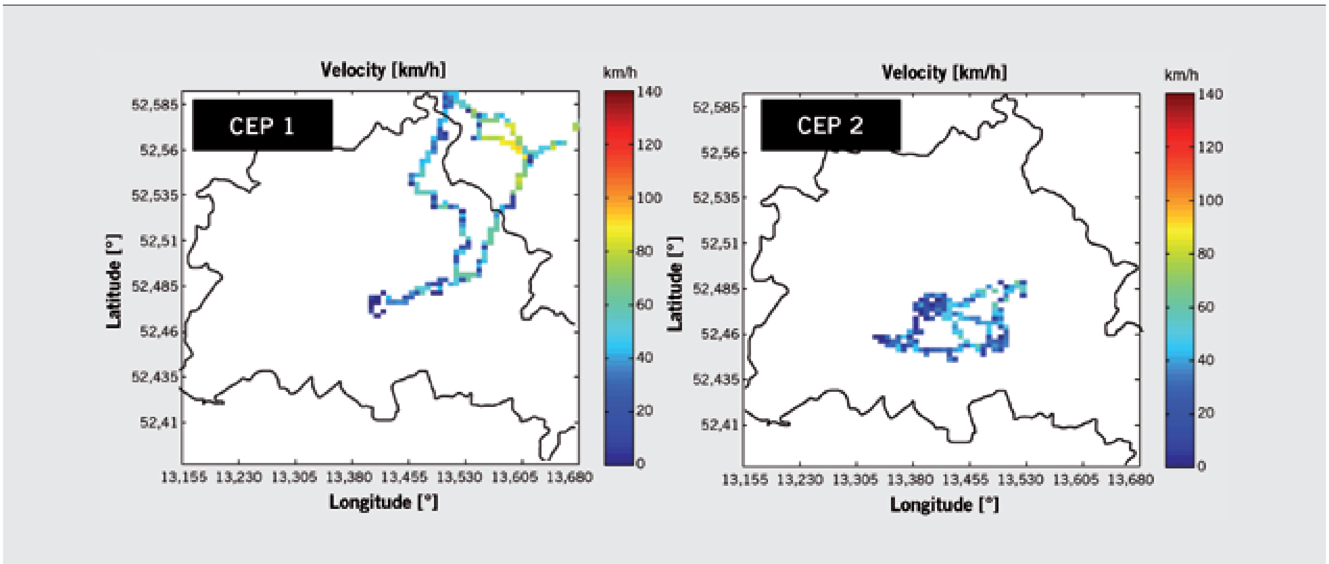
Electric vehicles might be also of interest due to other individual reasons: local emission-free driving, driving in downtown areas (Green Zone), marketing (eco-friendly innovative image), low-noise driving. ❶ visualises an overview of the applied methodology.

	CEP 1	CEP 2
DAILY MILEAGE Ø	39 km	32 km
DAILY MILEAGE (95 %)	41 km	53 km
REGULAR STANDING TIMES	7 PM – 6 AM	8 PM – 8 AM
ANNUAL MILEAGE	12,300 km	10,100 km

