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FUSION of Vehicle and Environmental Sensing

PORSCHE 997 GT3 with Electro-pneumatic Front Axle Lift System

HYBRID Drive System in the BMW ActiveHybrid 7

/// INTERVIEW

Hans-Georg Frischkorn
VDA

ENGINEERING TRENDS IN COMMERCIAL VEHICLES

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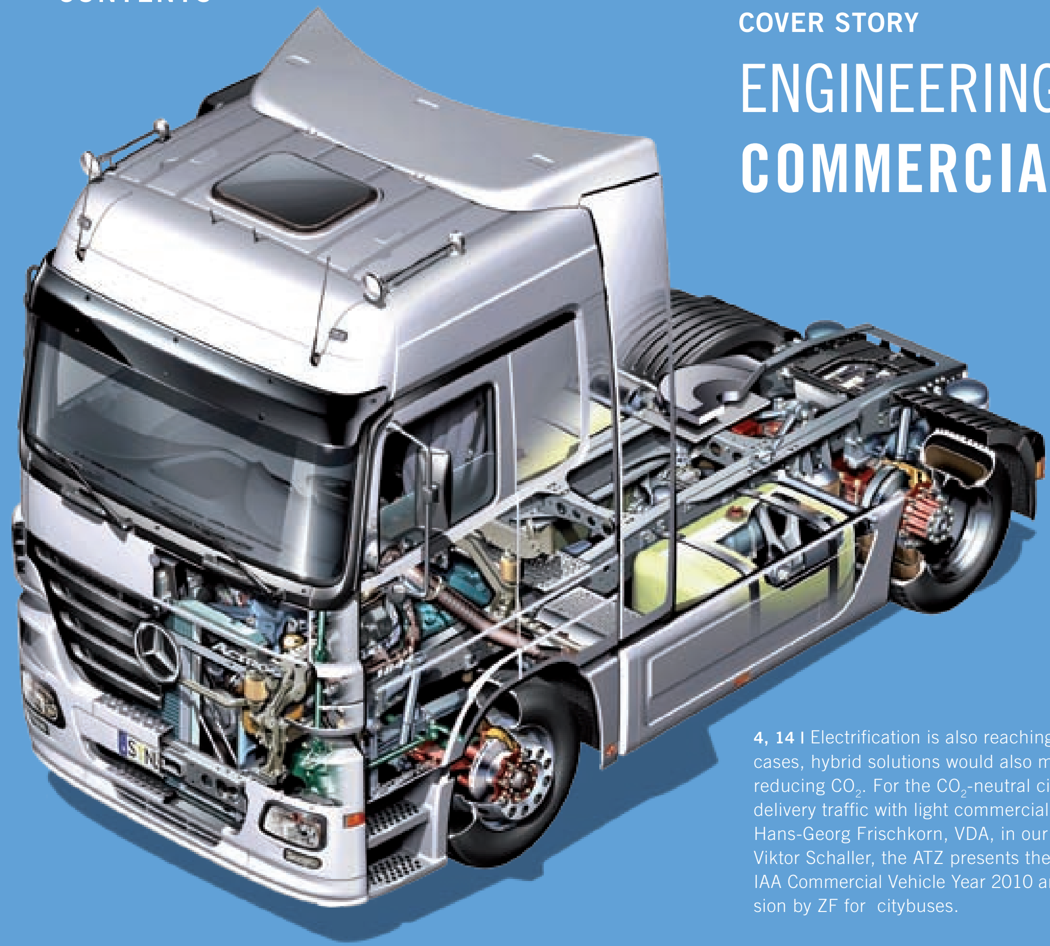


COVER STORY

ENGINEERING TRENDS IN COMMERCIAL VEHICLES

4, 14 I Electrification is also reaching out to commercial vehicles. “In many cases, hybrid solutions would also make a significant contribution towards reducing CO_2. For the CO_2-neutral city, which is currently a thing of the future, delivery traffic with light commercial vehicles is very important”, emphasizes Hans-Georg Frischkorn, VDA, in our interview. Together with Professor Karl Viktor Schaller, the ATZ presents the engineering trends in the industry in the IAA Commercial Vehicle Year 2010 and introduces a newly developed transmission by ZF for citybuses.

COVER FIGURE Scania **FIGURE ABOVE** Daimler

MANAGING CYCLES

Dear Reader,

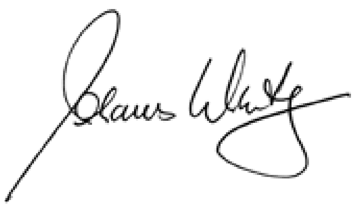
The recovery has started. It is not only the manufacturers of premium cars who are sensing a new momentum triggered by a strong increase in demand from abroad. The commercial vehicle sector is also emerging from the recession, although the gradient is by no means as steep as was hoped, at least not yet. The general opinion seems to be that the crisis is over. But the recovery itself represents a new challenge for production management. All areas are suffering from a lack of parts, especially electronic components from the Far East. And raw material prices are rising even faster than production volumes.

First we had massive overcapacities of more than 100 %, now we have problems in ramping up production to full capacity – does that make sense? Ever since the crisis I have been constantly hearing calls for more coordination to remove overcapacity from the market. This will remain a dream, and not a pleasant one. The only way to protect markets from overcapacity is to abolish them altogether and replace them by a state-socialist system. And not even China wants to return to that kind of inefficiency.

Events on relatively free markets, on the other hand, are characterised by cycles of boom and bust, and that has always been the case. The fact that there has been an increase in the amplitudes and the frequency of the cycles is due to the globalisation of automotive markets and the increasing harmonisation of the world economy.

Being a manager means accepting the facts without mawkish sentimentality. It is not a question of abolishing cycles but of managing them. Not only in the factory but also in development. Those who design products hold the key to flexible production. And even if development budgets do not fluctuate as strongly as production volumes, we were all made painfully aware in the recent crisis what it means for a development team when sales fall by 30 %, and in the commercial vehicle sector even by up to 50 %.

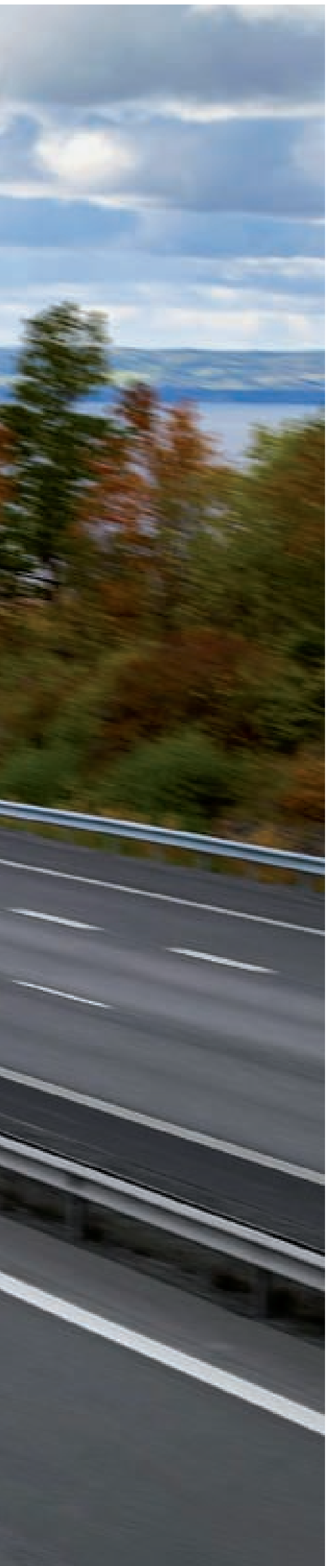
I am looking forward to an IAA Commercial Vehicles at the beginning of a recovery that will lead us to new heights.



JOHANNES WINTERHAGEN, Editor-in-Chief
Wiesbaden, 18 August 2010

COMMERCIAL VEHICLES FOR THE FUTURE

The R 730 tractor unit from Scania for 60 t tractor-trailer combinations is currently the world's most powerful truck, with 730 hp and 3500 Nm from its 16.4 l V8 diesel engine (Figure: Scania)



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TECHNOLOGICAL LEADERSHIP OF THE EUROPEANS

Even during the crisis in the automotive industry in 2009, development activities did not come to a standstill. Firstly, the technical and political background conditions for commercial vehicles in Europe have become much tougher. In addition to new emissions legislation, examples include future limits on CO_2 emissions and very welcome legislation on safety equipment, and this year the IAA Commercial Vehicles (23 to 30 September 2010) will once again witness the innovative power of manufacturers and suppliers who continued to develop cutting-edge technology to market-readiness even during the crisis. The technological leaders in the global commercial vehicle business are certainly the European manufacturers.

Secondly, the proportion of these new, innovative commercial vehicles on the world market is continuing to fall. Almost half of the world's heavy commercial vehicles will be registered in China in 2010 and 99 % of these will also be produced there. Without question, it is a major challenge for European manufacturers with small production volumes to develop state-of-the-art technology and at the same time to find intelligent platform concepts on a global scale.

There will be little fundamental change for commercial vehicle developers over the next few years. The key issues will remain the four areas of emissions, transport efficiency/CO_2, safety and new powertrains.

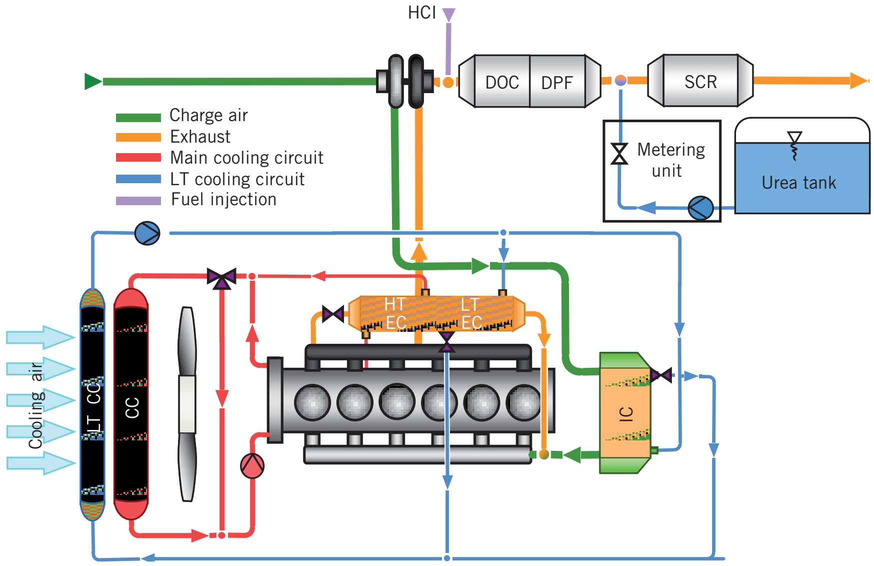
EMISSIONS

Almost all major manufacturers have their Euro 6 test fleets on the road and are busy collecting data in various summer and winter tests [1, 2]. The question "EGR or SCR?" has been answered. All manufacturers on almost all engines are combining the two systems of exhaust gas recirculation and selective catalytic reduction. They are also adding a diesel particulate filter – precisely what environmental politicians always wanted. The argument between the systems is a question of priorities. The EGR specialists will focus on high recirculation rates and low EGR mixture temperatures. Their SCR systems will be somewhat simpler in design, ❶.

The SCR faction on the other hand, due to their lack of EGR experience, will do exactly the opposite. However, the two groups have one thing in common: the space available on the frame for the tank and auxiliary units is becoming tighter – complex vehicles require sophisticated solutions with a multiple division of the exhaust aftertreatment system and insulated pipes. And, of course, things won't get any cheaper. With an asymptotic benefit for the environment, the costs of the powertrain have increased exponentially. Unfortunately, legislation has lost sight of the key issue: heavy commercial vehicles have not become more fuel-efficient in the past 15 years.

TRANSPORT EFFICIENCY AND CARBON DIOXIDE

One third of the CO_2 emission from road traffic comes from commercial vehicles. It is clear, therefore, that, in the wake of CO_2 legislation for passenger cars and vans, heavy commercial vehicles are now at the top of the agenda in Brussels. The test regulations currently being developed and the limit values still to be defined – they are to come into force from 2015/16 – will be very strict. No country will want to miss out on this potential source of income. In response, the commercial vehicle industry, just like its passen-



❶ Emission reduction concept with a focus on EGR – for the Euro 6 standard with low EGR mixture temperature and indirect intercooling (LT: low temperature, HT: high temperature; CC: coolant cooler; EC: exhaust cooler; IC: intercooler; DOC: diesel oxidation catalytic converter; DPF: diesel particulate filter; SCR: catalytic converter for selective catalytic reduction; HCI: fuel injection)

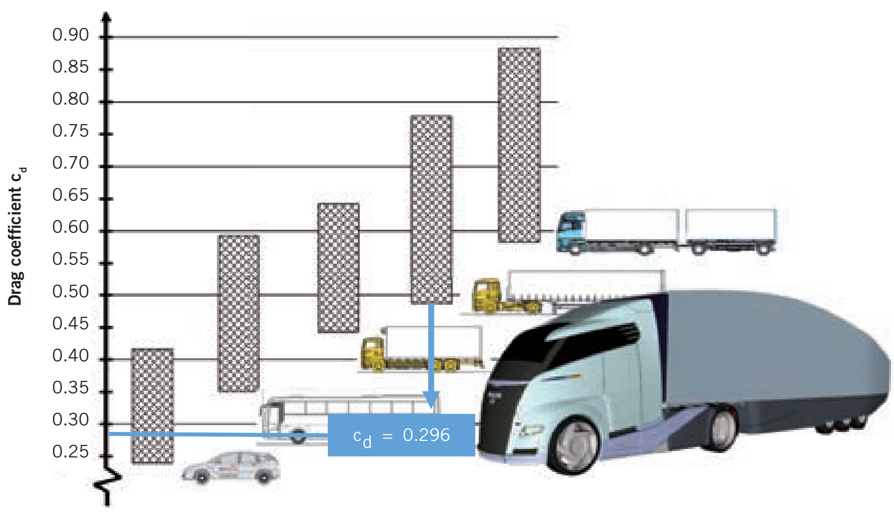
ger car colleagues, will identify and develop every possible means of cutting emissions, no matter how minor or complex it may be, and offer it to the end customer. Manufacturers with passenger car experience and connections may well have certain advantages in this respect.

By far the greatest potential for improving transport efficiency lies in improvements in the aerodynamic design of vehicle combinations. The tractor-trailer, which is currently the dominant vehicle in long-distance haulage, represents the reference for the concepts (the drag coefficient cd is approximately 0.53 today). The tractor unit, which is already aerodynamically optimised, is not the problem. The semi-trailer, on the other hand, could achieve a saving in fuel consumption of more than 20 % with a suitably aerodynamic design, ❷. However, this would mean that today's brick shape would have to be changed without any loss of volume or payload for the user. In this case, politicians could demonstrate – with a genuine attitude of give and take – how seriously they take a reduction in CO_2: minus 20 % CO_2 for somewhat more length and height, although the height as an inflatable "dolphin back" concept controlled by the toll system could only be used on suitable routes to reduce fuel consumption. As an important side effect, this aerodynamic trailer concept would also boost the economy of the trailer and semitrailer industry.

The tyres have second place in the CO_2 race. Research tyres that are optimised only with regard to rolling resistance can halve the rolling resistance of today's good tyres, although a realistic figure in the next decade is a 25 % reduction, which, in an aerodynamically optimised vehicle, will be reflected in a reduction in fuel consumption of significantly more than 10 %. The somewhat unpopular super single tyre for the drive axle will also experience a renaissance in the battle to reduce carbon emissions. In this respect, Europe is even behind the traditional USA: more than one million super single tyres are already fitted to Class 8-6 × 4 trucks. And, of course, the forthcoming legislation will include the tyres in detail.

As far as vehicle concepts as a whole are concerned, the trend for a long time was towards larger units. In Sweden, large trucks – including 60 t versions – are now a common sight on the roads. Following the political rejection of an EU-wide introduction of 60 t trucks, the situation is open once again. A synthesis of vehicles with the boundary conditions of maximum payload using the maximum legal loading of the axles and the lowest number of tyres (rolling resistance) has resulted in a new concept: the 38 t truck with two 10 t axles on the semitrailer, ❸. Although this vehicle concept loses around half a tonne of payload compared to the classical 40 t version, it will have significantly lower operating costs – without any logistical limitation. The somewhat lower tolerance in the load centre of gravity can be easily compensated for by the use of axle load measuring systems, which have long since been available.

With tank-to-wheel efficiencies of around 40 % (for example 40 % of the chemically bound energy in the diesel fuel is supplied as mechanical work to the wheel), current powertrains have very good efficiencies, and dramatic improvements can no longer be expected due to thermodynamic limits. The potentials lie in

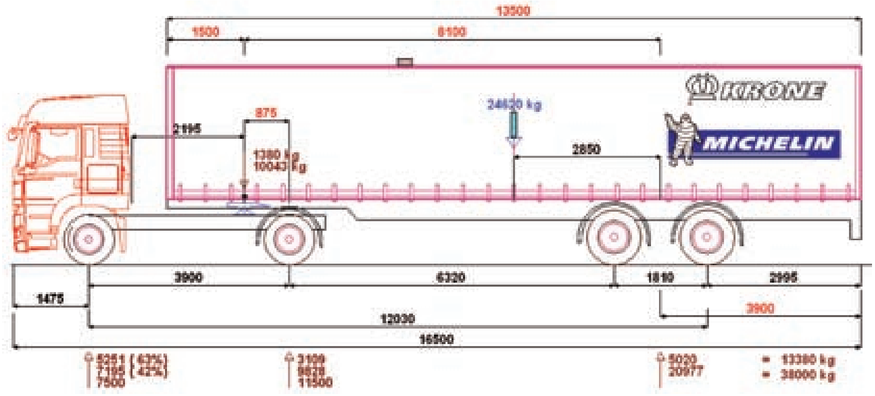


❷ 20 % lower fuel consumption due to aerodynamics – the "dolphin back" design can reduce drag from c_d = 0.53 to 0.30

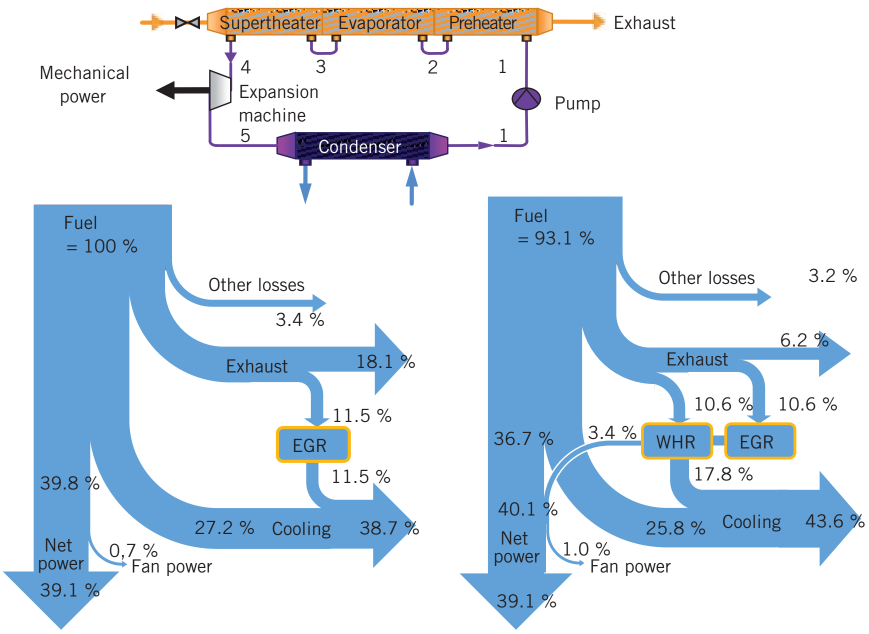
the auxiliary units and waste heat recuperation. Once again, we come up against the issue of emissions legislation. EGR engines have a considerably higher cooling performance requirement and high heat gradients (600 °C hot exhaust gas), which on the one hand requires new radiators and cooling air ducts as well as larger, more powerful cooling fans (with a negative influence on fuel consumption) but on the other hand allows an intelligent use of waste heat by means of the Rankine cycle (steam engine, ❹). As a result, a suitably designed commercial vehicle diesel engine can develop the same power output with 7 % less fuel at mean engine speed and mean load. The technology has been known for a long-time and is used in every power station. However, the components for motor vehicles, especially the expander that generates the power, still require considerable development work. There are mechanical similarities with the turbo-compound process in which the expander is designed as a fluid flow machine.

In a few years' time, the auxiliary units – the fan, compressor, coolant pump, engine oil pump and power steering – will be controlled according to demand for the first time or much better than today. Following the introduction of air compressors that can be deactivated when not required, one manufacturer will introduce a regulated water pump next year, a major step in the right direction. The power steering system can achieve significant energy savings through the use of electric systems, as has been demonstrated by the passenger car industry. Energy-efficient electric power steering is already available for light commercial vehicles (vans), ❺. On heavy commercial vehicles, this concept would also provide considerable mechanical simplification of steering systems for pusher, tag and multi-axle vehicles.

The final but very important lever to improve transport efficiency is the driving profile. An electronic horizon (E-horizon) in the navigation system allows fuel consumption-optimised speed profiles to be defined. The potentials are strongly dependent on the gradient profile being driven, and such systems are of little benefit in flat countries such as the Netherlands. An infrastructure designed specifically for commercial vehicles with low uphill and downhill gradients as well as long sections that can be driven at a constant speed (such as the one that was created for the railway at a high economic cost) would help to improve the efficiency of commercial vehicles in real application on the motorway. But this would certainly be one point on the transport minister's wish list that would be among the first to be cut as a result of economy measures.



❸ Operating costs – optimised vehicle concept with minimum number of tyres



❹ Energy flows on the diesel engine without (left) and with (right) waste heat recuperation (WHR) using the Rankine cycle steam process

SAFETY

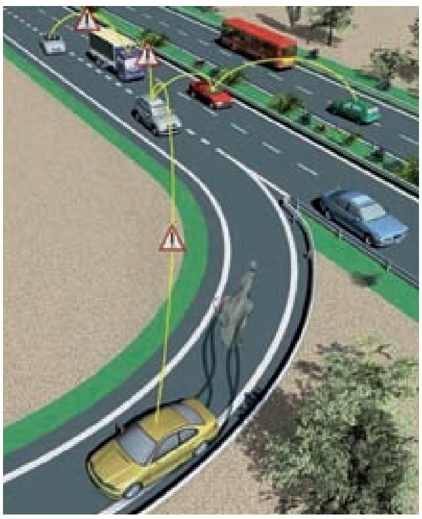
In recent years, groundbreaking safety systems have been developed and introduced by suppliers and OEMs, unfortunately with somewhat limited market success. The effectiveness of these systems was impressively demonstrated in large-scale field trials: vehicles with an electronic stability programme (ESP), lane departure warning (LDW) and an automatic emergency braking system (AEBS) had around 50 % fewer accidents, and the severity of the accidents was reduced by up to 90 %. Here too, the registration authorities have reacted and plan to combine what are currently around 50 homologation regulations on brakes and steering into a "General Safety Regulation", with mandatory introduction dates for ESP, LDW and AEBS. Although this step is an important and correct one for the commercial vehicle industry, the implementation regulations are not yet clear and are unlikely to be finalised until after the introduction

❺ Energy-efficient electric power steering, for example for a van (left: system, right: detail; Figure: ZF Lenksysteme)

dates. This will complete a further evolution step in commercial vehicle technology.

The next development stage is already recognisable. Following the introduction of vehicle-internal systems such as ABS/ESP and vehicle-autonomous systems with environmental monitoring such as AEBS, commercial vehicles are now being networked with other vehicles and with the infrastructure. The key to this "Safety 2.0" concept is modern communication technology, which has the capacity to transmit increasingly high data rates and is able to distribute information on the traffic situation collected by vehicles or by the infrastructure to many other vehicles, ❻. Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication takes place with high data rates with the following features:

: direct communication among vehicles
: communication over several vehicles (multi-hopping)
: communication of the vehicle with the infrastructure.



❻ Safety 2.0 – the commercial vehicle as a mobile information platform

These powerful systems cannot be advanced by one manufacturer alone. They can only be further developed if all those involved take part in the process, as is already the case in the Car-2-Car research communication consortium [3].

It is also clear that this will only function with the aid of the infrastructure operator and international standardisation, which means a lot of work for research and predevelopment.

ALTERNATIVE DRIVE SYSTEMS

The issue of electromobility in passenger cars is clearly settled – but what is the situation in the commercial vehicle sector? The hybrid drive system is almost perfect for use in urban buses, as their frequent stops provide ideal conditions for braking energy recuperation. In the meantime, all major manufacturers offer a hybrid as a standard option. Practical application will show whether the serial or parallel hybrid will become the dominant system. With energy savings of up to 30 %, it is the only mobile hybrid system to have a positive cost/benefit ratio for the end customer even without legislation or subsidies. The logical further development would be the "Digital Trolley Bus", which has no internal combustion engine at all and is recharged at bus stops inductively and without contact. This concept already existed in 1954 in Zürich in a simple form with a flywheel as a means of storing energy.

As far as the hybrid efficiency potential is concerned, the situation is somewhat less positive for delivery vehicles. With considerable effort with regard to cost and weight, an energy saving of approximately 10 % can be achieved, of which 5 % alone comes from the use of a stop/start function for the diesel engine. Nevertheless, the further development of these vehicles is unavoidable, as the logic of environmental zones will sooner or later demand zero emissions. In this case, cost-effective solutions will only be achieved by using passenger car battery technology, also for purely electrically powered distribution trucks.

For heavy commercial vehicles, it is hardly possible today to compensate for the additional weight of hybrid systems that have the necessary power output (and therefore the loss of transport efficiency) by savings in fuel consumption. Several fundamental innovations are required here.

Other alternative primary energy – fuel – energy converter chains such as natural gas – natural gas internal combustion engines or natural gas synthetic liquid fuel internal combustion engines make sense because the primary energy basis is broadened for mobility. Pure natural gas engines have had little success so far. Retrofit systems for diesel engines that make use of the tax-related cost benefit of natural gas for the customer can be cost-effective without increasing the level of complexity for the OEM.

OUTLOOK

In 2010, the IAA will once again become the platform for the future of commercial vehicles. Let us look forward to the innovations that suppliers and OEMs will be presenting. They will result in commercial vehicles that offer more safety and efficiency and will impressively demonstrate the leading position of the European commercial vehicle industry.

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"WE HAVE TO INVEST NOW"

Hans-Georg Frischkorn is the first computer scientist to take on the position of Director of Technology and Environment at the automotive industry association, the VDA. For the IAA issue, ATZ spoke to him for the first time on a range of subjects, including commercial vehicles.

The computer scientist **Hans-Georg Frischkorn** (53) was born with a love of cars. It comes as no surprise, therefore, that following his studies and many years working for IBM, he moved to BMW. Having started as an in-house R&D consultant in 1997, he went on to become project manager for the Z4 roadster, before finally being appointed Senior Vice President for Electrical and Electronic Systems. His expert knowledge made him a highly regarded – and feared – business partner for system suppliers. In 2006, he moved to General Motors in a similar function but with worldwide responsibility. Since 1 May 2010, Frischkorn has been working in Berlin as Director of Technology and Environment at the VDA. According to the experienced industrial manager, what he finds particularly exciting about his work at the VDA is the fact that he can provide support for the industry during a period of dramatic upheaval.

ATZ_You can look back on a career in electronics development and have now been appointed Director of Technology at an industry association that tends to be characterised by classic mechanical engineering. Is that an external sign of a paradigm shift?

FRISCHKORN_That is a question that concerns not only myself, but also the automotive industry as a whole. Long before the debate about electromobility began, the proportion of electronics in vehicles increased dramatically. More and more car manufacturers and suppliers see electronics as a key technology. The transformation of the automotive industry from a metal-processing sector to a system integration industry is well advanced. Electromobility is providing a further impetus in this respect.

It is true that manufacturers are making good progress. But what about the suppliers?

Of course, there are successful suppliers who are more involved in classic mechanical engineering product areas. This is the right route for them to take, because these tasks will still need to be done – even in the future, cars will not run on electronics alone. However, the focus is shifting. Over the past ten years, the major suppliers have pursued a similar strategy to the car manufacturers and significantly extended their electronics development capabilities.

Medium-sized companies are already facing the challenges of change. What can you as an association do?

The most important role of the VDA is to create transparency. We cannot overcome the challenges faced by individual member companies in the market. But what we can do is make it clear at an early stage where and how technologies are changing, in order to give the companies an opportunity to react.

Do you share the view expressed by the Federal Ministry of Transport that electromobility is the key issue of this legislative period?

I certainly see electromobility as a key issue for the German automotive industry beyond this legislative period. Essentially, it is a question of whether we can maintain the technological lead that we undoubtedly have with regard to traditional powertrains in a new and extended form for the next 20 to 30 years. We are in an excellent starting position. If we manage to develop electromobility jointly, quickly and energetically in the same way as we have begun to do with the National Platform, then we will continue to be successful.

There are still many people who have doubts about electromobility, including some from the industry. Is it obvious to you that all our vehicles will be electric one day?

We are focusing on our broadly based strategy and looking at several different options for powertrains. I haven't come across anyone at all in the industry who has serious doubts about the potential of this technology. The question is: how fast will it all take place? The challenge for our industry is that we know we have to invest now, although we are aware that sales and earnings in this area will still be extremely low in ten years time. Just consider the objective "one million vehicles by 2020". That is about two percent of the entire number of vehicles registered today. If we want to achieve aggressive fuel consumption targets in this period, we must make further investments in improved internal combustion engines and invest even more intensively in transmissions. In parallel with this, the new issue of electric vehicles must be addressed. That will put a major burden on companies' resources.

Many well-paid managers and scientists are working on the National Platform. What are the main results that need to be achieved before we can say that their time has been well spent?

If we already knew that, we wouldn't need the platform. We have only just begun working in this area. As far as the objective of the project is concerned, those technologies that are critical for success should be defined on completion of the project. In this case, „successful" means not only technically feasible electric vehicles but also those that can be produced at an acceptable cost. In other words, it is a question of achieving economics of scale quickly in the key technologies. At the same time, we also need

"I certainly see electromobility as a key issue."

to solve the problem of designing the infrastructure which will ensure that electric vehicles offer maximum customer benefit. Finally, we must find out which qualifications our workers will need and what sort of basic conditions the state must put in place. Initially, it is a matter of research funding, but in the medium term it is also a question of creating market incentives.

Let us talk about commercial vehicles. Electromobility is not a solution for wide areas of goods transport.

Commercial vehicle manufacturers are certainly working intensively on the issue of electrification, although that is not the

Hans-Georg Frischkorn sees an opportunity for electric delivery vehicles

same as fully electric vehicles. In many cases, hybrid solutions would also make a significant contribution towards reducing CO_2. For the CO_2-neutral city, which is currently a thing of the future, delivery traffic with light commercial vehicles is very important. We will therefore also see small vans with fully electric powertrains. If the costs are calculated over the product life cycle, cost-effectiveness can be achieved more quickly.

Beyond local delivery traffic, is the diesel engine still the main drive system?
Clean diesel engines will remain industry‘s work horse. It is possible that intelligent, second-generation biofuels, which do not impact on the food chain, will play an increasingly important role, perhaps even more than in cars. Equally importantly, there are companies in the VDA that are working intensively on hydrogen-powered drive systems.

The transport industry is pinning its hopes on biofuels. How justified is this approach?
We deliberately talk about a broadly based strategy because no technology alone can resolve the CO_2 issue. There can only be a mixture of different technologies, the sum of which will enable us to achieve the CO_2 targets.

But wouldn't it make more sense to reserve biofuel in the long term for those traffic segments that are not suitable for electric drive systems?
We should not be trying to make decisions like that now. We cannot currently predict the options that will be available to different modes of transport to enable CO_2 emissions to be reduced. If some areas were "guaranteed" a supply of biofuel, they would have little incentive to increase their research and development efforts and improve their existing systems. It is also true in this context that technological progress is the result of competition.

Supporting the automotive industry during a period of upheaval

As far as fuel cells are concerned, there are very different opinions among the manufacturers. Does an association have to remain neutral in such cases?
In the end, it is a discussion about content. The question is: how optimistic can we be that we will achieve even more significant improvements in the efficiency of batteries? If we make a further quantum leap in the energy density of batteries, with whatever technology, this will make electric cars more attractive. Fuel cells have a great deal of potential, but they require the establishment of a new infrastructure for hydrogen.

"We know the limits of physics."

How optimistic are you in this respect?
At this point, it is not a question of optimism or pessimism but of whether the two or three research approaches that are currently being pursued are successful or not.

Moore's Law, which says that the number of circuits on a chip will double every two years while costs remain the same, cannot therefore be applied to batteries?
Definitely not. We know the limits of physics when it comes to lithium ion technology and we are therefore being cautious. Technological progress is not linear. We cannot simply continue our development processes in the same way as before. This is why it is so important that all the players involved – the worlds of politics, business and science – are pulling together when it comes to the National Platform for Electromobility.

Hans-Georg Frischkorn, thank you very much for this interview.

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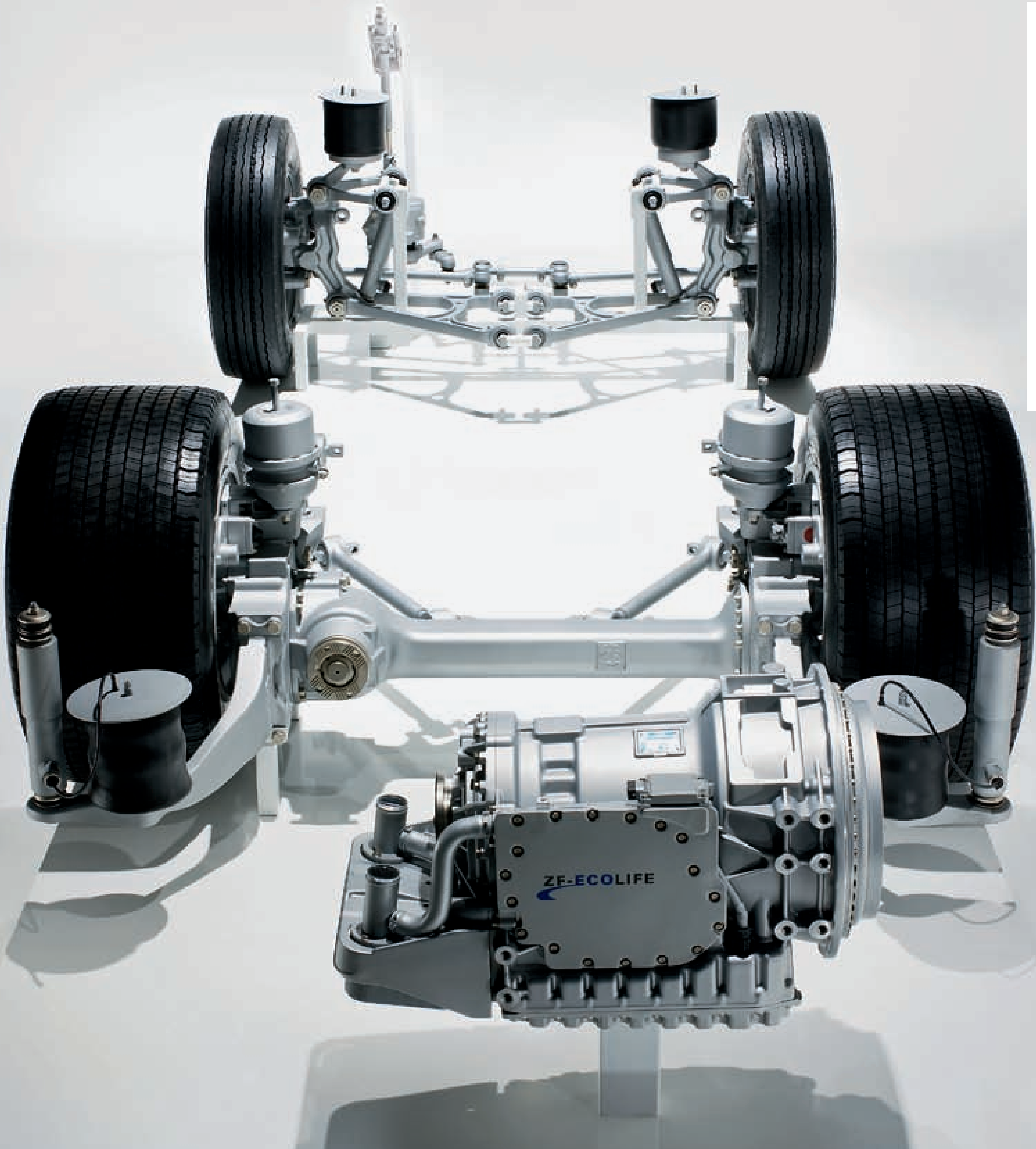
POWERSHIFT TRANSMISSIONS FOR CITY BUSES



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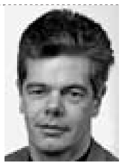

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With the new EcoLife powershift transmission, ZF Friedrichshafen AG has developed a city bus transmission with a three-stage planetary gear set that is already designed for future operating conditions. The objective of the development was clear: low operational costs, lots of power. With the transmission software TopoDyn Life, the transmission is in an optimal operation mode throughout the entire route.

MARKET REQUIREMENTS

The demands on modern city buses are steadily increasing. For one thing, the legal side must be taken into consideration: regulations regarding CO_2 emissions, noise development and safety requirements obligate not only the vehicle manufacturers, but also the suppliers of important components and systems. This places special significance on the driveline. In addition, economic aspects play an increasingly important role. A comparatively low reduction in fuel consumption per vehicle is already an important cost factor for transport services and fleet operators. That kind of savings can ensure your own long-term competitiveness. The same applies for longer maintenance intervals, which help reduce the lifelong operating costs of a bus, or the life-cycle costs (LCC). And of course comfort demands for passengers and driver must also be considered. Many passengers are not necessarily dependent on public transportation and can choose between the city bus and their own passenger car. That's when it's important to contradict the notion that riding the bus is impractical, uncomfortable, and a waste of time. These and future circumstances that are foreseeable today define the market requirements that a new generation of city bus transmissions must meet without fail. In short, they can be defined as follows:

- Increasing performance requirements for the engine means the transmission is subjected to increasing engine torque. Due to rising emission standards, the temperature level also rises and puts a strain on the vehicle's cooling system. At the same time, noise emissions should be reduced. These developments require a reaction – optimally without changing the available installation space.
- Because the tendency in public transportation is leaning towards higher vehicle availability (operate a lower number of buses with higher reliability), life span and LCC play an increasingly important role. Fuel consumption is of central importance here, which has a significant impact on the quantifiable customer benefits.
- Environment-related requirements are also strongly linked to the reduction of fuel consumption. The disposal of used transmission oil and reducing the brake lining wear are additional aspects related to this topic.

In order to define the complete requirements, ZF conducted extensive tests in the development phase of their new EcoLife powershift transmission for city buses. The focus was on the central requirements of vehicle operators pertaining to the efficiency, or the LCC (costs for operating, maintenance, repair and replacement parts). In terms of the technical requirements, LCC are significantly affected by fuel consumption, life span and reliability, brake and cooling systems, as well as oil change intervals. These characteristics were the focus during the development of EcoLife. For the vehicle manufacturer, another important aspect is the acquisition cost for a new transmission. For the sake of competitiveness, ZF placed great emphasis on a high standardization level for the individual components.

During the development phase, a comprehensive efficiency evaluation of the transmission for the entire lifespan of the vehicle was kept at the center – based on the LCC principle. This is made obvious by the choice of name: "Eco" represents the ecological and economical properties (emissions, fuel consumption, durability, comfort) of the product. The second part of the product name, "Life", focuses on the longer lifespan in spite of rising temperatures and performance requirements of current as well as future generation engines.

TECHNICAL DESIGN

With EcoLife, ❶, ZF has developed a completely new automatic transmission that is not based on previous generation transmissions. Because they currently meet the beforementioned customer requirements optimally, the function principle corresponds to a conventional automatic powershift transmission. The associated transmission diagram is characterized by a converter, a primary retarder and a three-stage planetary gear set with five shift elements for six gears.

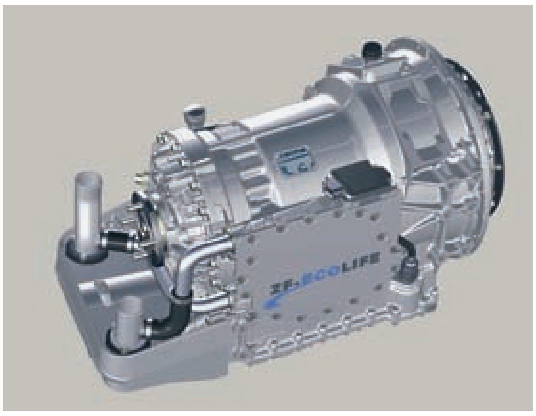
POWERFUL COOLING SYSTEM

Designed for highest power and cooling demands, it is possible to achieve a maximum input torque of 2000 Nm in connection with oil sump temperatures up to 15 °C higher, compared to the forerunning transmission Ecomat and similar transmissions from competitors. The transmission has a two-component cooling system consisting of a transmission heat exchanger integrated into the side of the housing and a mounted retarder heat exchanger located below the power take-off unit.

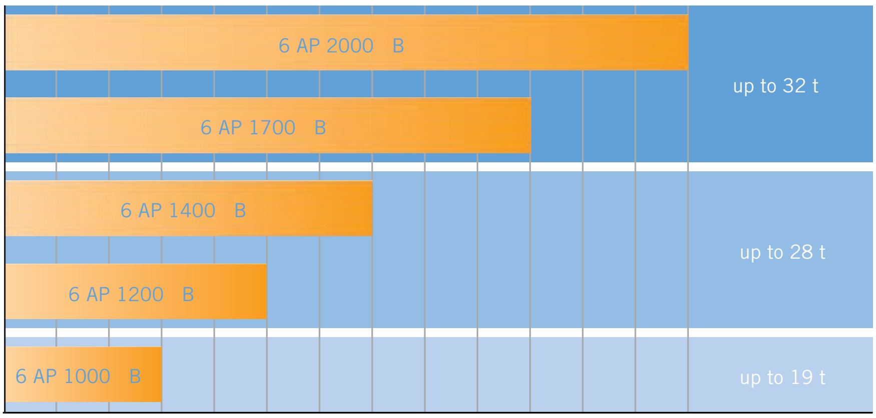
To improve the cooling of the on-site transmission electronics, the assembly was positioned directly on the transmission heat exchanger. This ensures optimal cooling and meets the stiff requirements for lifespan and temperature in the harsh engine environment. During the development of this highly-integrated cooling concept, emphasis was placed on keeping the number of interfaces to a minimum. That not only reduces the possibilities for malfunction during operation, but also during production and during installation into the vehicle. With that, the best possible prerequisites for high system reliability are established.

A well-known empirical value implies that, for tribiologically stressed components, a temperature reduction of 10 K can nearly double the lifespan. If the EcoLife is operated at today's temperature levels (approximately between 100 and 105 °C), or clearly below the assumed design temperature, a consequent lifespan increase of far more than 50 % can be expected in practice. All in all, the transmission is designed for a lifespan of $B_{10,rep3}$ = 700,000 km. That means that transmission breakdowns have to be faced after 700.000 km at a maximum of 10 % of the transmissions.

And in the future, the tendency toward higher temperatures in vehicle cooling systems will continue to develop. In spite of increasing cooling capacity, the average and maximum transmission temperatures will be above the current levels. Oil sump temperatures less than 105 °C, which will increase in the future up to 120 °C, present a great challenge to the oil manufacturers. For these applications, ZF has developed the two high-performance oils Ecofluid Aplus and Ecofluid Life. The economic benefits of these new fully synthetic oils become evident to the vehicle manufacturer and fleet operator not only due to obtainable oil sump temperatures, but also the time span between oil change intervals. For vehicles that are operated at the current common coolant temperature of 105 °C (measured in the oil sump), the oil change interval is extended from 150,000 to 180,000 km.



❶ Powershift transmission EcoLife with a two-part cooling system and on-site electronics (center)



❷ Standardized transmission modular kit for the transmission EcoLife for engine torques up to 2000 Nm at three vehicle-weight classes for example

LEVEL OF VARIANT DIVERSITY AND CONVERTER PERFORMANCE

ZF offers the new transmission with a high level of variant diversity. Five transmission types cover a relevant torque range from approximately 800 to 2000 Nm for city and interurban buses. In spite of this broad performance range, the transmission dimensions and connection dimensions for all five transmission types, including the electronic interfaces, are identical, ❷.

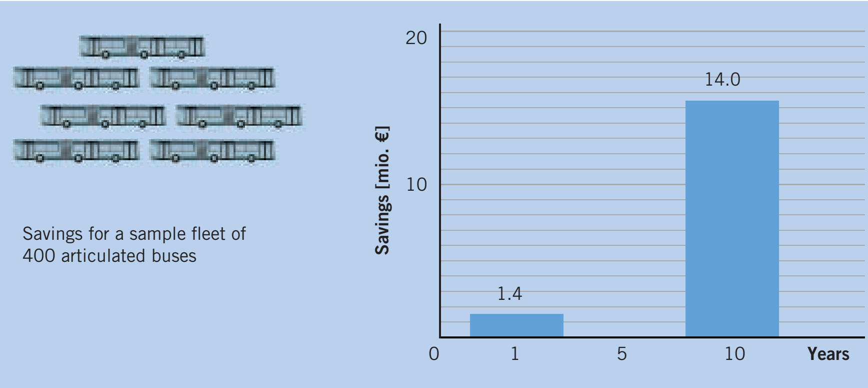
The gear set range contributed significantly to the optimization of the entire transmission. Compared to its predecessor Ecomat, EcoLife reduces the number of switch elements from six to five while keeping the same number of speeds at six.