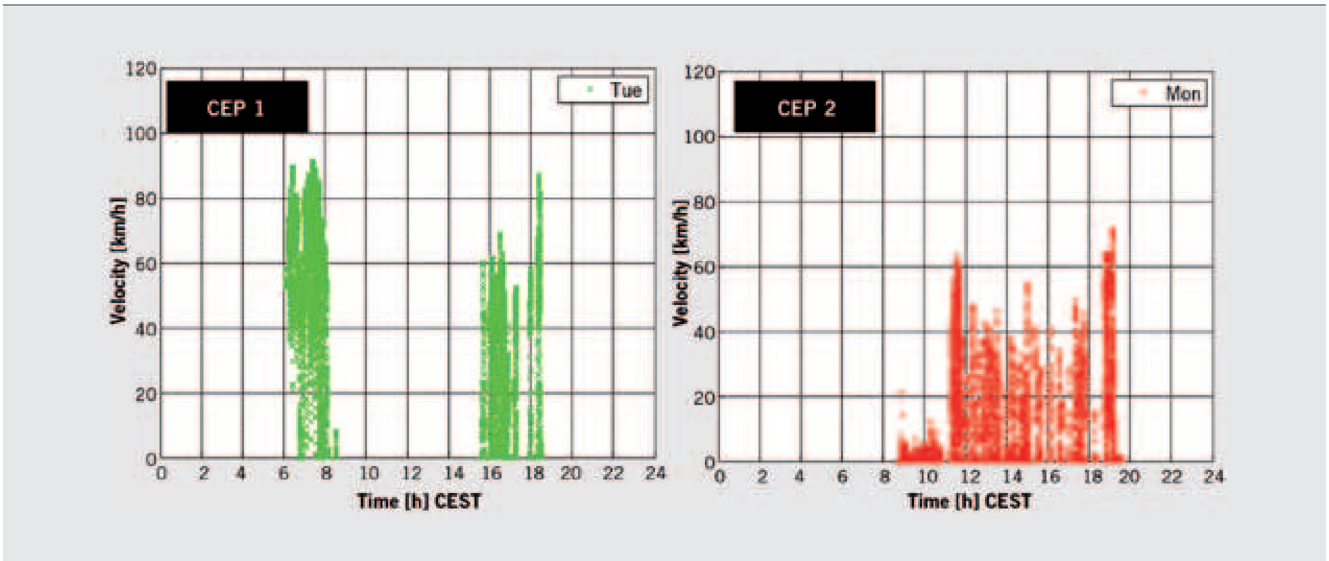
❸ Mileage and standing times for CEP 1 and CEP 2

3 EXAMPLE: DISTRIBUTION FACILITY

Courier, express and parcel services (CEP) rank among the fast-growing economic branches in Germany. With 179,000 employees and a mail volume of 2.18 billion items in 2009 [9] they re-



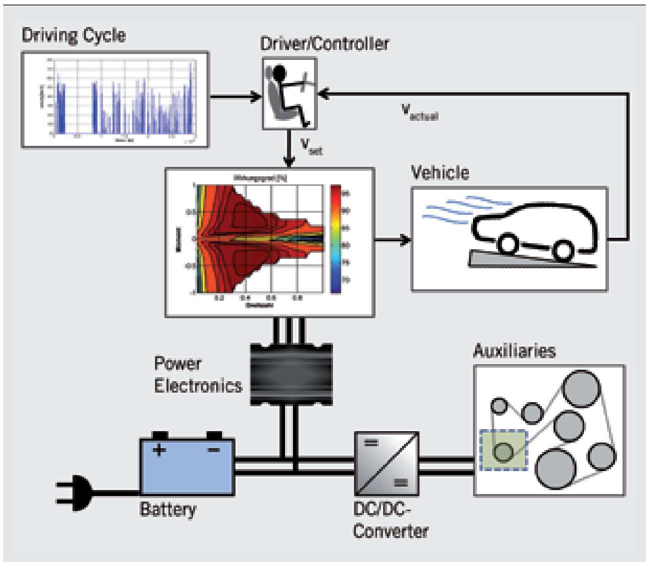
❹ GPS data and velocity of CEP 1 and CEP 2 vehicles during the analysed interval (CEP 1: 3 days, CEP 2: 6 days)



❺ Usage pattern of a representative weekday (CEP 1: Tuesday, CEP 2: Monday)

	CEP 1	CEP 1
NET WEIGHT [KG]	2300	1500
CROSS-SECTIONAL AREA [M²]	4.3	2.4
DRAG COEFFICIENT/ ROLLING FRICTION COEFFICIENT	0.32/0.01	0.31/0.01
ENERGY DENSITY [WH/KG]	100	100
EFFICIENCY RECUPERATION [%]	85	85

❻ Basic conditions in the simulation model (selection)



❼ Sketch of the vehicle model for determinig a user-optimised design

quire a substantial fleet volume. Most of the CEP service is carried out by road transport. According to the German association of international CEP services (Bundesverband internationaler Express- und Kurierdienste, BIEK e. V.), which operates a fleet of more than 30,000 vehicles, sustainability and energy-saving traffic are of growing interest, leading to a variety of activities. Thus, the CO_2 emission should be reduced by (tentative) use of alternative drive trains, efficient route scheduling and driver training. This prompted us to analyse the chances of CEP fleets to enter the electric mobility market. CEP services or suppliers with defined routes are characterised by predictable route profiles and many short stops. The vehicles usually have fixed parking spaces and long off-times, enabling a regular and gentle charging. Stop-and-go traffic, as often occurred in urban driving, leads to a significant influence of recuperation on the total consumption.

To investigate the real user behaviour, pre-selected vehicles have been equipped with the TU-veLOG over a multi-day time interval. This data logger records velocity, acceleration, GPS position and temperature [3].

3.1 ANALYSIS OF CEP USAGE DATA

The investigation addresses a company which delivers parcels by order of a large CEP service in a defined Berlin district. The parcels are transferred to and from the depot outside of Berlin and dispersed inside the district. These two tasks differ in both, applied vehicles and route pattern: one task deals with the transportation of a large amount of parcels over a long distance (indicated CEP 1), the other one comprises the delivery of a smaller amount of parcels in the discrete area (CEP 2). The fleet characteristics are listed in ❷.

Both usage types have been investigated separately. Both show regular routes, similar routes independent from the weekday and periodic driving/standing times as presented in ❸.

The daily distances of CEP 1 and CEP 2 are rather similar, but the detailed usage pattern reveals marked differences: While the CEP 1 vehicles cover a longer distance in the morning and in the afternoon, interrupted by a break of several hours, the CEP 2 vehicles are in use without larger interruptions all day long. This has a direct impact on possible charging times during the day and the corresponding battery dimension. Where applicable, the CEP 1 battery size can be smaller than specified by the total range when daytime breaks are used for recharging.

❹ presents the driven routes and the corresponding speed values during a three-day (CEP 1) and six-day (CEP 2) measurement period, respectively. ❺ shows the representative usage pattern on a distinct weekday.

3.2 VEHICLE DIMENSIONING

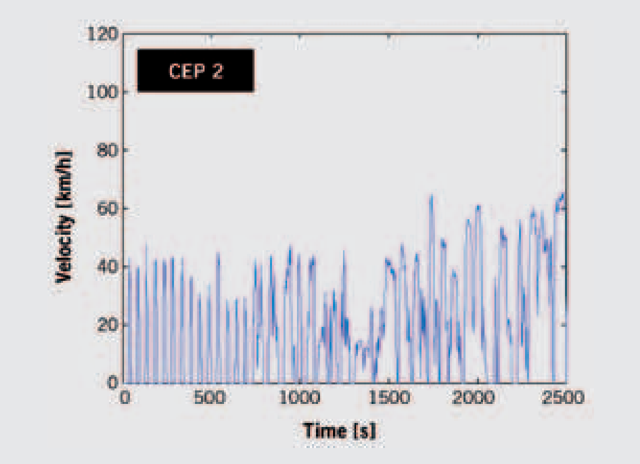
Currently, the company operates two different vehicles: two delivery vans (Mercedes Benz Sprinter, Diesel engine) for CEP 1, and five minivans (Volkswagen Caddy, Diesel engine) for CEP 2. The vehicles have been selected primarily due to fuel consumption and required load capacity.

To verify whether and how present-day vehicles can be replaced by pure electric alternatives, both, technical and economical boundary conditions have to be considered. An user-optimised battery design is essential for efficiency reasons. The required capacity is determined due to the individual driving profile. Here, the applied maximum range has to be determined carefully, since it has to be guaranteed that it can still be reached (1) at the end of the battery life time (State of Health (SOC) = 80 %) to ensure its operation over the whole vehicle life time, and (2) in case of using energy-consuming auxiliaries like heating or air-conditioning.