The new transmission also has optimized converter characteristics. Starting at the stall speed, the converter starting torque increases up to higher speed ratios. The result: more engine torque excess at the start of acceleration, a faster torque build-up, better vehicle acceleration, and a lower rpm speed at the completion of the lock-up clutch. Comprehensive vibration damping measures were taken throughout the entire EcoLife series. By using a torsion damper, gear changes can be made at speeds up to 150 rpm engine speed below the previous Ecomat transmission.

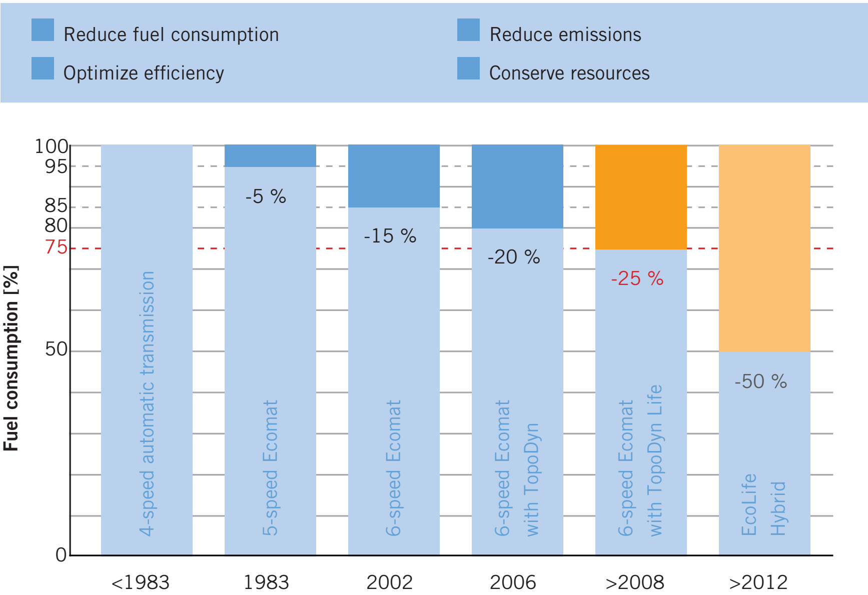
Measured against their entire operation time, city buses have a relatively high idle time, such as at traffic lights or while passengers are boarding or exiting. In order to minimize the fuel consumption of this operation state, ZF has further optimized the automatic idle shift (AIS). A precise variable hydraulic combined with a special clutch results in a speed differential reduction between engine and turbine. This causes a reduction in the converter absorption speed and therefore also a reduction in fuel consumption.

THE TRANSMISSION IN PRACTICE

In short, it can be said that EcoLife is the most modern bus transmission currently available on the market, due to the nume-



❸ Possible fuel savings in Euro of EcoLife with TopoDyn Life compared to the previous transmission Ecomat (assumed conditions: fuel price of 1.50 Euro per liter; 70,000 km traveled per year; 73.5 l / 100 km diesel consumption)



❹ Reduction of fuel consumption (transmission generations) – also by a hybrid module in 2012

rous new developments. Through the new cooling concept, the modern converter, and the powerful retarder, it achieves fuel savings above any other transmissions in its class. This was confirmed not only by more than 20 field test vehicles which accumulated a total mileage far beyond 3 millions km, but also by more than 6000 transmissions currently in use in the first series applications.

Due to technical innovations, in everyday use, up to 5 % fuel can be saved (compared to the previous transmission Ecomat with topography-based shifting software TopoDyn). Extrapolated to a city bus fleet with 400 articulated buses which cover a distance of 70,000 kilometers annually, a total savings of 14 million Euros solely on fuel can be achieved over ten years (assumed fuel price: 1.50 Euro per liter), ❸.

TOPOGRAPHY-BASED SHIFTING

The huge reductions in fuel consumption are due to the topography-based transmission control software TopoDyn Life, which is standard equipment for every EcoLife automatic transmission. With this software, the transmission is in an optimal operation mode throughout the entire route. The software developed by ZF calculates the current switch points while traveling, and adapts the shift characteristic to the respective route profile.

Parameters such as topography, current load and acceleration rates, and variable road resistances due to road surface or curve angle all enter into the equation. Advance calculation of pulling power is used for long ascents. This ensures that the shifting procedure is only actuated when the speed will not be decreased, and, in this way, prevents possible gear hunting. Topography also is used in the calculation of descents: The steeper the slope, the more the retarder power is reinforced. This protects the service brakes from overheating and reduces wear.

PRIMARY RETARDER SPECIFICALLY FOR CITY BUSES

Along with hill descent control, the retarder of the new transmission is also distinguished by its high performance. During normal operation conditions, it is also in constant use, which relieves the service brakes and reduces brake wear. Compared to the primary retarder of the ZF-Ecomat, the new ZF-EcoLife city bus retarder can generate up to 40 % more braking torque.

With the new cooling system including two heat exchangers it is optimized especially for city bus operation. Passengers probably will not notice the fuel-saving measures or the reduction in annoying noises while traveling. Due to a new helical gearing of the planetary gear set and the intelligent shifting strategy, the background noise is noticeably reduced while in motion.

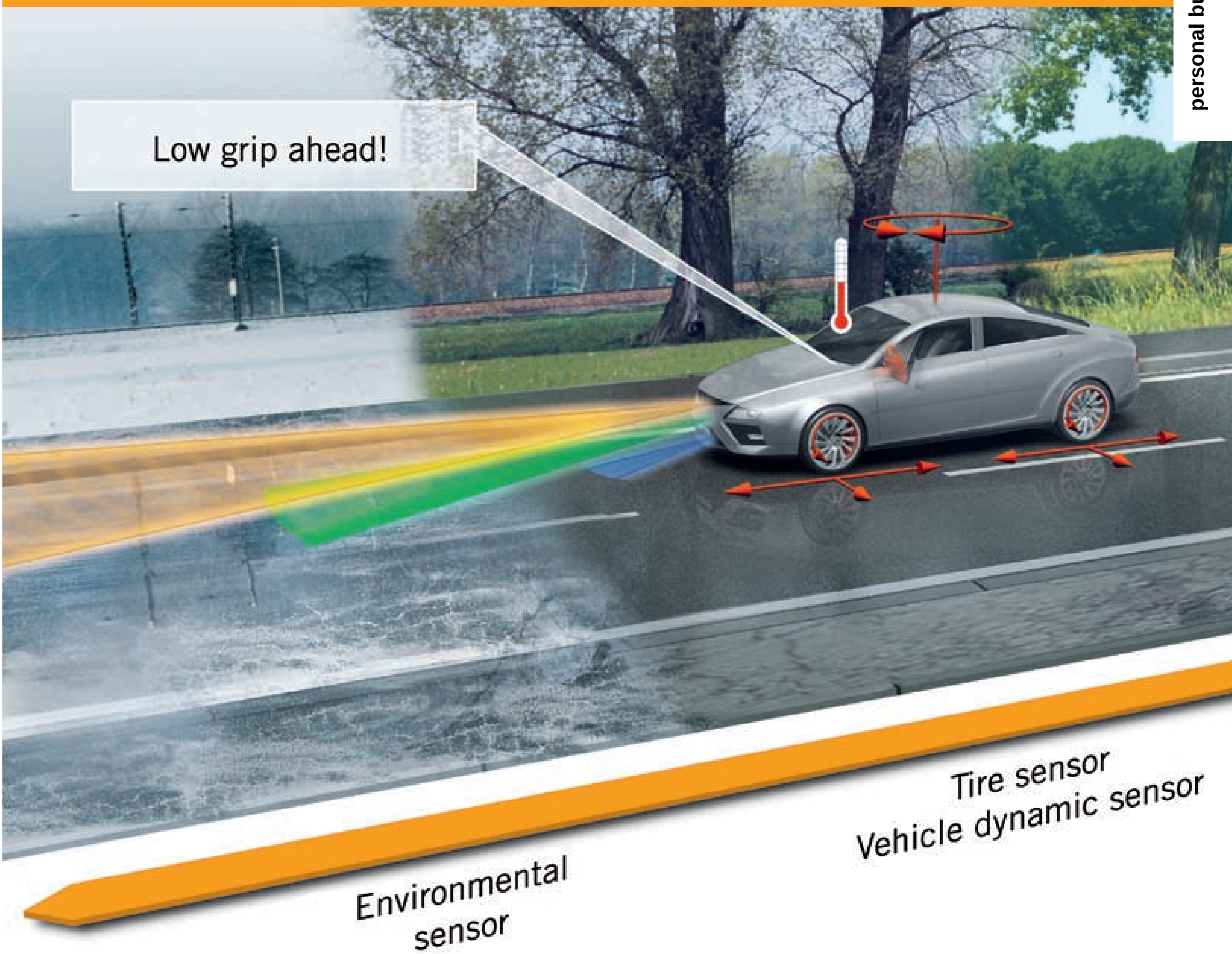
ADDITIONAL FUEL CONSUMPTION SAVINGS IN VIEW

The new six-gear powershift transmission EcoLife from ZF is now already aiming toward the electrification of the driveline, and in so doing, once again proves its capacity to adapt to future challenges. In the hybrid variation, ❹, currently being developed, the torque converter will be replaced by a hybrid module, which is located in the converter housing and has an additional capacity of 120 kW.

All hybrid functionalities associated with passenger cars are obtainable with the hybrid variation of EcoLife: including start-stop automatic, boosting and recuperation, and electrical start-up and purely electric driving. This – and the corresponding possible smaller dimensioning of the combustion engine – enable additional fuel consumption savings.

FUSION OF VEHICLE AND ENVIRONMENTAL SENSING

Currently, it is the driver's responsibility to estimate road friction and to adapt vehicle speed and safety distance accordingly. Continental, together with partners, have designed a new active safety approach that helps to avoid misjudging road conditions. Vehicle and environmental data are used to estimate the available and the used tire-road friction. The system output gives the driver an advance warning – and thus more reaction time.



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MOTIVATION

Estimating the friction forces between tires and road provides the most important bit of information for adapting driving behaviour. Yet, a correct estimation of the tire-road friction potential is entirely up to the driver's carefulness. He or she will use a combination of temperature information, weather forecast and visual input to estimate the level of grip. An experienced driver may brake gently during vehicle startup to check whether this triggers the anti-lock braking system (ABS) but this will only reveal problems if the driver suspects any. The issue is quite relevant: According to the Destatis 2007 statistics, nearly 40 % of all single car accidents with injured persons occured under rainy, snowy or icy conditions [1].

Electronic control systems such as ABS and the Electronic Stability Control (ESC) are a great help but they are only activated when the maximum friction has already been exceeded. A new active safety system developed within the FRICTI@N project provides this missing bit of information by estimating friction via sensor fusion.

SYSTEM ARCHITECTURE AND FUNCTION PRINCIPLE

The new approach is based on data coming from standard in-vehicle sensors, from environmental sensors and from tire sensors. These data are fed into a gateway (interface) that provides the sensor data to three feature fusion blocks within the friction processing model as shown in ❶:

- the environmental feature fusion sub-module (EFF) computes all the available information on weather and road surface conditions
- the vehicle feature fusion sub-module (VFF) estimates the tire-road friction potential
- the tire feature fusion sub-module (TFF) models and calculates the actual tire friction based on a Burckhardt tire model.

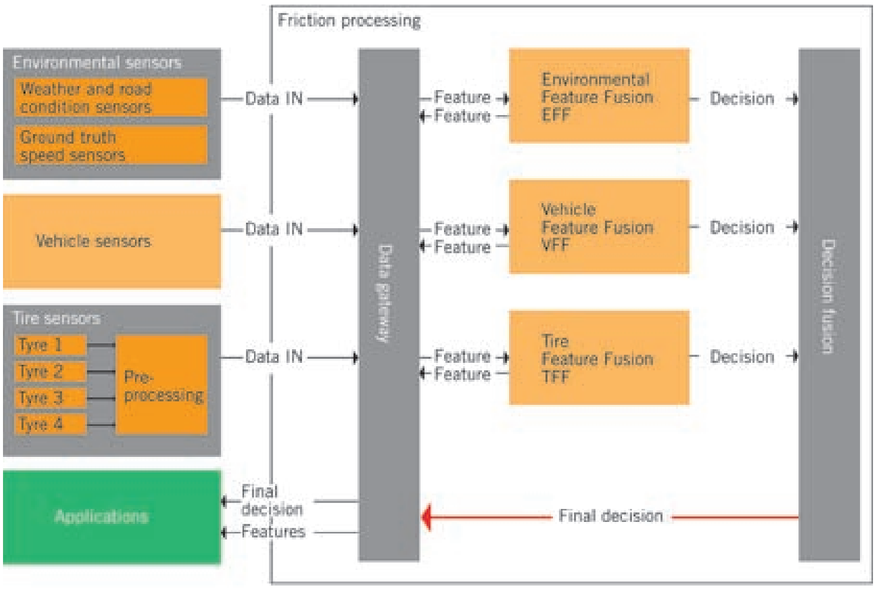
Each friction processing sub-module provides the same type of decision output:

- actual friction used
- actual friction available
- predicted friction
- validity tags, that means quality of information
- road and tire condition information.

This output is finalised by the decision making block which integrates all three sub-module decisions. The gateway is an important part of the model as it ensures that the approach remains a generic one: Only the gateway has to be updated for different car applications.

FRICTION ESTIMATION BASED ON VEHICLE DYNAMICS SENSORS

A vehicle's dynamic response is strongly affected by the tire-road friction potential coefficient. This provides the basis for friction estimation based on vehicle dynamic sensors. There is a clear relation between friction coefficient and tire slip on different road surfaces in braking situations. The VFF block's algorithms estimate the friction potential based on a comparison between the vehicle's actual response, as measured by vehicle sensors, and a reference model, depending on the friction coefficient. The VFF has been



❶ Proposal for the architecture of the friction measurement and processing system

implemented as a Matlab/Simulink model and tested via dSpace "Autobox" on the test vehicles Audi A6, ❷, and Fiat Stilo.

The friction estimation approach uses two algorithms, working in parallel, ❸. The Continental solution mainly uses standard in-vehicle sensors, measuring longitudinal and lateral acceleration, flag of the braking signal, wheel speeds, yaw rate and steering wheel angle. This lateral dynamics approach consists of a vehicle lateral dynamic model and the adaptation estimation block that estimates the friction. The common two-track vehicle model is used with a tire model that was specifically parameterised, while the car body and chassis are treated as rigid.

The second solution, developed by the Centro Ricerche Fiat (CRF), is based on sensing the steering torque. It exploits the effect that the tire self-aligning moment characteristics show non-linearity and saturation at lower values of side slip angle than the lateral force characteristic. Thus, the CRF solution is quicker than the lateral dynamics solution but it requires sensors to measure steering torque. The CRF solution compares data measured by standard vehicle sensors plus steering wheel angle information to the output of a friction reference model. To estimate the friction potential the system requires a minimum amount of side slip angle in order to detect a difference between the measured and the reference input.

In the subsequent VFF fusion block the Continental and CRF input signals on potential and available friction are weighted and fused, depending on an additional situation detector which classifies the current level of driving dynamics as either zero, low, medium or high. If both bits of friction information come with a quality flag "valid" and fulfill the evaluation criteria, the weighting factor is 0.5. To achieve maximum safety, the lower potential friction and the higher estimated used friction values of both solutions will be used.

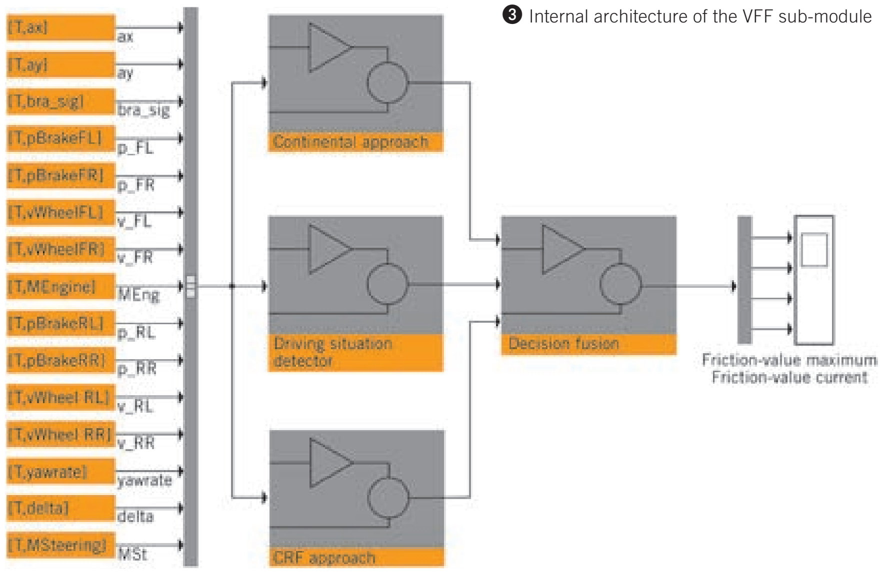
This fusion strategy within the VFF submodule provides the most reliable information from the two approaches according to driving situation and quality flag of the output. The test results in ❹ show a good convergence between Continental's and CRF's estimation: The correct output is chosen according to the quality flags. The measurements refer to a Fiat Stilo prototype equipped with the VFF sensor cluster only.

ENVIRONMENTAL SENSING

Environmental conditions directly influence road conditions and thus the potential friction coefficient. Therefore, an assistance system that shall reliably offer advance warnings to the driver needs data on environmental conditions. This information is computed in the Environmental Friction Fusion sub module (EFF). In contrast to the measuring of vehicle dynamics, some of the environmental sensors are not yet in-vehicle standards. Within the FRICTI@N project five sensors were used to detect environmental conditions:

: a laser scanner detects rain and snow between 50 m and up to 100 m ahead
: a "Road Eye" sensor monitors the road state at short range (0.4 up to 1.5 m ahead)
: an "IcOR" infrared polarisation camera detects ice between 5 and up to 20 m ahead
: a thermometer measures the road surface temperature
: an air thermometer provides information about the ambient temperature.

❷ The test vehicle equipped with the new tire-road friction sensor fusion system components



❸ Internal architecture of the VFF sub-module

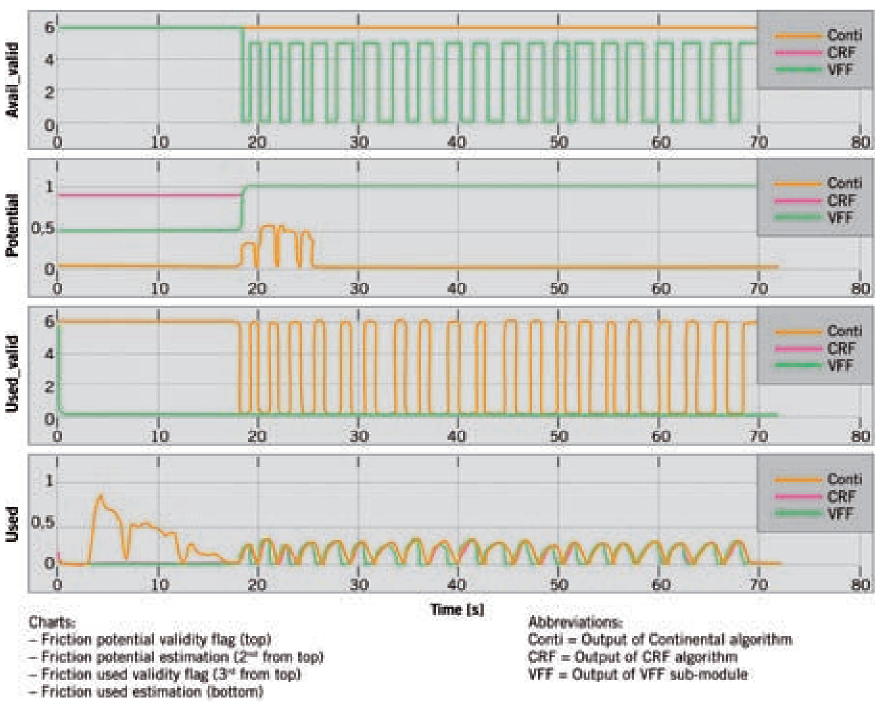
The fusion of all incoming environmental data is done within the four main processing blocks of the EFF, ❺. Each sensor provides data on the probability of ice, snow or water. Plausability checks are performed on the probability values by multiplying them with factors based on air or road temperature measurements. The final EFF output is an estimation of the friction potential under the prevailing environmental and road surface conditions as detected by vehicle sensors and the general detection validity.

Normally, laser scanners such as the Ibeo "Lux" system used within FRICTI@N must not be sensitive to adverse weather conditions such as rain, snow and fog because they are typically used as information source for multiple Advanced Driver Assistance Solutions (ADAS) such as Adaptive Cruise Control (ACC) Stop & Go, Automatic Emergency Braking, Pre-Crash and Pedestrian Protection. By enhancing the sensor embedded algorithms, however, the laser scanner can also detect and classify measurements on precipitation like snow and rain by interpreting typical patterns of backscattered laser pulses. Snow density or precipitation correlate to the number and distribution of measurements.

Momentary road conditions were measured by two sensor systems with specific advantages each: To get fast and reliable information about icy or wet surfaces, the "Road Eye" system uses two laser diodes with different wavelengths for different materials and a photo detector. This laser diode system can classify surfaces as either dry, wet, icy or snowy. The only downside to this fast responding measuring principle is that it only covers a small patch just ahead of the right tire.

To compensate for this and to give the driver more advance warning, the second sensor, called "IcOR", is an infrared camera which measures polarisation differences and estimates granularity. Ice for instance reduces the amount of vertically polarised light, compared to the horizontal plane [2, 3]. Thus, mirror-like surfaces such as ice or water on the road are detected by observing "abnormal" changes in the relative difference between horizontal and vertical polarisation.

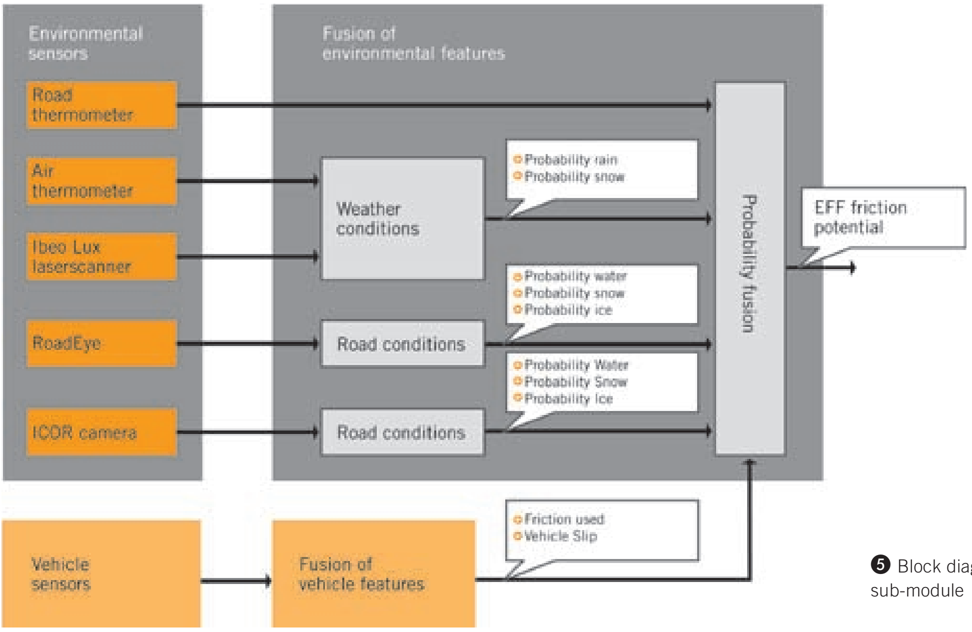
Road surface granularity [4] is used as a second parameter. This is based on the observation that an icy road has a smoother surface than asphalt or snow. The detection strategy uses low-pass filtering of the image to make it more blurry. Subsequently, the contrast between the original and low-pass filtered image provides information on the share of small granularity in the image. With a range of 50 up to 100 m, this system detects potential danger ahead of the vehicle with 80 % accuracy and thus provides valuable reaction time to the driver. On the other hand, this level of accuracy is not high enough to use this system alone. In combination, though, the chosen measurement principles come very close to the requirements of a friction estimation solution.



❹ Friction estimation test results from the Fiat Stilo test vehicle

DECISION FUSION

The decision fusion module as shown in ① combines the values of used and potential friction provided by the three feature fusion blocks, VFF, EFF and TFF. It also



❺ Block diagram of the environmental friction estimation sub-module

introduces µ-slip curves as part of further plausibility checks. Additionally, the EFF road condition classification is compared with µ-slip measurement as a final check of the road condition output.

Valid VFF measurements and resulting friction potential output that has passed plausibility checks is generally considered as more accurate than EFF measurements. If no instantaneous VFF output is available, though, EFF measurements and earlier valid measurements are combined as best guesses. As environmental sensors can provide continuos measurement they can end up dominating the fusion process. For that reason a good balance between the continuous and discontinuous measurements is important for the fusion and for achieving a safe estimate. Friction used is a continuous measurement that serves as the backbone of fusion calculations. To detect dangerous parts of the road and to trigger a warning, abrupt changes in friction values are specifically monitored.

SUMMARY AND OUTLOOK

In-vehicle and environmental sensor fusion opens up a new way of warning the driver about adverse road conditions – before active safety systems such as ABS and ESC need to intervene. Within the integrated driver assistance strategy ADAS this new approach to sensor fusion addresses one of the main causes for accidents. In total, simulation and Volvo driving tests at Arjeplog, Sweden, have shown that the three main feature fusion submodules provide output with a high level of accuracy and thus a basis for automated decision fusion.

Having proven that road friction estimation works, future development efforts can focus on further improving road type classification with cost-effective environmental sensors. Motorcycle applications for instance would benefit from this, because already tiny details such as single leaves or road markings can result in abrupt changes of friction potential. Current algorithm development concentrates on combining several methods to achieve a more continuous estimate. In the long run co-operative systems could be used to exchange the measurements between several users (Car-2-Car).

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THE ELECTROPNEUMATIC FRONT AXLE LIFT SYSTEM OF THE PORSCHE 997 GT3

Similar to racing cars, the new 911 GT3 lies very close to the road in order to achieve high driving dynamics. The resulting restrictions in day-to-day usability can be compensated by using an additional lift system at the front axle. Porsche uses an electropneumatic system here.

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manages the business division Two-Stage Compressors at the Ventrex Automotive GmbH in Graz (Austria).

MOTIVATION

The GT3 chassis is 30 mm lower compared to the 911 Carrera, permitting a low centre of gravity and favourable aerodynamics. The lower chassis also reduces the ground clearance and the ramp approach angle compared to conventional vehicles which can sometimes become apparent in everyday situations. This above all affects the front chassis area when the vehicle is driven onto ramps, up driveways and over speedblockers in urban and residential areas. The front axle lift system developed by the Motor Sport department in Weissach can help prevent the vehicle bottoming out in these situations. Together with the system supplier, Ventrex Automotive, it was possible to develop the system for the market within a very brief time. The electropneumatic system, now available as an option for the new 911 GT3 for the first time, significantly enhances day-to-day usability. It allows the vehicle to be raised by around 30 mm at the front up to a speed of around 50 km/h. This can prevent damage to the body and allows, for example, speedblockers to be crossed with a much lower risk of bottoming out.

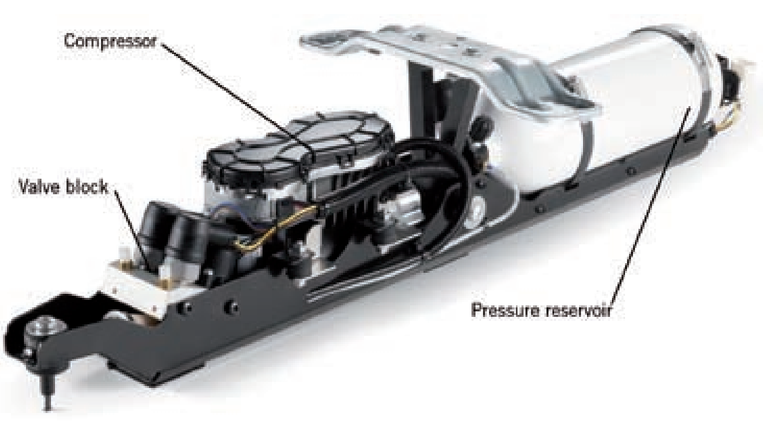
SYSTEM FUNCTION AND OPERATION

The main components of the electropneumatic front axle lift system are the function module, the special front axle shock absorbers and the electronic control unit. The function module, shown in ❶, provides the compressed air and includes a compressor, a pressure reservoir and a valve block.

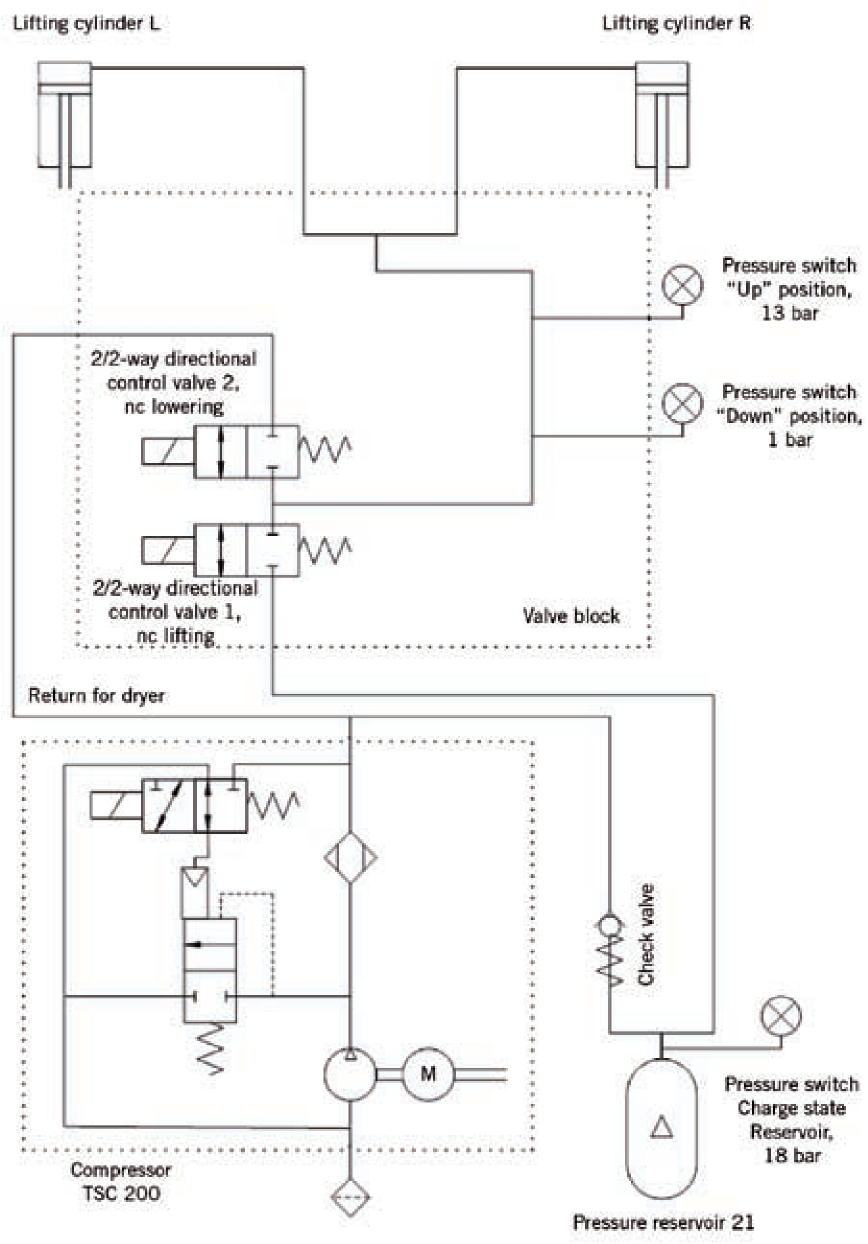
The compressor generates the required system pressure of 18 bar and delivers it to the pressure reservoir. A pressure switch permanently monitors the pressure level in the reservoir and the compressor automatically adjusts the pressure if necessary. The pressure reservoir has a capacity of 2 l. Two electromagnetic valves on the valve block control the pressure build-up in the front axle shock absorbers. This valve block also accommodates two other pressure switches that provide the basic information for the vehicle lift position.

The conventional suspension strut at the front axle is used as a pneumatic cylinder for the lift function. Pneumatic connecting lines conduct the compressed air generated in the function module into the corresponding working chambers of the shock absorbers. The overall system is controlled by a modular electronic control unit which processes system information such as the vehicle speed and the air pressure in the pressure reservoir and shock absorbers.

The driver operates the lift function with a button in the centre console. When the driver activates the lift function by pressing the button, the ‘lift valve’ on the valve block opens and allows compressed air to flow from the pressure reservoir into the corresponding front axle shock absorber chambers, as shown in ❷. When the pressure of 13 bar required for the raised position is reached, this is detected by a pressure switch and signalled to the control unit. The “lift valve” is then



❶ Function module which comprises the compressor, the valve block and the pressure reservoir



❷ Pneumatic layout of the front axle lift system

closed again automatically and the "LIFT" logo in the instrument cluster indicates the raised position to the driver. The pressure built up in the shock absorber chambers causes the shock absorbers to extend by around 20 mm. This extension of the suspension struts raises the body by around 30 mm at the front edge of the front spoiler.

The driver can also press the button to lower the body. Pressing the button when the vehicle is in the raised position opens the "lower valve" and the air can escape from the shock absorber chambers. As the pressure decreases in the shock absorber chambers, the shock absorbers return to their original length. The designated pressure switch detects when the pressure has been fully relieved and signals this to the control unit. The vehicle has returned to its original position; this is indicated to the driver when the "LIFT" logo goes out.

SAFETY FUNCTIONS

For safety reasons, the control system includes various blocking conditions for which activation of the lift system is prevented or interrupted.

Activation of the lift system is permitted only if the vehicle has not exceeded a speed of 50 km/h. This limit prevents the changed vehicle aerodynamics of the raised vehicle from affecting the driving dynamics. If the speed limit is exceeded in raised position, the vehicle is automatically lowered to the basic level again.

Lowering of the vehicle is permitted only when the doors are closed. This condition prevents damage to the doors when parking over raised objects such as a kerb.

Frequent operation of the lift function in succession imposes a constant demand on the compressor to maintain the required system pressure. This can place a great thermal load on the compressor, especially if the outside temperatures are high. For this reason, a protective function continuously monitors the compressor temperature. The temperature switch sends a signal to the control unit if the maximum permissible temperature is exceeded. The lifting function will then be deactivated until the compressor is ready for use again.

Furthermore, a so-called anti-play function is integrated to prevent unnecessary up and down movements of the vehicle and the associated burden on the compressor. It limits the number of lifting activations to six within 60 s. If this number is exceeded, a corresponding protective function is triggered and manual activation of the lifting function remains blocked for 2 min.

Linking the system to an automatic headlight leveling system provides another safety aspect. This ensures that oncoming traffic is not blinded when the vehicle is raised at the front axle.

STATE OF THE ART

Some competitors also offer a lift system for the front axle and various retrofit solutions are available on the market as well. However, these systems are generally operated by hydraulics and require extensive modifications to the existing vehicle. By contrast, the electropneumatic system in the new 911 GT3 offers better performance and greater day-to-day usability.

With the special system structure in the new 911 GT3, the driving comfort and the suspension as well as damping characteristics are not impaired in any way in the lowered position.

❸ Lift system at the front axle of the GT3

The system requires around 4 s to raise the axle completely, permitting rapid availability in case of obstacles that appear suddenly or have to be crossed in traffic. The driver can press a button on the operating panel to activate the lifting function without having to stop and wait for the end of the lifting process.

The compact component configuration allowed the lift system to be integrated into the existing vehicle architecture of the GT3 with little effort, ❸. In terms of driving dynamics, the system is ideally accommodated in the lowest possible installation situation in the centre tunnel. The low system weight of only 6 kg also ensures that the driving dynamics of the GT3 are not impaired.

Moreover, the air-operated lift system is much less sensitive compared to a system operated with oil. Air is compressible and the occurring pressure peaks (for example, when crossing a road irregularity) are only fractions of those encountered when using incompressible media such as oil. Above all, the lower pressures subject the seals to much lower loads and no environmentally harmful fluids emerge in the event of leaks.

The integration of the lift system into the vehicle network architecture permitted an ideal display and feedback concept for the driver. The instrument informs the driver about the current lift position and indicates any system faults. A light-emitting diode in the operating button additionally provides feedback about the current status of the lift function.

COMPONENTS

A wheel-guiding suspension strut with an upside-down shock absorber has been installed in the GT3 for several vehicle generations, ❹. With this shock absorber system, the shock absorber tube, guided in two plain bushes in an outer tube, performs the task of guiding the wheel. The actual shock absorber piston rod sticks out of the bottom of the shock absorber tube and is in turn bolted together with the outer tube base.

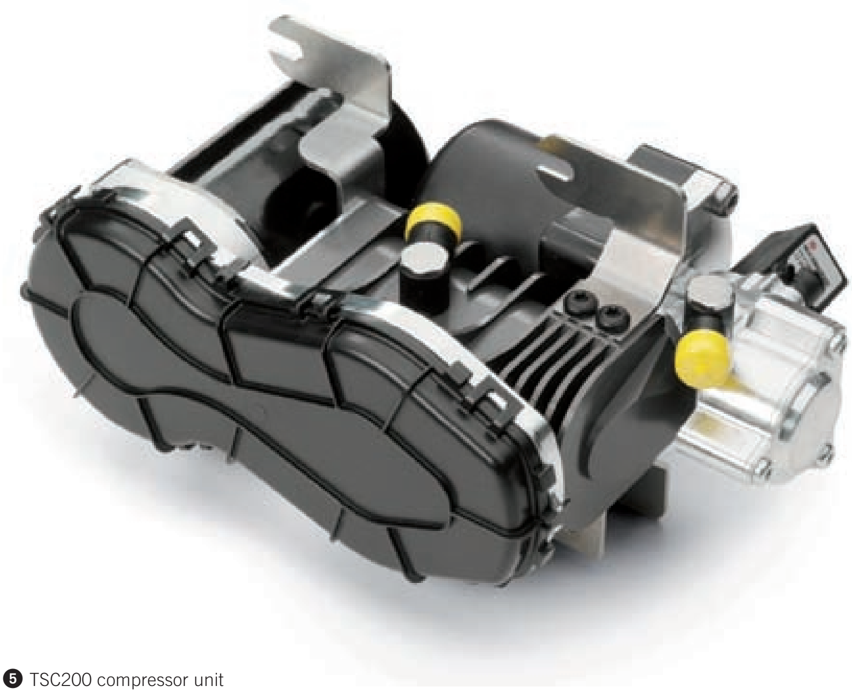
This design results in a hollow space between the guide tube and outer tube. The volume of this space changes with the suspension compression and can therefore be used as a pneumatic cylinder. In order to use the shock absorber for this purpose, the outer tube had to be modified. It was fitted with a separate base which is constructed with or without seals and compressed air connection depending on the type (with/without lift system). The stop buffer integrated into the pressure space was also provided with air guide channels which are required to admit air and release it from the suspension strut.

As additional measures, it was necessary to modify the seal between the outer tube and shock absorber tube and to change the shock absorber seal package and fix it in axial direction for a secure seat under pressure application.

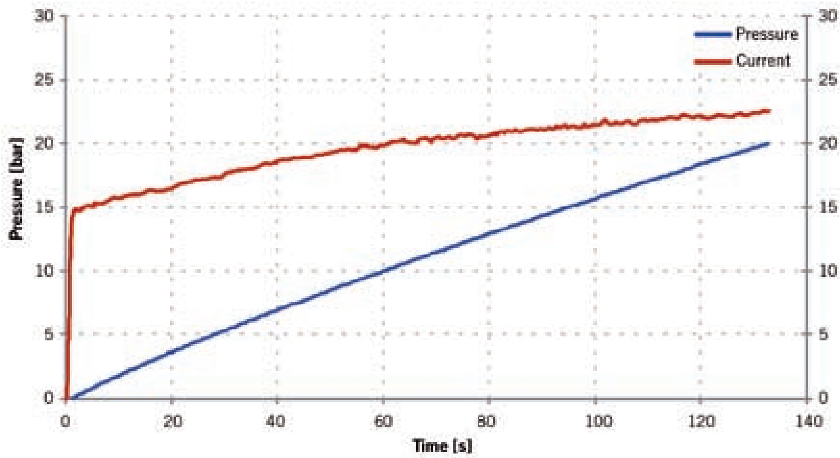
Overall, the result is a very simple lift suspension strut which is nearly neutral in terms of cost, space requirement and weight compared to a conventional suspension strut.

The TSC200 compressor used, ❺, meets the high demands in terms of size, weight, performance and sound emission.

❹ Front axle shock absorber with compressed air chamber of the lift function



❺ TSC200 compressor unit



❻ TSC200 supply characteristic

It is a new development from Ventrex Automotive. The compressor (maintenance-free dry-running compressor) functions according to a two-stage principle and thereby realises an ideal relationship between size and performance. The compressor, driven by a high-speed DC motor via a toothed belt, is characterised by its quiet operation.

An integrated adsorption air dryer with regeneration function reduces the water content in the compressed air and includes both a drain valve unit and a maximum pressure limiting function. The compact unit measures 224 x 148 x 84 mm, weighs only 2.4 kg and is fastened via elastomer decoupling elements to the unit carrier of the function module.

A special feature of the compressor is its modular design. Different power variants can be realised as required by adapting the drive ratio and possibly the motor; active fan cooling can be integrated as an option. The supply diagram, ❻, shows the compressor characteristic selected for use in the GT3 lift system.

SUMMARY

The electropneumatic lift system in the 911 GT3 meets the high demands for weight, reliability and function. Above all, the pneumatic version of the system has allowed advantages to be achieved compared to hydraulic systems already on the market. The system's convincing features include short lifting times and simple, safe operation. The driving dynamics properties of the 911 GT3 are not affected, despite the greater day-to-day usability.

THE HYBRID DRIVE SYSTEM
IN THE BMW ACTIVE HYBRID 7

In addition to the BMW ActiveHybrid X6, which was launched onto the market in October 2009 as a full hybrid, BMW is now unveiling the ActiveHybrid 7, a mild hybrid, as a further model in the series. BMW Group has already delivered 1.8 million BMW cars featuring EfficientDynamics technology to customers. As a result, a large number of BMW models have consumption-reducing measures built in. Only by this means was fleet consumption able to fall to below 160 g CO_2/km by as early as 2008.

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MOTIVATION

BMW hybrid models are a further technological step towards reducing fuel consumption and represent the bridge to fully electric driving.

With the ActiveHybrid 7, the BMW EfficientDynamics strategy is being supplemented by the world's most powerful hybrid series-production car.

As well as the driving dynamics typical of BMW, the car also displays the full potential of a mild hybrid concept with regard to the reduction of CO_2 emissions. Thanks to a consistently consumption-oriented drive system design, coupled with a wealth of optimisation measures in drive management, a relatively low value of 219 g CO_2/km was achieved in the European driving cycle for an eight-cylinder luxury saloon car.

DEVELOPMENT GOALS

During the development of the ActiveHybrid 7, the focus lay on the following customer-related requirements:

: reduction of fuel consumption by 17 % versus the 750i comparison model
: driving performance equal to or better than the 750i
: additional weight of less than 75 kg due to the hybrid components
: global use
: compliance with current emissions requirements, including Japan Green Car 4 Star rating
: first use of a lithium ion HV battery in the automotive sector together with Daimler AG.

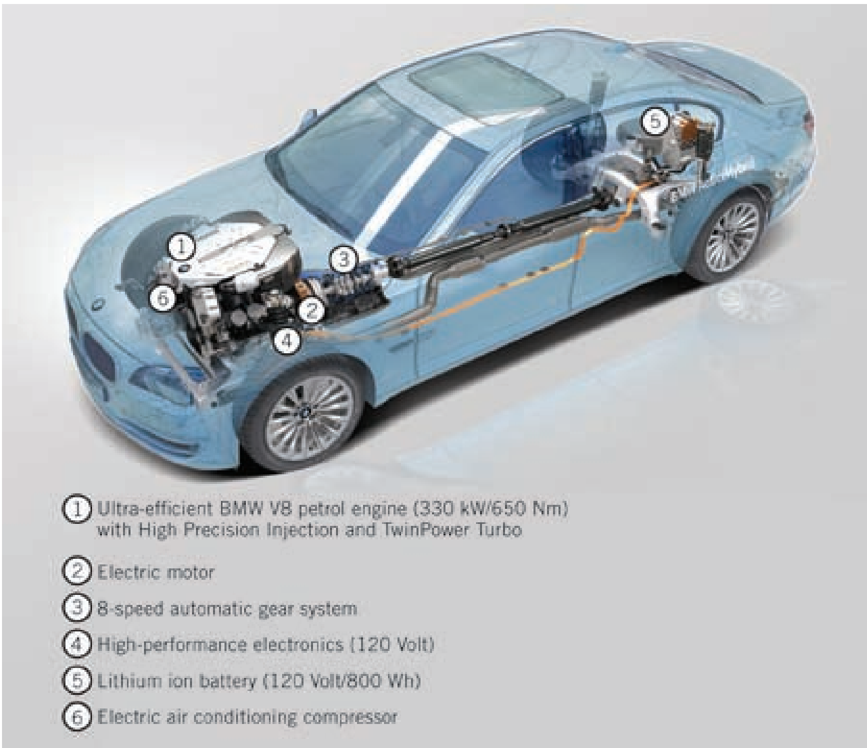
DRIVE CONCEPT

The drive system of the 750iA needed to undergo significant modification in order to satisfy the hybrid-specific requirements of the ActiveHybrid 7, ❶.