Scenario	CHARACTERISTICS	AUX [W]	RANGE
1	safety relevant AUX* only	261	CEP1-a: 45 km (95 % of all trips)
2	comfort and safety relevant AUX*	931	CEP1-b: 65 km (plus reserve)
3	summerday with air-conditioning (50 %)	1431	CEP2-a: 45 km (95 % of all trips)
4	winter day with heating (worst case)	2931	CEP2-b: 65 km (plus reserve)

* AUX = Auxiliary unit(s)

❽ Scenarios regarding different auxiliary units and ranges



❾ CEP 2 individual driving cycle

The expected frequency of heating/air-conditioning usage has been estimated based on weather statistics. On average, the daytime temperature decreases below 0 °C on 80 days during a year. However, days with a maximum temperature of ≤ 0 °C cover only 5 % of the year (20 days). On 47 days, a dayside temperature of ≥ 20 °C is recorded, 12 days out of them are characterised by a dayside temperature maximum of ≥ 30 °C. Based on these temperature values, it can be assumed that the CEP vehicle has an enhanced energy demand due to heating at 20 % of its usage time and due to air-conditioning at 13 % of its usage time. At ¼ of this time a large energy consumption has to be taken into account. Related to 315 working days per year an enhanced energy demand by heating/air-conditioning has to be expected for 109 days, out of them 27 days with large energy demand. Consequently, the battery would not be stressed markedly by heating/air-conditioning on 256 days of a year (equivalent to 70 % of the year). It has to be mentioned that the climate trend approaches a higher frequency of extreme weather events. This would be connected with an increase of days with large energy demand by heating/air-conditioning.

Based on these results, the use of different auxiliary units has been incorporated in the simulation. An overview is given in ❽.

Since the battery is the most important cost controlling factor, the dimensioning has to be as user-optimised as possible. To comply with individual requirements, a modular range of different battery sizes is considered reasonable in correspondence to the different motorisation variants of conventional vehicles. A comprehensive simulation has been executed to design the battery regarding driving profile, battery aging and the mentioned boundary conditions.

3.3 USER-OPTIMISED DESIGN

To determine the required battery dimension a simulation model was set up in the object-oriented Dymola environment, ❼.

It is composed by a driver model and the corresponding drive train model with the components electric motor (with power electronics), combustion engine, gear box, auxiliary units and drag model. The driver model is based on a controller, applying a given real (e. g. recorded) driving profile as command variable. The battery model has been developed at the Centre for Solar Energy and Hydrogen Research (ZSW Stuttgart, Germany) and implemented in Matlab Simulink. It consists of three sub-models and a simplified battery management. The first sub-model simulates the terminal voltage in dependence of the terminal current. The second (thermal) one models the cell temperature or battery temperature, respectively. The third one, the open-circuit voltage model, connects the State of Charge (SOC) and the temperature under steady-state conditions. The battery model allows for simulating different cell types and battery types with low effort by script-controlled parameterisation [8]. The vehicle model output variable is the electric power which is needed to cover the total energy demand. Together with the outside temperature, it serves as input variable for the battery model, effecting the battery charging/discharging. The battery recharge at the grid is implemented by a charging model based on the efficiency map of the charger.

According to the vehicle data, ❻, and the recorded routes it calculates the required battery size for the given user behaviour. For both vehicles, one charging interval is assumed, which can be realised during the night off-time. Several scenarios have been generated concerning range and auxiliary consumption. ⑧ pools the different assumptions. All calculations implicate a degree of recu-

CEP 1	MIN. DESIGN		SUMMER DAY		WINTER DAY	
	45 km	65 km	45 km	65 km	45 km	65 km
VEHICLE MASS [kg]	2610	2718	2617	2728	2626	2741
CONSUMPTION [kWh/100km]	45.5	45.9	46.9	47.3	48.6	49.0
CAPACITY [kWh]	28.9	42.1	29.8	43.3	30.9	44.9
BATTERY WEIGHT [kg]	310	418	317	428	326	441

CEP 2	MIN. DESIGN		SUMMER DAY		WINTER DAY	
	55 km	65 km	55 km	65 km	55 km	65 km
VEHICLE MASS [kg]	1605	1620	1644	1666	1694	1724
CONSUMPTION [kWh/100km]	13.0	13.1	19.4	19.4	27.5	27.6
CAPACITY [kWh]	10.1	12.0	15.01	17.8	21.31	25.3
BATTERY WEIGHT [kg]	105	120	144	166	194	224

❿ Results of battery dimensioning for CEP 1 and CEP 2 fleet vehicles

	2011	2015	2020	REF.
ELECTRICITY RATE (HOME MIX) [€/kWh]	0,215	0,217	0,226	[10]
DIESEL FUEL [€/l]	1,34	1,40	1,48	[10]
BATTERY PRICE (MODULE) [€/kWh]	871	457	300	[11]

⓫ Development of battery costs and operating expenses 2011 – 2020

peration of 85 % and an efficient SOC of 64 %. The latter is composed by a battery capacity of 80 % and a SOH of 80 %.

The calculations are based on the individual CEP fleet driving cycle. To optimise the calculation time but incorporating the recorded data of several weeks, a dedicated driving cycle generator has been developed to reduce the driving profiles to a representative velocity profile. It implements the route distribution (city driving, rural road driving, motorway trips), the individual velocities and acceleration/deceleration values. The short cycle quickly permits to derive representative consumption values and an overview over the given driving pattern. An example of the individual velocity profile for a CEP 2 vehicle is presented in ❾.

Here, the maximum speed range of about 50 km/h and the high frequency of breaking situations suggest a good suitability for electric use. The simulation results of CEP 1 and CEP 2 are summarised in ❿ for different scenarios. The minimum design corresponds to scenario 1.

Evaluating the results means to take into account secondary effects: A smaller battery size directly leads to a lower vehicle mass, thus allowing for a smaller engine or a larger payload, respectively. The decision for a particular design is then affected by the (now expendable) variety of usage purposes and can be found out by suitable calculation tools.

3.4 ECONOMICAL ASPECTS

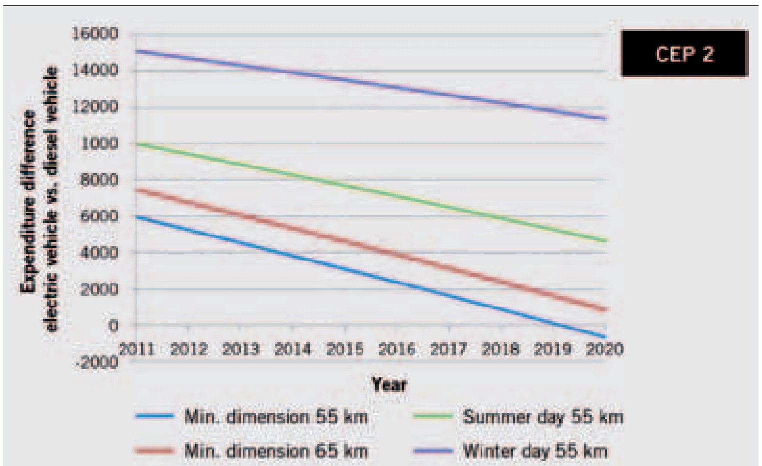
In a next step it has to be examined whether the individually optimised electric vehicle can amortise its initial costs during its life time. Hence, costs of the drive train, energy costs and fuel prices up to 2020 have been compared for each driving profile. The development of the operational costs and battery prices is framed in ⓫.