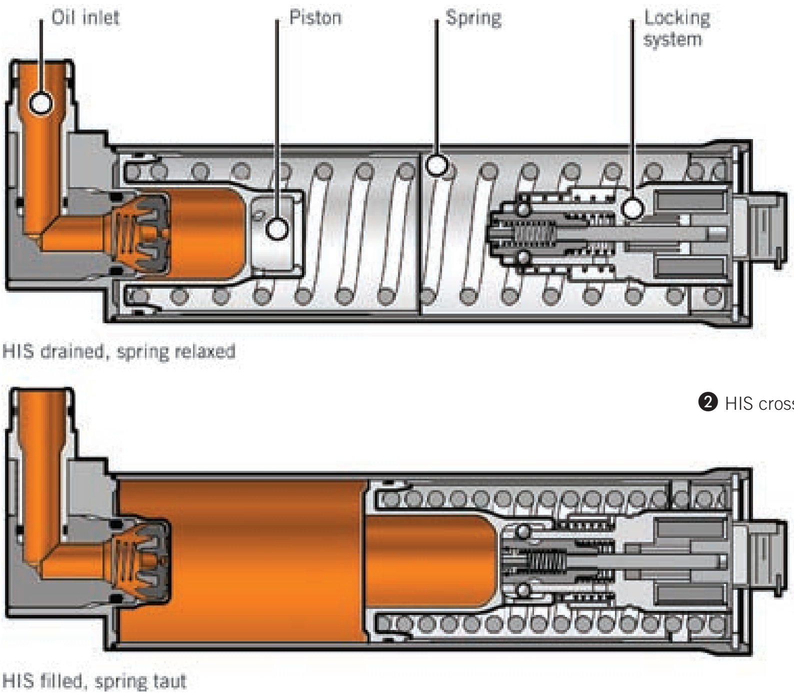
No noticeable limitations were permitted to the carrying capacity or luggage compartment volume. Overall, it was possible to meet the requirements since the weight increase caused by the hybrid components is 75 kg and the volume of luggage compartment space required for the lithium ion battery is 40 l.

The ActiveHybrid 7 was designed as a parallel hybrid and therefore uses an electric machine on the crankshaft.

With this concept, the internal combustion engine and electric motor can exert an additive effect on the crankshaft.



❶ The drive system of the ActiveHybrid 7



❷ HIS cross-section

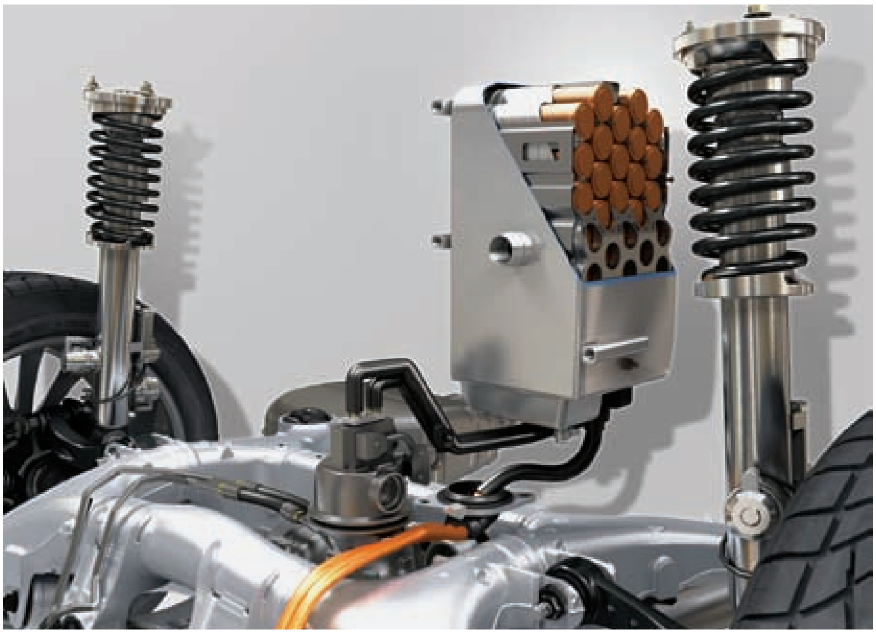
This gives the ActiveHybrid 7 a torque of 520 Nm even at speeds of 1,000 rpm. In terms of package, costs, fuel consumption and driving performance, the mild hybrid is ideal in the power range from 15 to 20 kW. A further increase in electrical power would generate a further improvement in driving performance, but with the chosen system configuration there would be no further reduction in fuel consumption. At the same time, weight, costs and package problems would increase.

THE HYBRID DRIVE SYSTEM AND ITS COMPONENTS

The 4.4 l eight-cylinder petrol engine which is also used in the 750i basic version is used as the internal combustion engine. In its basic design, the unique design principle with two turbochargers arranged directly in V between the cylinder banks still offers adequate potential for the increase in power output and torque achieved in the ActiveHybrid 7. By adapting the engine application, a maximum torque of 650 Nm is now available between 2,000 and 4,500 rpm, as well as a maximum power output of 330 kW between 5,500 and 6,000 rpm. This generates traction at low speeds and long-lasting thrust up to the maximum speed.

The modifications to the basic engine include the use of optimised basic engine bearings and the simplification of the belt drive through the removal of the mechanical air conditioning compressor and 12 V generator. The additional moment of inertia of the electric motor is taken into account by the use of a specially designed viscous damper.

To transfer the driving torque, which is generated jointly by the V8 engine and the electric motor, the BMW ActiveHybrid 7 features a newly-developed eight-gear automatic transmission with adapted control (EGS) that has been developed especially for the requirements and potential of hybrid technology. It combines shifting comfort, sportiness and efficiency at a level never before attained. Two additional gears coupled with increased gear ratio spread, all with reduced weight, ensure improved driving performance and, in particular, significantly reduced fuel consumption. The core of the new eight-gear automatic transmission is an innovative wheel set design with improved efficiency and small gear jumps. This benefits the sporting character of the transmission system and thus also the dynamic design of the BMW ActiveHybrid 7 that is characteristic of the brand. The smaller speed jumps also enhance the luxury saloon car's shifting comfort. For the mild hybrid application, the gears were enabled for torques of up to 700 Nm. To facilitate the integration of the electric motor between the internal combustion engine and the torque converter, the gear housing was lengthened by 47 mm. An additional device was also integrated for the start-stop function in order to ensure a comfortable and dynamic starting process when the engine starts up. When the engine is switched off, the gears are free from any power transmission. The rapid establishment of power



❸ Lithium ion battery

transmission is made possible by the use of the hydraulic impulse accumulator (HIS), ❷: the pre-filling of the clutches takes place in parallel with the starting of the internal combustion engine. The power transmission can be created once the idling speed has been reached either comfortably or highly dynamically, depending on the driver's preference.

One technical highlight of the system is the ultra-efficient lithium ion battery, ❸, which is new in automotive engineering. The energy density of the lithium ion cells exhibits the highest values of all the storage cells available. Weighing 25 kg, the HV battery has a capacity of 0.8 kWh and is barely larger than a conventional starter battery.

The maximum output of the lithium ion battery is 20 kW, ensuring reliable starting of the V8 petrol engine at all temperatures. It can store and discharge braking energy very quickly.

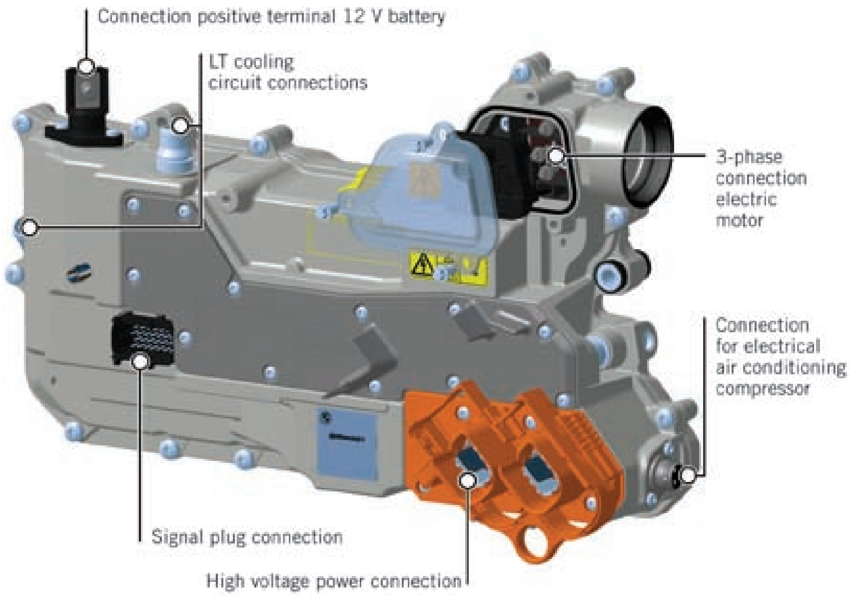
The HV battery features its own internal control unit (SME) that includes the component-related control functions. Due to internal storage management and an optimised cooling concept through direct connection to the air conditioning unit, the lithium ion battery is always operated in a working temperature range from 25 to 35 °C.

During the course of development, the behaviour of the battery was considered over the entire lifetime of the vehicle. The deciding factors for the chronological development of the battery performance were analysed using statistical methods (including the use of the Six Sigma method) and integrated into the design of the operating strategy and battery management. Coordinating customer benefits and the availability of the battery ensures that the hybrid functions such as automatic start-stop, recuperation, air conditioning when stationary and boosting are available over the vehicle's entire lifetime.

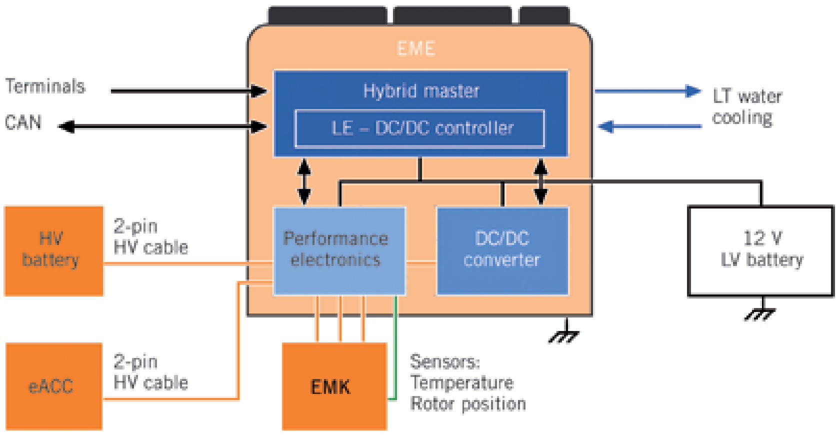
The safety concept monitors each of the total of 35 cells for current, voltage and temperature, complying with the requirements that are placed on vehicles in the high-end range.

The BMW ActiveHybrid 7 and the Mercedes-Benz S 400 Hybrid are the world's first hybrid cars with this technology.

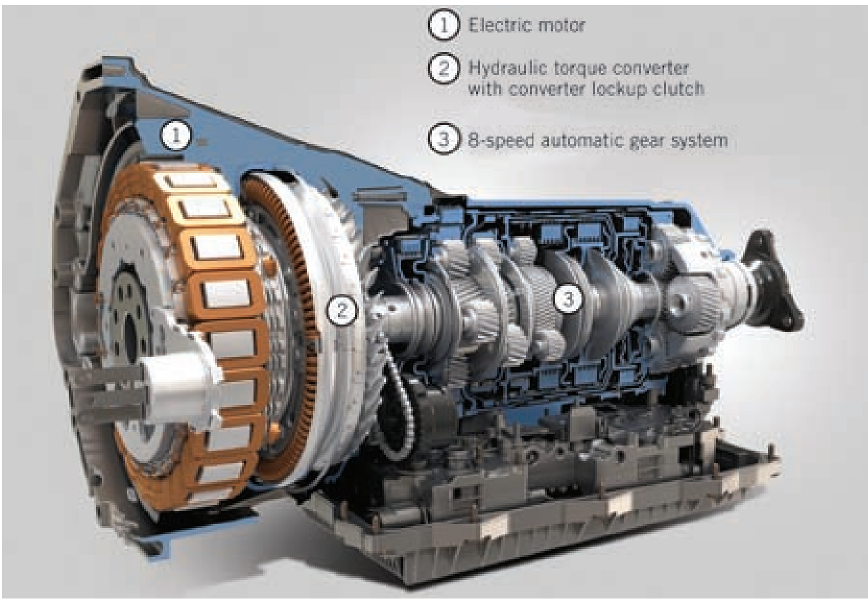
The hybrid system's central control unit is the Electric Motor Electronics (EME), ❹. The EME comprises a pulse width modulated inverter and the DC/DC converter, enabling it to integrate the functions for controlling the



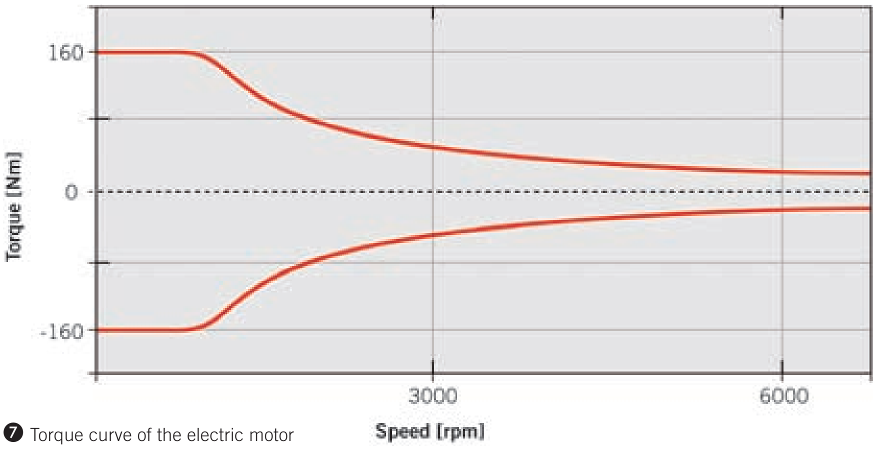
❹ EME hybrid control unit



❺ Overview of EME and interfaces



❻ Connection of the electric motor



❼ Torque curve of the electric motor

electric motor and transferring power between the 12 V on-board electrical system and the lithium ion battery into a single control unit. The functions of the hybrid operating strategy are also implemented in the EME, through which the operating status is selected depending on the driving conditions. The control unit weighs 12.2 kg.

The EME is installed on the engine in the lower area of the crankcase and linked to the electric motor via conductor rails. This allows the compact integration of the control unit and short cabling for the electric motor's three phases.

The engine-mounted installation space makes high demands on the EME with regard to vibration stability and temperature resistance. As a result, the control unit's hardware was specifically designed to cope with the high stresses it is exposed to.

The pulse width modulated inverter is used to control the electric machine.

The voltage of the HV on-board electrical system is converted into three phases, to which the coils of the electric motor are connected, ❺. Depending on the control of the rotating field, it is possible to output the torque via the electric motor (motor operation) and recover braking energy (generator operation). The pulse width modulated inverter is designed for operating voltages ranging from 85 to 125 V and can output currents of up to 125 A. This enables the electric motor to be operated at 15 kW.

Energy is exchanged between the lithium ion battery and the 12 V on-board electrical system via the bi-directional DC/DC converter. Usually, energy is taken from the HV battery and supplied to the on-board electrical system. This means that energy stored can be used efficiently and the power of the electric machine when used as a generator can be fed into the 12 V on-board electrical system. Due to its bi-directional operation, however, the lithium ion battery can also be charged if this is required for the operating strategy, or if external chargers are connected. The DC/DC converter can permanently output currents of up to 150 A on the on-board electrical system side. With a peak output of 2.1 kW, the on-board electrical system can also be provided with adequate power even at extreme load points. The high performance data of the DC/DC converter mean that no 12 V alternator is required.

The EME is liquid-cooled and connected to the low-temperature circuit of the cooling system.

The synchronous motor connected to the crankshaft delivers 15 kW and supports the eight-cylinder engine during start-up and acceleration with a torque of up to 160 Nm. With a maximum starting torque of 210 Nm, comfortable starts of the internal combustion engine can be assured even at low temperatures (as low as -25 °C). It therefore takes over the function of the starter motor and alternator in a single powerful component, ❻.

In order to save installation space in the axial vehicle direction, the EMC was designed as an external rotor motor. This provides the added advantage of a large active magnetic surface. A special flexible plate with an angled converter bolting provides a low-vibration mechanical connection between the electric machine and the gears. The optimised design of the electric machine in relation to its construction and operating strategy means that liquid cooling is not required.

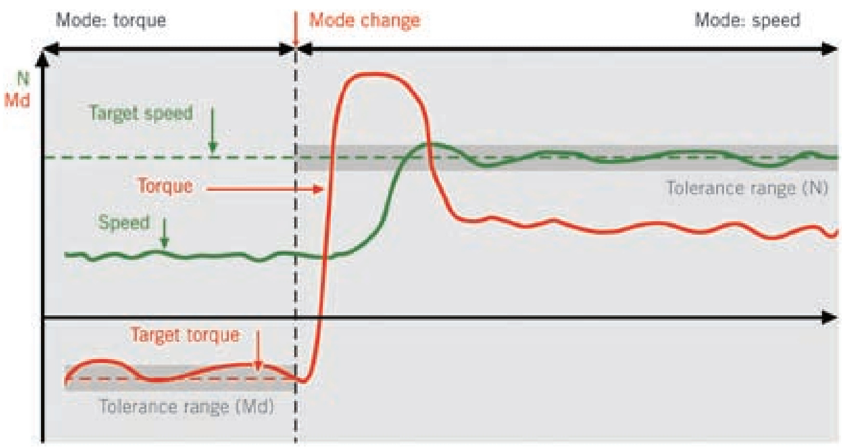
The curve of the electric motor's maximum torque over the speed is shown in ❼. As can be seen, the electric motor can output its maximum torque even at low speeds, thus extending the internal combustion engine's torque curve. The usable speed band is therefore extended towards fuel-saving low speeds.

In generator operation, the electric machine works with high efficiency due to its crankshaft-mounted installation. Battery-less operation to support the on-board electrical system and to safeguard system availability is also possible.

The EMC can be controlled according to speed, torque and voltage, ensuring that the best control strategy is applied at every operating point.

An example of the transition between two modes is shown in ❽.

In torque-based mode, the electric motor's torque is maintained in a tolerance band around the target specifica-



❽ Control of the electric motor

tion. This mode is chosen, for instance, during boosting or recuperation. If a fixed target speed is required by the operating strategy during the transition to idle, the motor is switched to speed-based mode. The speed is then maintained in a defined band while the electric motor's resulting torque adjusts.

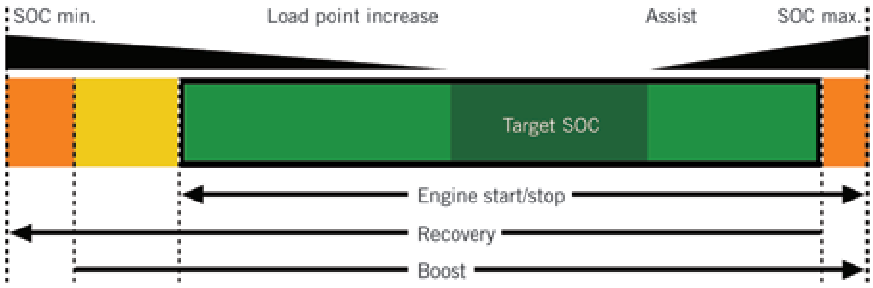
HYBRID FUNCTIONS

The conventional group of control units comprising the DME and EGS is supplemented on the ActiveHybrid 7's powertrain by the hybrid-specific control units EME and SME. The DME's existing torque structure has been revised in order to coordinate the two power sources of the internal combustion engine and the electric motor. The operating strategy, partitioned on the EME, controls the reduced-consumption hybrid functions, which comprise the automatic engine start-stop function, recuperation and operating point optimisation.

In order to exploit the maximum fuel consumption potential, a holistic view needs to be taken during the design and optimisation of the energy-related operating strategy. Depending on the sub-systems' operating status in the overall vehicle, the storage and discharge of electrical energy is controlled in a targeted manner as a function of the HV battery's state of charge (SOC), ❾.

The majority of the charging energy can be obtained through recuperation; the rest is generated by an increase in the internal combustion engine's load point in the electric motor's generator mode. To minimise the quantity of fuel required for the internal combustion engine, the operating strategy is used to define the internal combustion engine's characteristic map ranges for the load point shift with the maximum possible degree of overall efficiency. The energy stored is used for the start/stop function, for targeted drive assistance (boosting and assistance) and to supply the on-board electrical system and auxiliary components (for example, the electric air conditioning compressor).

The automatic start/stop function causes the automatic switch-off of the internal combustion engine when idling and makes a considerable contribution towards reducing fuel consumption. High ASSF availability is a basic requirement that must be ensured through a suitably-optimised operating strategy.

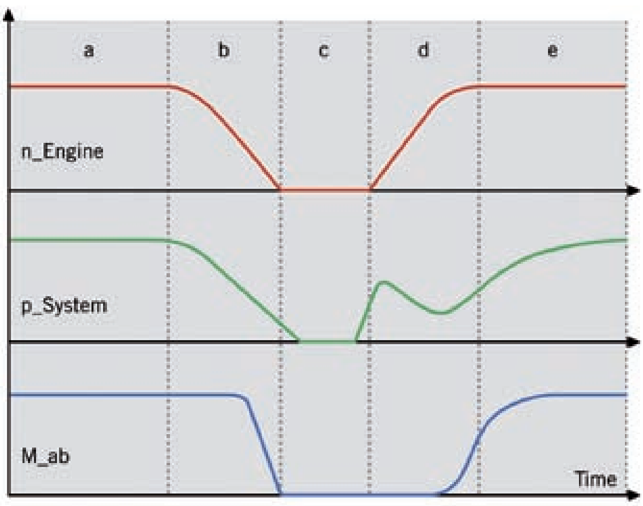


❾ Operating strategy

During development, particular attention was paid to comfort and starting dynamics. To do this, electric motor speed control with oscillation technology-optimised linear speed increases was used. By adapting and synchronising the internal combustion engine, electric motor and transmission application, it was possible to create a virtually vibration-free engine start without speed overshoots, ❿.

The high electrical starting torque and independently developed quickstart functions of the direct-injection petrol engine facilitate instant and dynamic response starts of a standard typical of BMW, even from engine standstill, without any customer-relevant detractions compared to the conventional basic version.

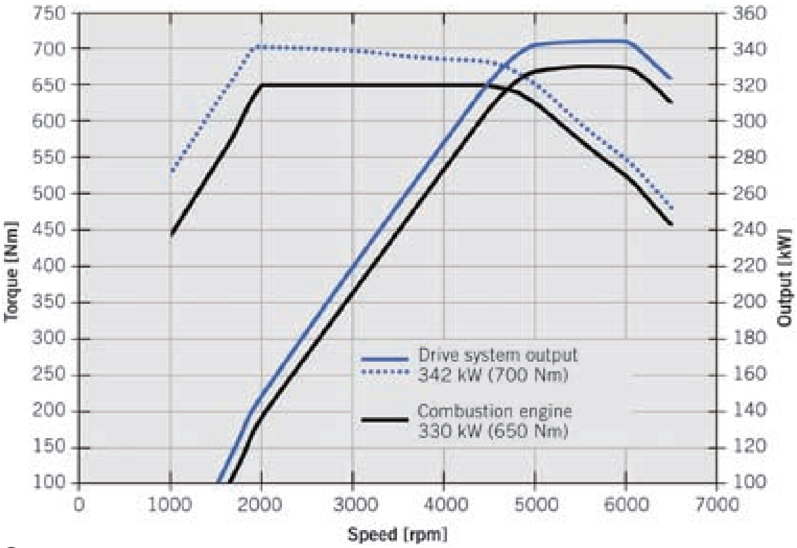
The BMW ActiveHybrid 7 intensively uses not only thrust phases but also, most importantly, the braking phases to recover energy. The electric motor, which is positioned between the internal combustion engine and the transmission, takes over the role of the alternator. The gear control ensures the best possible operating point for the electric motor. As soon as the driver takes his foot off the accelerator, the electric motor switches to generator mode and the kinetic energy is converted into electric energy. If the brake pedal is touched lightly, the car is first also slowed



a Idling regulated by the electric motor/gears in power transmission
b Comfort-optimised stop of the combustion engine/gears open power transmission following system pressure drop
c Engine idle phase/gears not in power transmission
d Engine start phase with regulated speed buildup and simultaneous compensation of the combustion engine torque by the electric engine/pre-conditioning of the hydraulic system gears through HIS, comfort-orientated buildup of the power transmission
e Transition to regulated idling/power transmission established

n_engine = Combustion engine speed
p_System = Hydraulic system pressure gears
M_ab = Drive torque/power transmission

❿ ASSF: automatic start/stop function



⓫ Hybrid system full load diagram

down through the increased generator braking torque in order to supply the energy, which would otherwise be lost as frictional heat, to the HV battery.

Only with more pressure on the brake pedal is the mechanical friction brake also activated. The control exerted by the dynamic stability control (DSC) ensures on-demand coordination of the electrical and mechanical braking effect. The controllability of the braking system remains unaffected. The transition between electric engine-based deceleration and mechanical deceleration is not perceivable by the driver. The decision to use a pedal-linked system was made since, compared to a pedal-neutral system, it offers the advantage of a more direct braking pedal feel as well as a better cost/benefit ratio.

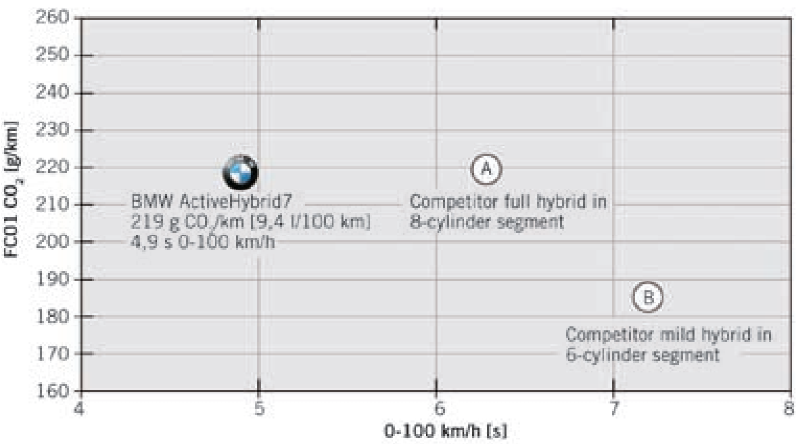
During boosting, the internal combustion engine is supported by positive driving torque from the electric motor. The constant high torque of the electric motor at low speeds supplements the internal combustion engine, thus facilitating the use of a longer final drive ratio with improved car performance. Advantages include the significantly increased maximum full system load and compensation of the delayed actuation behaviour of the turbocharger during non-stationary acceleration procedures. At high SOC values, the internal combustion engine can be relieved by the electric motor to provide additional fuel consumption savings, allowing part of the driver's desired torque to be converted into electromotive energy to reduce the energy excess.

The BMW ActiveHybrid 7's driving mode has a maximum system output of 342 kW and a maximum torque of 700 Nm, ⓫. Thrust in comparable power output regions was previously achievable almost only with engines with significantly more engine capacity and generally also associated with a correspondingly higher fuel consumption.

The BMW ActiveHybrid 7, however, combines the significantly tangible increase in dynamism with an equally impressive efficiency gain. As a result, it was possible to achieve a reduction in CO_2 of around 17 % to 219 g/km (9.4 l/100 km) in the NEDC compared to the conventional basic variant.

The EU5 and ULEVII exhaust emissions standards are safely complied with. Of particular note is the certification of the ActiveHybrid 7 according to the Green Car 4 Star rating, which has been applicable in Japan since 2009. This includes undercutting the existing Japanese emissions limit by 75 % and a range increase of 25 %. Despite this, there are no sacrifices in terms of dynamism. With an acceleration of 4.9 s from 0 to 100 km/h, the saloon car is approaching sports car performance and assumes a special position among its competitors, ⓬. The car's performance can be combined with a fuel consumption value that is around the level of the values exhibited by full hybrid competitor models.

The power development is available from idling speed. The response behaviour is reinforced by the driving torque that is also contributed by the electric motor and is particularly noticeable to the customer. Each acceleration request is ensured subjectively without delay due to the rapid torque build-up and the gear change that occurs spontaneously, regardless of the driver's request. The speed level during cruising has been lowered further in order to harness further fuel consumption potential and in order to boost comfort. The maximum speed of the BMW ActiveHybrid 7 is limited electronically to 250 km/h.



⓬ CO_2 emissions and driving performance compared to competitors

SUMMARY

It has been possible to develop a drive system in the ActiveHybrid 7 that satisfies all the customer's requirements in the premium segment. Fuel consumption equals that of classical six-cylinder drive systems, while dynamism is at the level of previous twelve-cylinder engines. With the ActiveHybrid 7, the customer gains a typical BMW hybrid without having to accept the usual compromises between driving performance and payload.

ROLL STABILISATION OF TRUCK CABINS FOR COMMERCIAL VEHICLES

In passenger cars, active suspension is a well known solution for more comfort and handling. However, even though commercial vehicles designers have the same objective, truck drivers do not yet benefit from active suspension technology. TNO developed and successfully implemented the active roll stabilisation system ARS which uses an hydraulic rotary actuator in the secondary suspension of a truck. Road tests demonstrate an improved comfort in combination with increased driver feedback – when compared to an equivalent air suspended truck cabin.

COMPROMISE BETWEEN A PRIMARY AND SECONDARY SUSPENSION

A commercial vehicle's suspension consists of a primary (chassis) and secondary (cabin) suspension. The wide range of weights that these vehicles have to deal with, from unloaded to fully loaded, poses serious constraints on the primary suspension's design. For the design of the secondary suspension, driving comfort and vehicle feedback are the most important criteria.

Today the most comfortable cabins are suspended by four air springs, one on each corner. The low stiffness of these springs, together with the integrated hydraulic damper, provides good vertical cabin comfort under most conditions. However, during cornering the springs' low vertical stiffness results in excessive cabin roll, which can negatively affect the vehicle's (steering) feedback.

In order to reduce the cabin roll motion, a relatively stiff torsion bar is integrated between chassis and cabin. While the stiff torsion bar benefits driver feedback, it negatively affects comfort, for example on asymmetric road inputs. With the objective to improve both ride comfort and steering performance in commercial vehicles using active cabin suspension, TNO started a development project to evaluate the added value of active roll stabilisation (ARS) in the secondary suspension of a tractor.

MULTI-BODY TRACTOR SEMI-TRAILER MODEL

To study the comfort issues related to commercial vehicles, a Matlab SimMechanics multi-body model was built-up and developed for a tractor semi-trailer combination with 44 degrees-of-freedom. Measurements from a variety of tests on a real tractor with a semi-trailer were used to validate the model.

These tests were also performed in the simulation environment, using vehicle parameters obtained from measurements on the real vehicle. The model, suitable for comfort and attitude evaluations, was used to evaluate the added value of ARS on the cabin comfort.

TEST RIG EVALUATION

To demonstrate the ARS system in a full size truck, existing automotive components were selected, deriving certain specifications from multi-body simulations. Key component of the ARS system is a hydraulic rotary actuator. The actuator pressure is controlled by a Wheatstone bridge (WSB) valve block, a hydraulic circuit using four pressure control valves configured like its electrical equivalent.

Compared with a conventional hydraulic setup – using a single pressure control valve in combination with a directional valve – the WSB has superior pressure control performance as it does not suffer from strong non-linearity's at low pressures and when changing pressure sign. Controllability in the on-centre area is extremely important for the application of skyhook roll damping.

Before integration in the demonstrator vehicle, all components were evaluated on a test rig. The measured component characteristics were used for development of a detailed hydraulic model of the ARS system in Simulink. This model was used in combination with the multi-body model to develop the active cabin suspension controller. The low level pressure and current control required for the individual solenoid valves was developed and tuned on the test rig. Because the WSB has four pressure control valves, multiple solutions are possible to realise a particular pressure set point. These additional degrees-of-freedom were used to optimise control performance and minimise energy consumption. The architecture of the actuator

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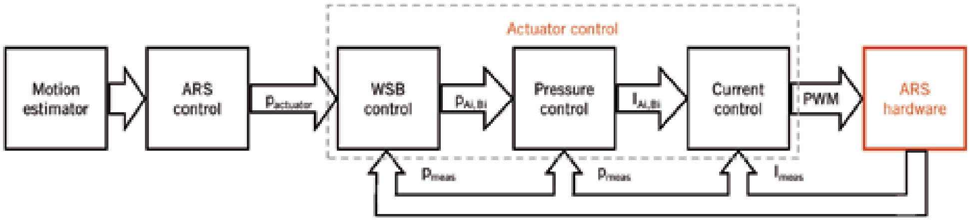


❶ Control architecture of the actuator with Wheatstone bridge (WSB), pressure control and current control

controller, composed of WSB, pressure and current control is shown in ❶.

FULL SCALE DEMONSTRATOR

A standard tractor with an air-suspended cabin was modified to demonstrate the ARS system. The vehicle's original cabin stabiliser was divided in two parts and the hydraulic rotary actuator fitted in-between. Controlled by the WSB, the actuator enables active adjustment of the cabin's torsion bar angle. Hydraulic power is supplied by a radial piston pump driven by the combustion engine. To allow excessive testing in the prototype phase, an oil-air cooler is integrated in the hydraulic circuit. An overview of the ARS system components is shown in ❷.

The tractor is fitted with more than 20 motion sensors used for model validation purposes and to determine the vehicle's comfort level for different chassis settings. A rapid control prototyping (RCP) platform is used for both data acquisition and control implementation. The platform controls the solenoid valves using 24-V operated PWM power stages with integrated current measurement.

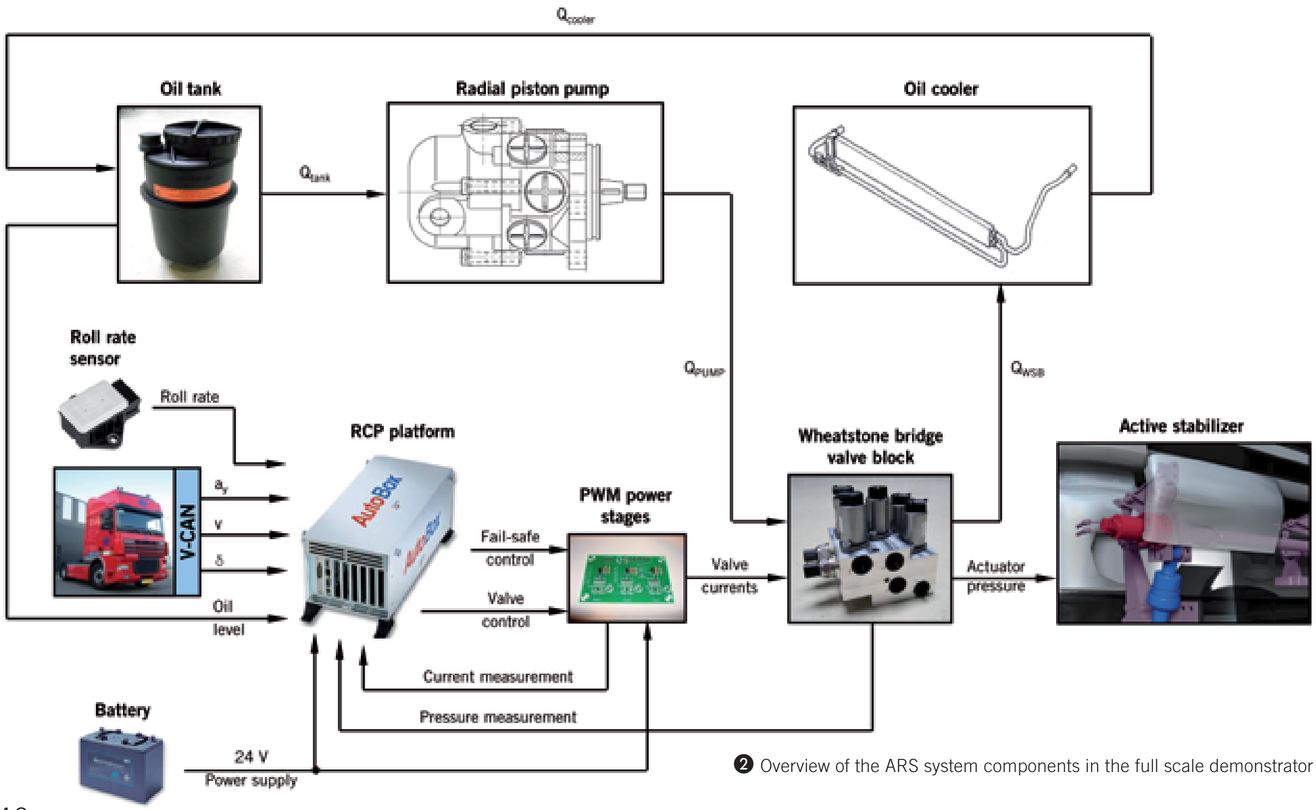
CONTROL DEVELOPMENT

The ARS control algorithm was first developed using the multi-body tractor semi-trailer model, which was extended with the ARS hydraulic model. Due to the good model representation, only minor tuning was required in the vehicle. Two different control functionalities are implemented in the ARS controller: active roll stabilisation and skyhook roll damping.

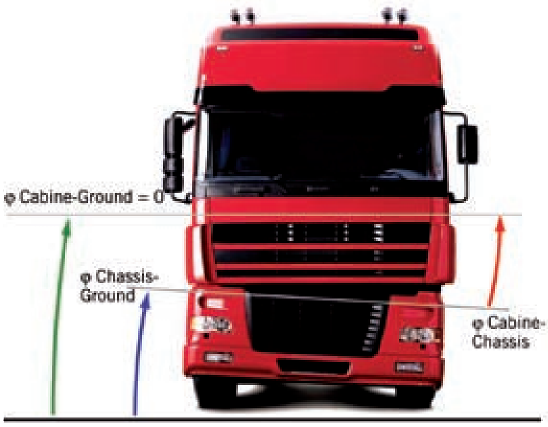
With the integration of an active roll stabiliser in the secondary suspension of a truck, the cabin roll during cornering can be compensated actively. This functionality is called active roll stabilisation and results in a more direct response of the cabin roll motion on the steering input. To realize this functionality, the controller uses the lateral acceleration to calculate the required actuator torque. To compensate for time delays of the controlled system, a model is implemented to estimate the lateral acceleration based on the motion signals available on the vehicle CAN bus (see "Motion estimator" in ①).

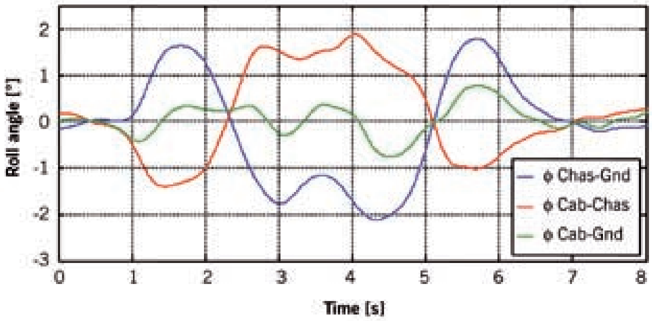
Result is a smoothed, non delayed lateral acceleration signal which can even compensate for road banking. Measurements of a lane change performed with the ARS demonstrator vehicle at 70 km/h with a maximum lateral acceleration of 3 m/s² are shown in ❸.

During straight line driving the ARS system only adds minor roll stiffness to the secondary suspension, which has a positive effect on the cabin comfort. Still, the stiff primary stabiliser in combination with the relatively high seating position of the driver can result in a considerable lateral motion



❷ Overview of the ARS system components in the full scale demonstrator





❸ Definition of angles (left) and measurement of the roll angle (right) during a lane change with the ARS demonstrator (v_x = 70 km/h; $a_{y,max}$ = 3 m/s²)

due to road unevenness. In addition, trailer roll motion further increases the feeling of discomfort. Simulation studies with the multi-body tractor-semi trailer model indicated that a skyhook roll damping control strategy considerably improves driver comfort. By adding a roll rate sensor to the cabin, this feature has been implemented successfully in the demonstrator vehicle.

MEASUREMENT RESULTS

To quantify the added value of the ARS system, the original vehicle (standard vehicle with air suspended cabin) was evaluated on different road types. The measurement data for translation and rotation during these tests was registered and used to determine the comfort index conform ISO 2631. When the ARS system was installed, the same measurement set was collected to compare the comfort indices. As can be seen from ❹, the ARS system improves the overall cabin comfort in translation with more than 16 %, as was estimated at the beginning of the project from the multi-body simulations.

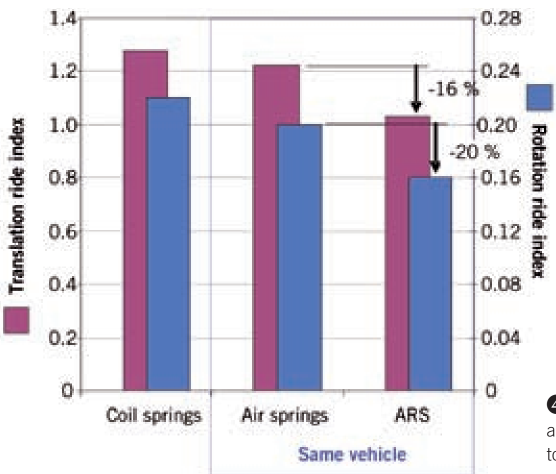
Since the ARS system primary actuates the cabin roll motion, improvement is mainly found in the roll index and in the lateral translation index.

Driver feedback is a property that is difficult to judge objectively. For this reason evaluations were performed with different drivers. The direct response of the cabin motion to the drivers steering input was experienced very positively by all drivers. Especially the combination of the direct vehicle feedback with the improved cabin comfort was judged as a unique selling point.

PROOF OF TECHNICAL FEASIBILITY

Compared to passenger cars, durability requirements for commercial vehicles are about five times higher. Trucks for long distance transport are designed for a lifecycle of 1.5 million km, which poses high demands on system components. To proof the technical feasibility of ARS for truck cabin suspension, the life cycle expectation of each component was evaluated against the 1.5 million km requirement. To this end, on-road durability data was collected and representative load cycles were calculated. The evaluations have proven the feasibility of the pump, stabiliser, actuator and WSB to meet this requirement.

Hydraulic active suspension systems are often associated with high energy consumption, which is an even greater issue in commercial transport. To check the impact of the ARS system on the energy consumption of trucks, the system has been evaluated on different road types over several hundreds of kilometres. From these data the energy consumption on each road type has been estimated by replaying the logged pump speed and pressure on a test rig. Using a road mix for long distance transport, the average energy consumption of the ARS system is about 850 W. With the application of some proven optimisation measures, the energy consumption can even be reduced by more than 40 %, bringing the average consumption to below 500 W.

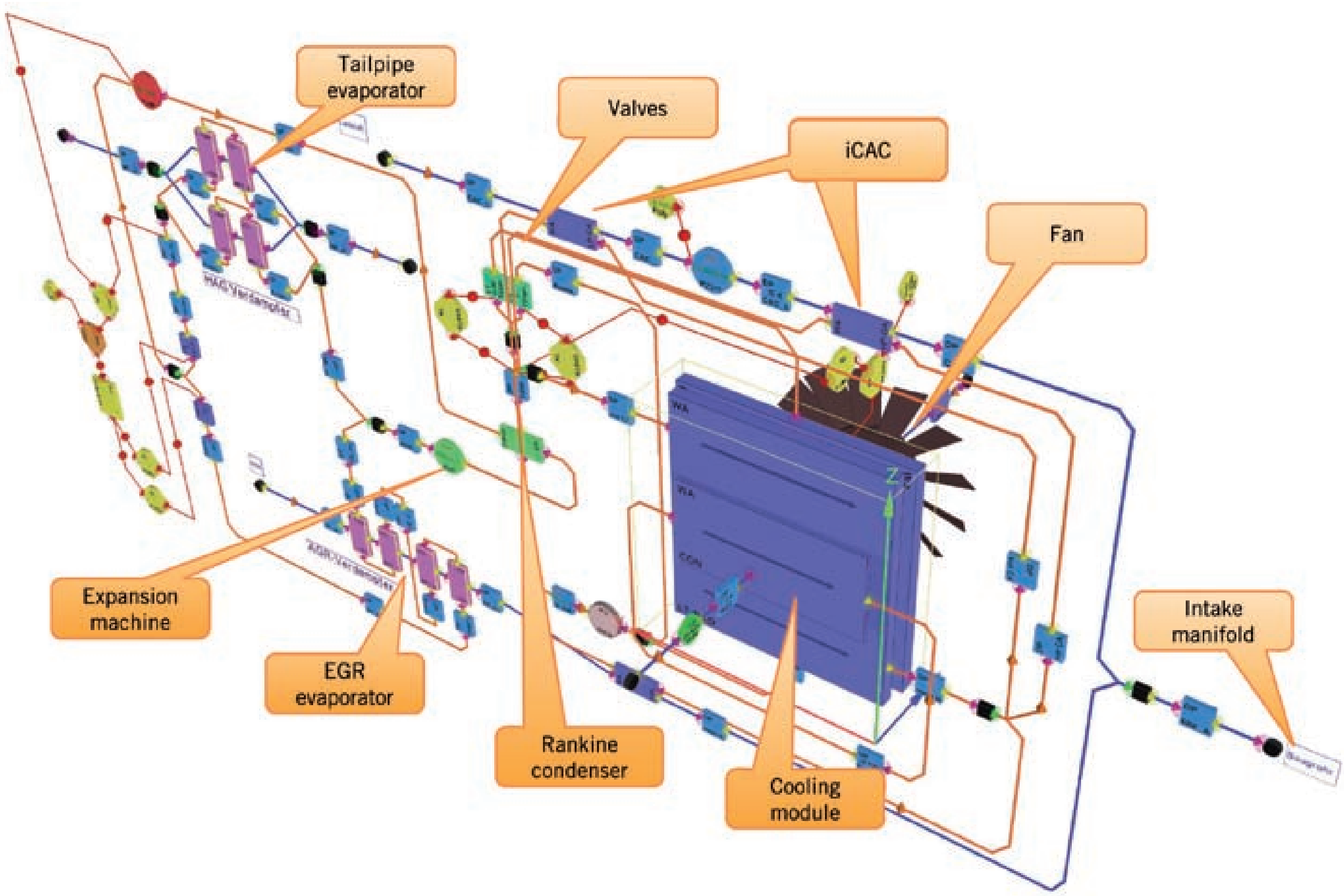


❹ Comfort measurement for translation and rotation of the demonstrator conform to ISO 2631

SUMMARY

Over the last few decades, the level of driver comfort in commercial vehicles increased significantly. However, due to its high position above the road, the roll and pitch behaviour of the cabin still causes discomfort for the driver, which is very difficult to solve using passive suspension elements only.