Neither tax expenses, insurance and maintenance costs nor resale values have been incorporated in the examination, since we cannot refer to a sufficient amount of empirical values or experiences to conduct a well-grounded total cost analysis at the moment. Even though further company-specific issues like depreciation and discounting have not been considered. ⓬ shows the expenditure difference between a diesel vehicle and the electrified pendant for different scenarios regarding CEP 2. For the diesel vehicle, an average consumption of 7.1 l/100 km was assessed as obtained from the fleet test of CEP 2 vehicles.

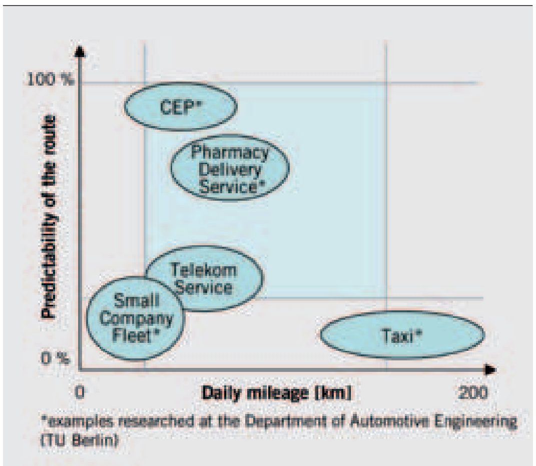
While the CEP 2 BEV barely amortise the additional expenses in case of minimal dimensioning and a life time of 10 years, this aim cannot be reached anymore taking into account additional auxiliaries. The expenditure difference could not be overcompensated by tax/insurance privileges. Corresponding to the mentioned analysis, a range extension by 5 km would imply an average expenditure increase of 1150 € due to the extended battery.

4 CONCLUSION AND POTENTIAL TARGET GROUPS

It has been shown that an advantageous or self-financing investment can only be realised at the moment (2011) if the BEV are operated routinely exhausting the maximum range. The financial disadvantage significantly increases with an increasing difference between average mileage and maximal permissable range. However, some BEV are still under operation in CEP services. For example, a BEV Smith Edison Panel Van is offered. The Ford Transid-based van is experimentally applied by several delivery services (e. g. DHL, Royal Mail, TNT) [4]. According to the OEM, it is equipped with a lithium ion battery of 40 kWh (consumption: 20 kWh/100 km), allowing for a maximum range of 160 km, which can be reduced by the use of air-conditioning, heating or large payload. The van satisfies the requirements of load volume (11m³) and charging time (10 hours). With initial costs of 71,000 € it markedly exceeds the initial costs of a comparable diesel vehicle (MB Sprinter, approx. 34,000 € exclusive of VAT). Assuming a usual CEP vehicle life time of ten years, the difference cannot be overcome regarding CEP 1 conditions.



⓬ Expenditure difference between diesel vehicle and electric vehicle



⓭ Selected fleets and their characteristics

Apart from the cost calculations, other factors have to be taken into account: an additional use of the BEV for private purposes is barely possible, since it does not allow for covering longer distances. Thus, the monetary benefit of private usage as part of the payment is not applicable but has to be compensated by an increase of the salary for instance. Moreover, the flexibility of the vehicles is reduced due to the necessary off-time for charging.

However, some fleets seem to be suited for operating BEV. Provided that the drive train design is optimised to the individual user case, large oversizing costs can be avoided. Hence, the focus is on fleets with a sufficiently large operational performance (to amortise the initial costs by lower operating expenses), predictable time schedules and the daytime breaks for recharging. A charging station at the depot would be profitable. The most promising driving pattern would correspond to urban driving, but the BEV might also be sufficient for delivery services or social services in rural regions. ⓭ presents a variety of fleets, which is currently investigated concerning its route scheduling and daily driving performance.

For large fleets it could be reasonable to bypass the disadvantage of the decreasing battery capacity by applying a sophisticated fleet management: vehicles with reduced capacity could be operated on short distances, batteries can be swapped between different vehicles.

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