With the integration of an ARS system in combination with a skyhook roll damping strategy, TNO developed a solution that offers superior handling capabilities along with uncompromised cabin comfort. The ARS cabin suspension system was implemented and evaluated in a real truck. The technical feasibility was proven clearly.



THERMAL MANAGEMENT FOR FUTURE COMMERCIAL VEHICLES

In 2013, the Euro VI emissions standard will come into force. Thermal management has a significant role to play in meeting this standard. The optimization of the engine cooling system, introduced by Behr, can lead to a 3 to 5 % fuel consumption reduction in a Euro VI engined vehicle. A further reduction of up to 5 % may be possible through the integration of a Rankine cycle system into the vehicle, since this process allows the unused exhaust heat to be converted into useful work.

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REQUIREMENTS

In order to achieve the necessary reduction in NO_x emissions for Euro VI economically, a combination of exhaust gas recirculation (EGR) and aftertreatment (SCR) will be used. A possible system architecture is shown in ❶.

This means that cooled EGR will be brought in across the board. Consequently, the demands placed on the engine cooling system will increase compared to those of Euro 5. Up to an extra 100 kW must be transferred from the EGR cooler and through the cooling system to the ambient air. Thus larger and performance enhanced radiators and stronger fans with new fan drives are necessary. The radiators must withstand higher loadings. Due to more powerful coolant pumps, higher temperatures and changes in the cooling system architectures, the pressures in the cooling system will rise from today's 2 bar to between 3 and 4 bar (relative). As a result of the use of EGR, higher charge air pressures (up to 4 bar (rel.) compared to 3.5 bar (rel.) up to now) and temperatures (up to 240 °C compared to a maximum of around 200 °C up to now) are to be expected, which means increase loads for the intercooler.

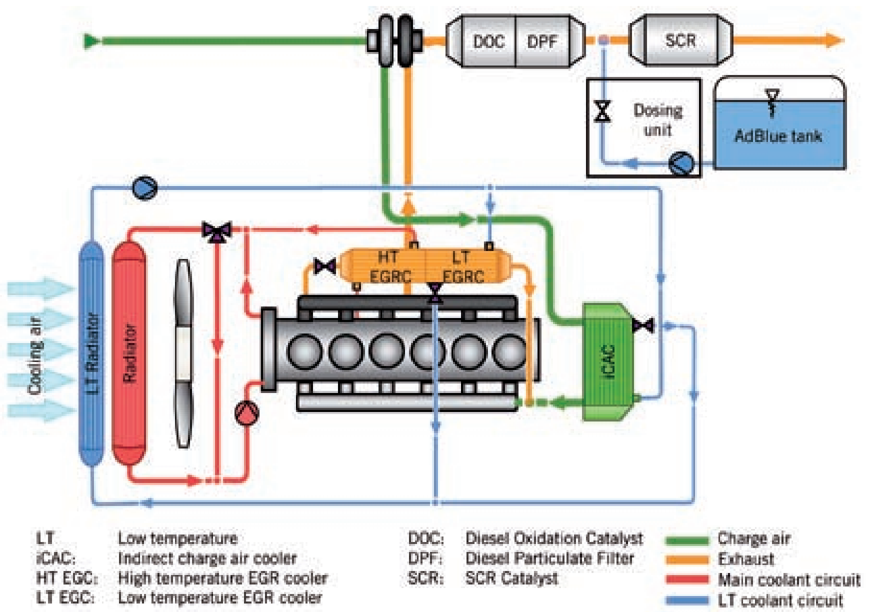
In order to satisfy these higher demands, the complete vehicle cooling system has been optimised and several new components developed. These cooling systems and the Rankine cycle will be presented in the following paper. Further information on the development of the engine cooling system can be found in [1].

ENERGY EFFICIENT COOLING SYSTEM

The use of specially developed simulation methods has improved the performance density of the radiator and the fan, thus reducing the amount of material required, ❷. At the same time, the increased durability requirements have been fulfilled.

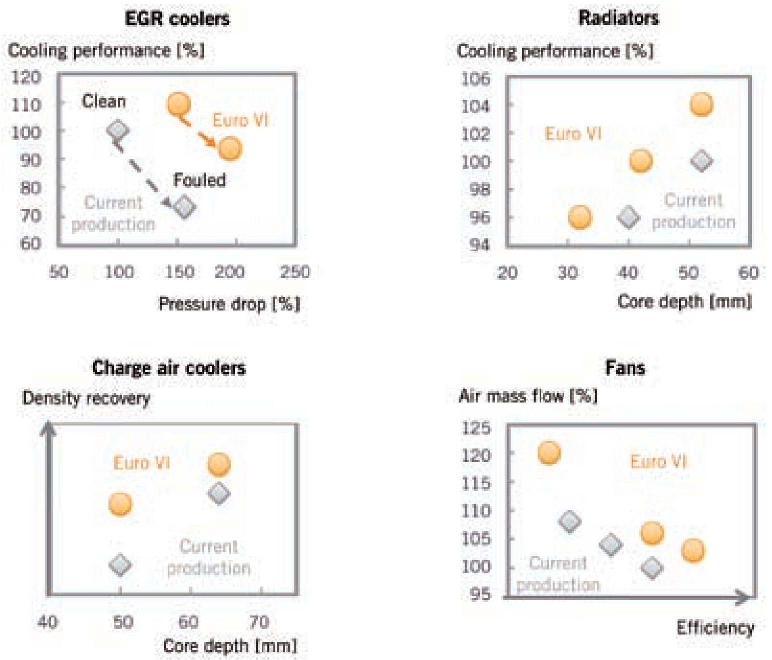
The new EGR cooler delivers up to 50 K lower exhaust outlet temperatures with a significantly reduced sensitivity to fouling. This allows a calibration of the engine for improved fuel consumption; an improvement of up to 2 % has been measured. The newly developed radiators and intercoolers enable a total reduction in axial packaging space of about 25 mm to be achieved with the same cross-sectional specific performance. This results in a better air flow through the cooling module, which means that the required fan power can be reduced by up to 10 %. With the same depth, it has been possible to reduce the pressure drop across the intercooler, which means reduced compressor work.

With the new fan, it is possible to increase the air mass flow significantly, even with the same fan diameter. The relationship between performance and



❶ Schematic layout of a cooling system for an EGR plus SCR Euro VI engine efficiency has been improved through the further development of the fan blade and hub. A new concept for the integration of the fan into the cooling module has been shown to have stable operation and increased efficiency under highly throttled conditions. Thus the fan axial space requirement has been reduced and, even in tightly packaged situations, the flow through the coolers improved.

Up to now, the contribution of the fan operation to the average vehicle fuel consumption could be ignored. At Euro VI, the increased heat rejection could result in the necessity to activate the fan more often, which may lead to an unwanted increase in fuel consumption. Depending upon the ambient temperature, between 1 to 2 % may be measured. A larger cooling system with the new component developments described above will help to prevent the majority of this possible increase. However, the higher air flow through the cooling module could lead to an increase in the vehicle's aerodynamic drag coefficient (c_d). Consequently, the air flow must be optimised: air guides before the cooling module mean that the stagnation pressure can be better utilized and leaks, which are detrimental to the drag coefficient, can be prevented. Downstream air guides will reduce the drive power requirements for the fan. In combination, this will mean that, under real world driving conditions, the fan power requirements can be held at today's normal levels.



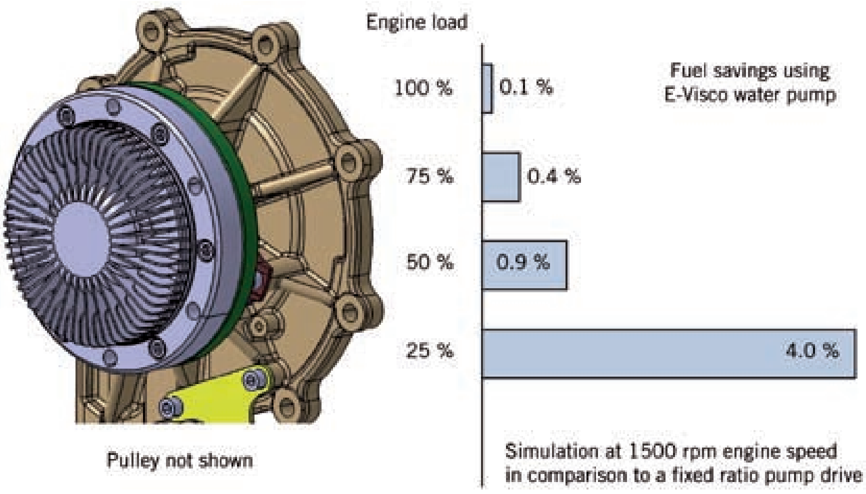
❷ Further development of the cooling system components for Euro VI

CHANGES TO THE SYSTEM ARCHITECTURE

As a result of the improved transient response and reduced pressure loss, a fuel consumption reduction of up to 2 % can be achieved when using a cooling system architecture including indirect charge air cooling, as shown in ①. The improved transient response comes from the reduced installed air volume with indirect charge air cooling, which leads to a quicker build up of boost pressure. Furthermore, the thermal inertia of the indirect intercooler limits the charge air temperature during tip in. Both of these effects reduce the emissions during transient operation, thus enabling a more fuel efficient engine calibration. In addition, the system can be easily expanded to include low-temperature EGR cooling. The lower EGR outlet temperatures lead to reduced NO_x emissions, which, as previously shown [2], can also allow a more fuel efficient engine calibration. This gives a further potential fuel consumption reduction of around 2 %.

ON-DEMAND CONTROL

The increased air mass flow requirement will be fulfilled either by a higher speed and efficiency optimised fan or a higher performance fan. For both solutions, new drives have been developed. These drives have both a higher torque transfer capability and improved modulation characteristic. When the installed fan power is increased, the heat generated in the drive also increases. More cooling of the clutch is needed, which means that the fan may need to be engaged more often. Therefore, the passive cooling capability of the Euro VI fan drives has been significantly improved. In addition, the dynamic on-off response of the clutch has been improved to ensure that the fan reaches the required speed more quickly. This helps to reduce fuel



❸ The Visco water pump drive and its potential fuel consumption advantages consumption and has also improved the cold start characteristic of the clutch.

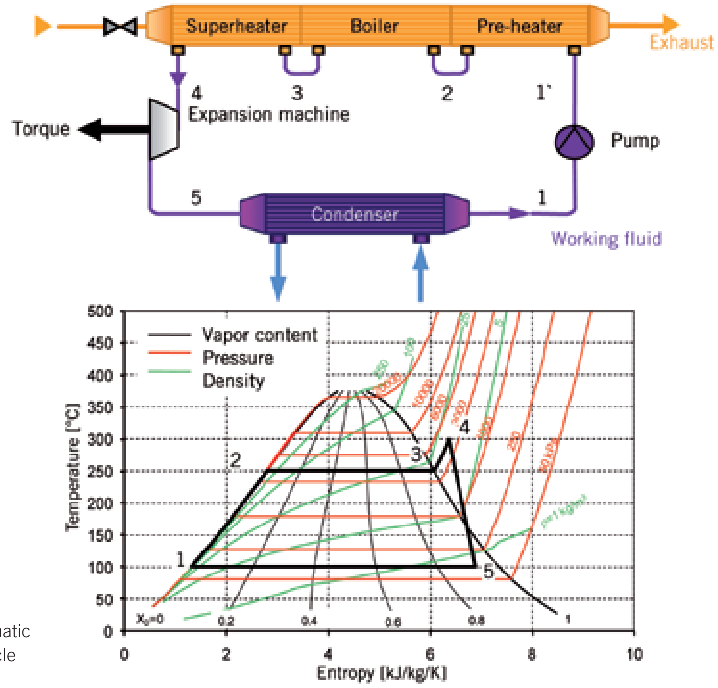
The Visco principle has now been carried over to water pumps. These are almost always driven with a belt running at a constant ratio to the engine speed. The Visco drive can be integrated into the pulley and, just like in the fan drive, can be controlled on-demand electronically. Thus, the water pump speed can be controlled depending on the demanded engine power. As such, 1 % of fuel consumption can be saved in driving conditions on average, ❸.

OUTLOOK

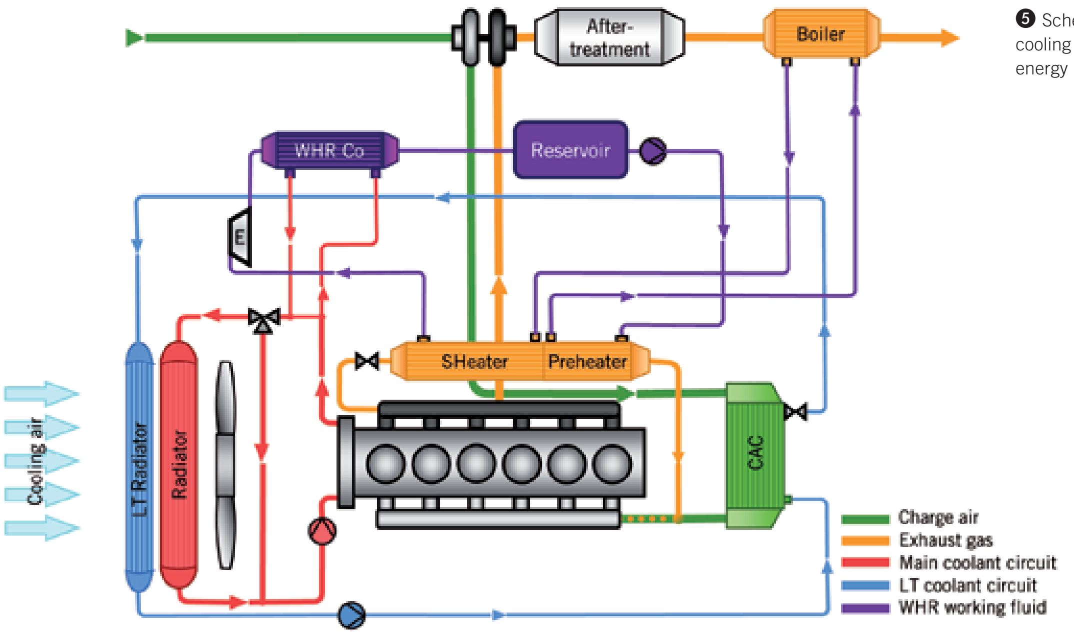
In truck engines with EGR, the exhaust gas temperatures can be up to 600 °C upstream of the turbocharger and up to 450 °C downstream. This waste heat still contains a significant potential for work, which cannot be used in a conventional process but which could be utilised through a secondary heat-to-power process, such as the Rankine cycle, which is currently in use in gas or steam power plants to improve their efficiency [3]. In this closed steam power cycle, a pressurised working fluid is heated using an external heat source. The fluid evaporates and is super heated before being expanded across a machine to produce usable work, ❹.

For the cooling system, this means that the development of new heat exchangers is necessary and the Rankine system must be integrated into the complete vehicle thermal management.

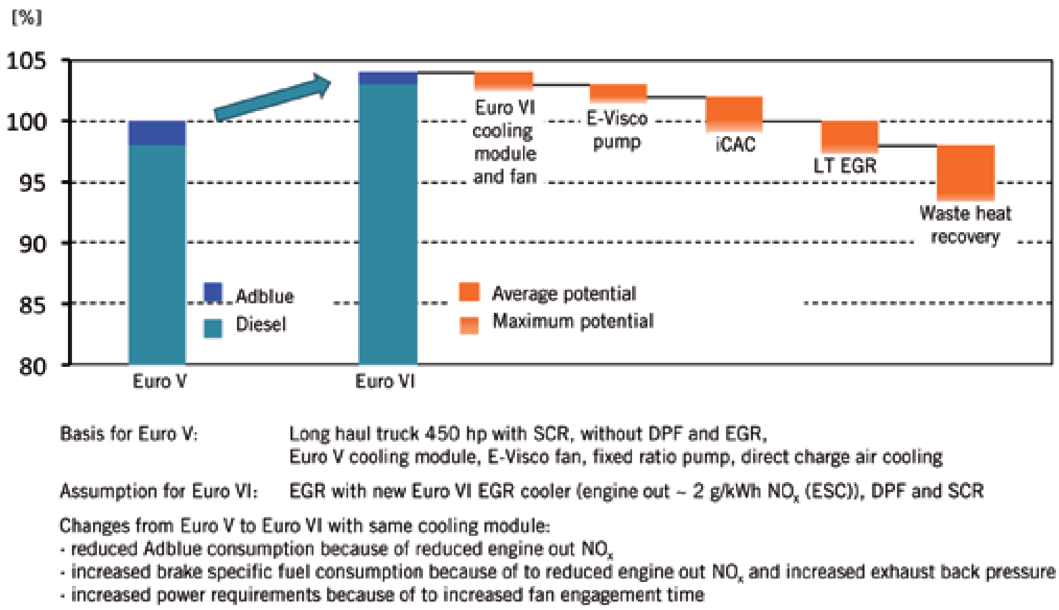
It is, therefore, important that the heat sources and sinks are used in such a way that not only the steam process but also the complete system is optimised. Through the cooling system, which supports the Rankine system, the charge air cooling and EGR cooling will be influenced. Additional heat rejection requirements will also increase the required driven fan power. Thus, the complete system optimization must consider three aspects: the usable power from the Rankine cycle, the engine efficiency and the auxiliary power requirements of the cooling system. Consequently, the system simulation methods



❹ Function schematic for the Rankine cycle based on water



❺ Schematic layout of an engine cooling circuit including exhaust energy recovery via the Rankine cycle



❻ Estimate of long haul truck fuel consumption

were extended to include the Rankine cycle. The system investigation shows that, under realistic boundary conditions, a fuel consumption reduction of up to 5 % in a typical long haul truck could be achieved. EGR is an ideal heat source for the Rankine cycle, especially at higher EGR rates. On the one hand, a large amount of heat is available from the EGR to drive the Rankine process. On the other hand, the energy extracted by the Rankine cycle reduces the cooling requirements. In order to achieve the maximum amount of useful work, it is necessary to use other heat sources, such as the tailpipe exhaust. However, this will then increase the cooling requirements to such an extent that, depending on the vehicle speed and the ambient temperatures, it may be necessary in some cases to limit the amount of work recuperated.

At least three new heat exchangers will be necessary for the Rankine system: a tailpipe evaporator, an EGR evaporator that replaces the EGR cooler and a condenser, ❺. These components will differ significantly from those used in the power generation industry. It will be a challenge to achieve the thermodynamic requirements in the packaging space available on a truck.

As such, high power density components are in development but there are still issues to resolve. The answers will have a significant influence on the thermodynamic layout, the design principle and the materials used. One question, for example, concerns the choice of the best working fluid.

Fluids under investigation include water, alcohols, such as ethanol, and other organic fluids. Each fluid has advantages and disadvantages, and the choice of working fluid has a significant impact on the components, the system layout, the vehicle cooling system and the potential risks inherent in vehicle operation or maintenance.

The question of how the power will be transferred is also open. Of particular importance is the expansion machine and its coupling to the drive train. This will have a significant effect on the overall system performance and its applicability to long haul truck applications. In order to drive the technology development forward, new suppliers have the opportunity to enter the market.

SUMMARY

Thermal management is a key technology to reduce the fuel consumption of future commercial vehicles. It has an influence on the engine combustion processes, the vehicle aerodynamics and waste heat recovery. The innovations relating to low-temperature EGR cooling and indirect charge air cooling have succeeded in improving engine efficiency. The aerodynamic optimization of the cooling system, fitted with efficient components, and the demand controlled operation of the fan and water pump through the application of E-Visco drives will reduce the power consumption of the cooling system under real driving conditions. The Rankine cycle will bring further heat management requirements. By using an integrated systems approach that considers the interactions of the individual sub-systems, thermal management has the potential to contribute a reduction in fuel consumption of up to 10 % in the future commercial vehicle, ❻.

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SIMULATION-BASED HOMOLOGATION OF BRAKES FOR TRAILERS

From 2011 onwards, electronic stability controls (ESC) have to be integrated into heavy commercial vehicles. Thus, it is now permitted to use simulation systems to cope with the increasing certification requirements. Haldex Brake Products and IPG Automotive realized the first simulation-based homologation according to the requirements of the ECE 13/11 regulations. The simulation project tested electronic stability functions for truck trailers. The use of the TruckMaker simulation software for these purposes opens up new possibilities for virtual test driving.

MOTIVATION

The ECE 13/11 regulation provides the option of using simulation for "other vehicles, vehicle variants and other load conditions", the dynamic manoeuvres are standard manoeuvres [1, 2]. However, the ECE 13/11 regulation imposes validation requirements, including verification of the simulation tool by comparison with the real-world tests. Additionally, the simulation tool must be approved by the Technical Service [1, 2].

The use of ESC in heavy commercial vehicles poses new challenges which cannot be simply projected from "car" to "truck". Whereas cars are built on similar concepts, trucks come in a nearly infinite number of combinations of tractor and trailer, numbers of axles, tyres, pneumatic brake systems etc. The huge number of different trailer configurations extends the variant matrix. Attention must be paid to model quality for flexible body structures and loads. To handle the complexity – with more than 50 degrees of freedom (DOF) – highly capable simulation tools in terms of model variety, quality and real-time capability are required.

ROLL-OVER SIMULATOR

Second generation Haldex EB+-system is a brake control system for semi-, centre-axle and full trailers having air brakes. It provides the necessary components to enable compatibility with either electronically and pneumatically signalled or a pneumatically only signalled towing vehicle. In addition to normal service brake control, EB+ also contains a roll stability system. The EB+ system provides electro-pneumatic control of the trailer brakes with built in load sensing and anti-lock functions. This uses a lateral accelerometer, in addition to the existing sensed variables (wheel speeds and pressures), to determine if the vehicle is close to its roll threshold.

Haldex decided to use a simulation solution since the conventional approach involved considerable costs, time and complexity. In addition, the company desired to use the simulation for efficient homologation of future soft- and hardware changes to the braking and stability system as well as for the simulation of fail-safe and functional tests within the development process. Haldex opted for IPG due to the company's experience in vehicle dynamics and Hardware-in-the-Loop (HiL) testing expertise.

As there was no precedent to refer to, it was important to bring together the specific expertise of the three partners: Haldex as system manufacturer, TÜV as Technical Service and IPG as vehicle dynamics specialist. Due to the complexity of actuators, sensors and pneumatic elements of ESC systems, a HiL test bench was selected which integrates real-world active control systems into simulation.

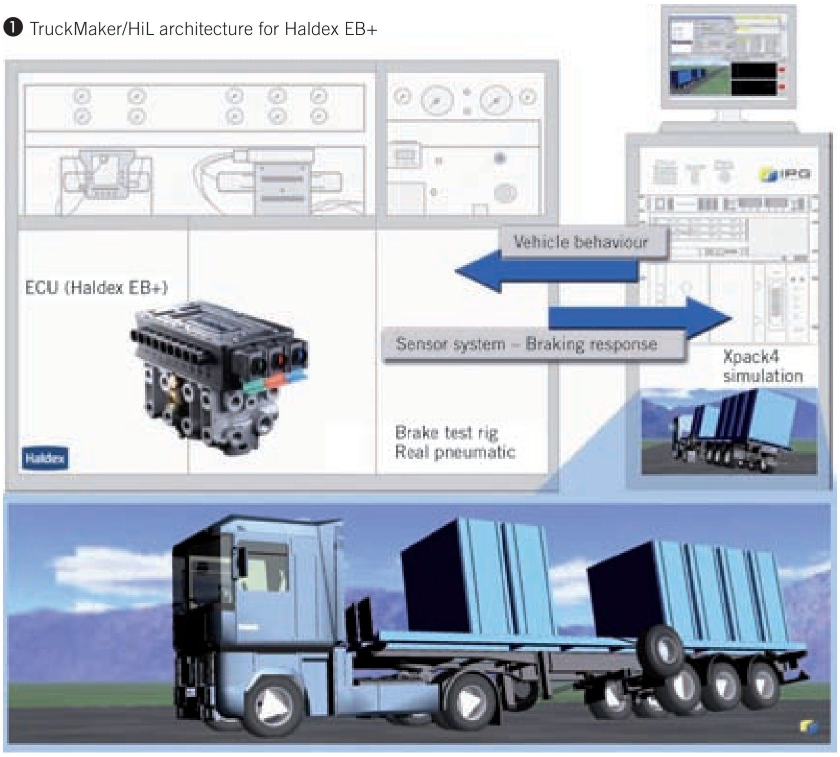
IPG's simulation solution "TruckMaker" is suited for the vehicle dynamics simulation of heavy commercial vehicles – from office simulations on PC through to HiL tests on large test rigs, ❶. The TruckMaker/HiL architecture provides the platform of the virtual drive test running on the Xpack4 real-time hardware. This allows high performance and flexibility of the components. Via suitable analogue, digital or CAN based I/O cards the models exchange the respective signals. An important role is played by pneumatics which may be implemented into the HiL system. Using a host PC, the simulation can be operated and visualized online. To satisfy the accuracy requirements truck and trailer-specific modifications had to be made.

The new roll-over simulator enables comprehensive virtual road tests and thus the verification of the roll stability up to the physical limits of the road test with all required vehicle, trailer, tyre, road surfaces and load parameter variations. The large number of up to 50 DOF, the cyclical ground scans of the many tyres, the fully non-linear kinematics and compliance description of the numerous axles pose a challenge to real-time behaviour, ❷.

TEST MATRIX AND VEHICLE VARIANTS

Out of 33 total vehicle/trailer variants a few master variants were selected for real-world testing. The intention was to demonstrate the ESC performance of all other variants with TruckMaker/HiL simulation with a total of more than 1000 single test cases. For this purpose simulation software extensions had to be realized by developing a comprehensive

❶ TruckMaker/HiL architecture for Haldex EB+



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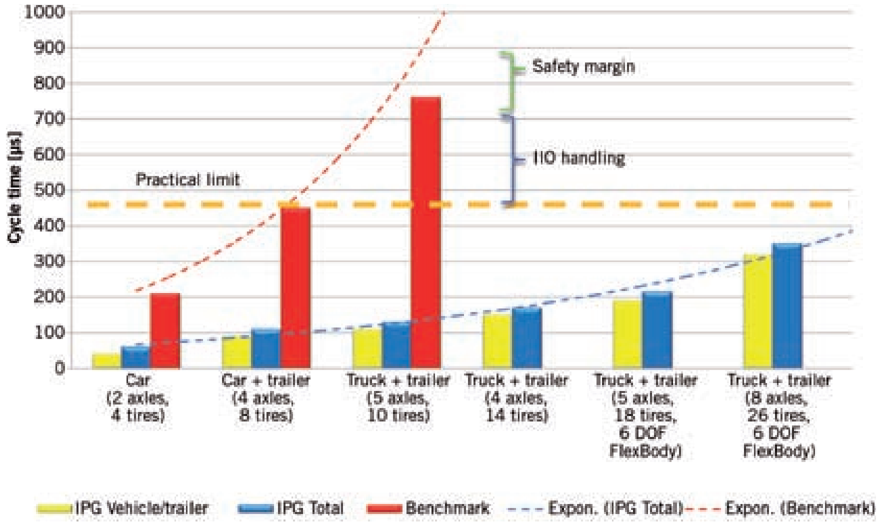


❷ TruckMaker realtime performance chart

truck and trailer model library in order to fulfil the requirements of ECE 13/11, primarily:

- semi-trailer, centre-axle trailer and full-trailer models
- multi-axles, steered axles with single and twin tyres
- different hitch systems
- flexible body structures
- configurable load situations (fixed or moving loads)
- different powertrain variants (4x2, 4x4, 6x2, 6x4, 6x6…)
- pneumatic brake model
- test automation and test management tools
- extension of the driver model for truck driving skills needed for closed loop manoeuvres.

Afterwards, the final test matrix had to be established. The experts found out that the tests proposed by ECE 13/11 could not be identically applied for truck-trailer combinations – since the vehicle dynamics of a truck differ from those of cars. The test programme had to be modified respectively. After a review the experts established the test manoeuvres, ❸, listed below. Only closed-loop manoeuvres were defined as they are better suited to simulate use cases (driver is integrated into driver-vehicle-road loop and carries out vehicle-independent driving tasks):

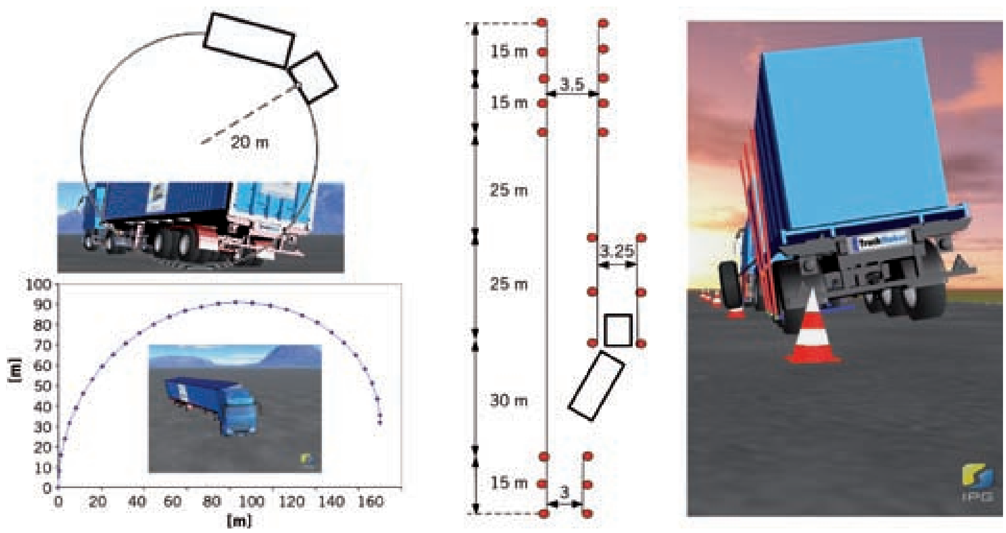
- constant circle clockwise and anti-clockwise
- increase curvature
- double lane change.

TESTING AND SIMULATION

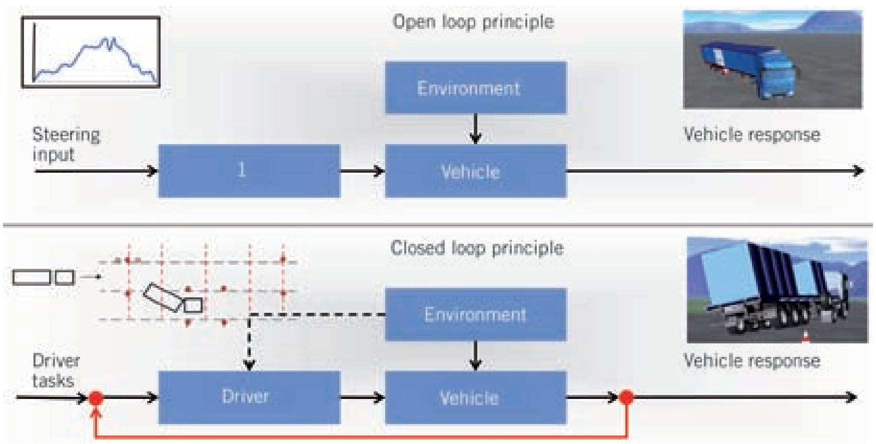
The Technical Service soon realized that ECE 13/11 lacks specifications to assure the quality of the simulation process. The validation quality of the models themselves, the repeatability and re-traceability as well as the robustness of the simulation results are crucial issues. Additionally, the Technical Service had applied principles which assure the reliability of the results and allow the simulation to be repeated even after many years.

The homologation tests served to demonstrate the function of the EB+ and to gather the validation data. For these data an extension of the measuring point schedule for trucks and trailers was necessary to ensure the requisite comparability. The key parameters were: speed, side slip angle, steering wheel angle, lateral acceleration, heading angle, yaw rate, roll angle, roll rate, wheel speed, valve activity, brake pressure and tip-off distance.

Two procedures were established for the validation: Firstly, the simulation quality of the truck/trailer model including embedded brake components was to be demonstrated on the simulation test rig. To eliminate driver influence, the input parameters of the driver were specified as speed and steering angle in the open loop of the simulation environment and the vehicle's response from the real-world measurements was compared with the simulation results. Secondly, it was to be demonstrated that the closed-loop driving manoeuvres can be reliably reconstructed with a suitable driver model. The



❸ Defined test manoeuvers for truck and trailer combinations



❹ Validation procedures – open loop and closed loop principles

IPGDriver as appropriate driver model has the skill to run up to the vehicle dynamics limit and offers a huge number of suitable functions such as automatic planning, learning and adaptation capabilities. After making the extensions for truck-specific behaviour, it was possible to see whether modelling in the limit range could be successfully achieved in the closed-loop manoeuvre [3], ❹.

In an extensive validation activity the experts evaluated the signals in comparison between road test and simulation as well as the key characteristics of roll-over speed. Every diagram was analysed and additional variant calculations carried out as needed. The experts came to the conclusion that firstly, the demonstration of the model quality was fully successful; secondly, positive proof was provided that the "Driver" model simulates the test driver in an outstanding manner; and thirdly, the desired large number of truck and trailer variants can thus be modelled and homologated in simulation.

SIMULATION TOOL TEST REPORT

The "Vehicle Stability Function Simulation Tool Test Report" prepared by TÜV Nord was successfully submitted to the KBA for confirmation of TruckMaker according to regulation ECE 13/11. The following is a quote from the evaluation by TÜV Nord: "Whereas the Special Validation Procedure [open loop] utilised the same input variables from the vehicle test, the Standard Simulation Procedure [closed loop] is designed to normally be used independently from any vehicle test. However, it was shown that both procedures correlated well with the measured vehicle data", ❺ and ❻.

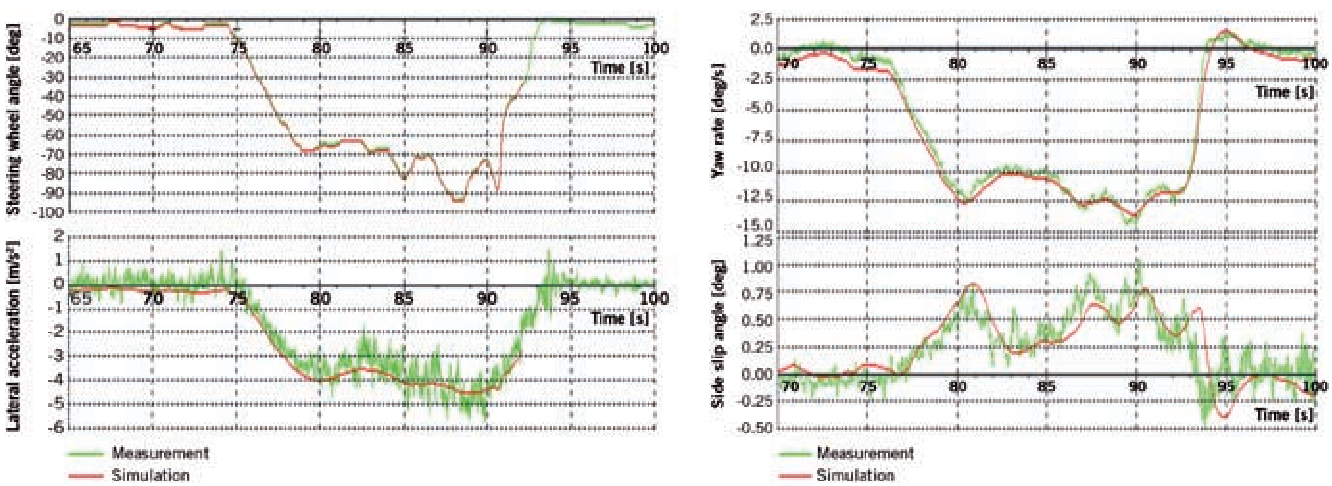
TOOL BOX AND TEST AUTOMATION

Without automating the tests, such a high volume of all variants – a total of 1000 – would be hardly manageable. To secure a robust process, a special homologation tool box was developed. It is based on the test automation with ScriptControl and the new functions of the TruckMaker TestManager. For this purpose, various brake ECU configurations, truck-trailer variants, the manoeuvre catalogue and the test methods were implemented. A test number system according to a fixed nomenclature was realised as well as the use of the automatic archive function and creation of a single or a finished homologation report. This report can be used by the Technical Service as an annex for the homologation.

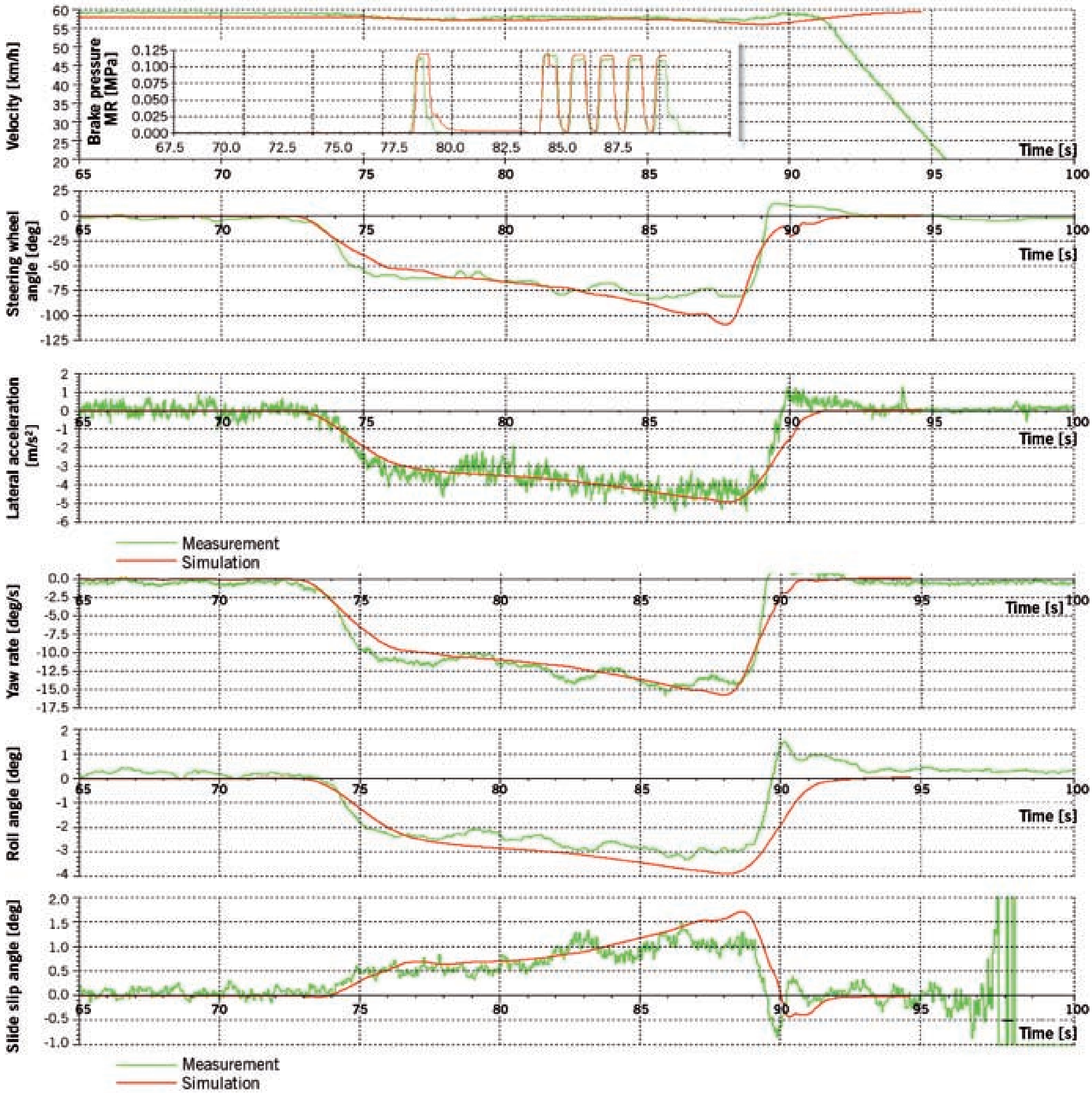
CONCLUSION

In collaboration with IPG Automotive, Haldex achieved the first successful simulation-based homologation of their EB+ roll stability system. This new option leads to highly attractive time and cost savings. It also offers transparency and flexibility for the entire homologation process. In addition, Haldex can simulate future software releases and variants in this area as well as failsafe and functional testing.

ESC and other advanced active safety systems are gradually being phased in accordance to regulatory requirements. However, the use of simulation will help to considerably ease the burden on automotive OEMs and suppliers. Networking ESC with other driver assistance functions



❺ Open loop validation results



❻ Closed loop validation results with brake intervention

like automatic emergency braking systems, adaptive cruise control and lane departure warning systems offers further potential for accident avoidance [4]. Here, the use of simulation tools will be particularly beneficial because the traffic scenarios and networking of multi ECU's increase the related complexity. TruckMaker is already prepared for this challenge and contains all extensions required for simulation such as sensor simulation (radar, lidar, ultra-sonic), controller interfaces, camera based sensors, traffic, traffic control, road infrastructure and environment [5]

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

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REPRESENTATIVE TESTING OF COMMERCIAL VEHICLES

There is an effort to maximize the payload of vehicles within the legal framework and to develop more fuel-efficient drive systems with low emissions. Hence the determination of representative requirements to cover reliability and durability at a maximum lightweight and cost potential are of crucial importance. At the Institute of Automotive Engineering the so-called 3D-method was developed for the purpose of identifying the representative customer's requirements. This method systematically divides customer operation in driver, driven vehicle and driving environs. This paper presents the creation of representative testing requirements for commercial vehicles using the 3D-method based on a huge database of customer measurements realized in cooperation with Daimler AG.

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1 METHOD

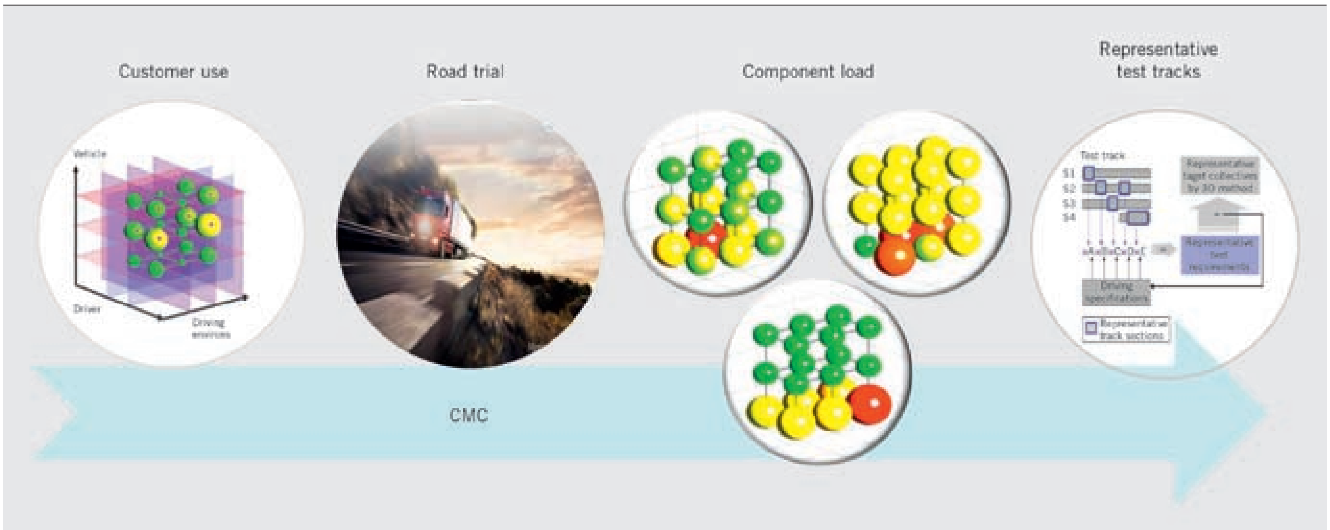
For the definition of representative testing requirements, the customer use space, in which the statistically relevant customers operate their vehicles, has to be defined in the first step. The customer use has to be measured in order to determine the fatigue fatigue damage influence of the observed components regarding the customers defined within the 3D parameter space. With the measured data it is possible to identify the customer use. The measurements were carried out within the scope of the CMC project (Customer Market Correlation) of the Daimler AG. The analysis of the measurements is possible by means of mathematical methods, the identification of customer type and component-specific load factors. The customer type with the highest load factor is called "representative customer" and defines the testing specifications for the observed components. With the knowledge of representative loads for different components on selected test track sections a customer-oriented and efficient experimental design can be determined for the testing. The approach is illustrated in ❶.

2 CLASSIFICATION OF CUSTOMER USE

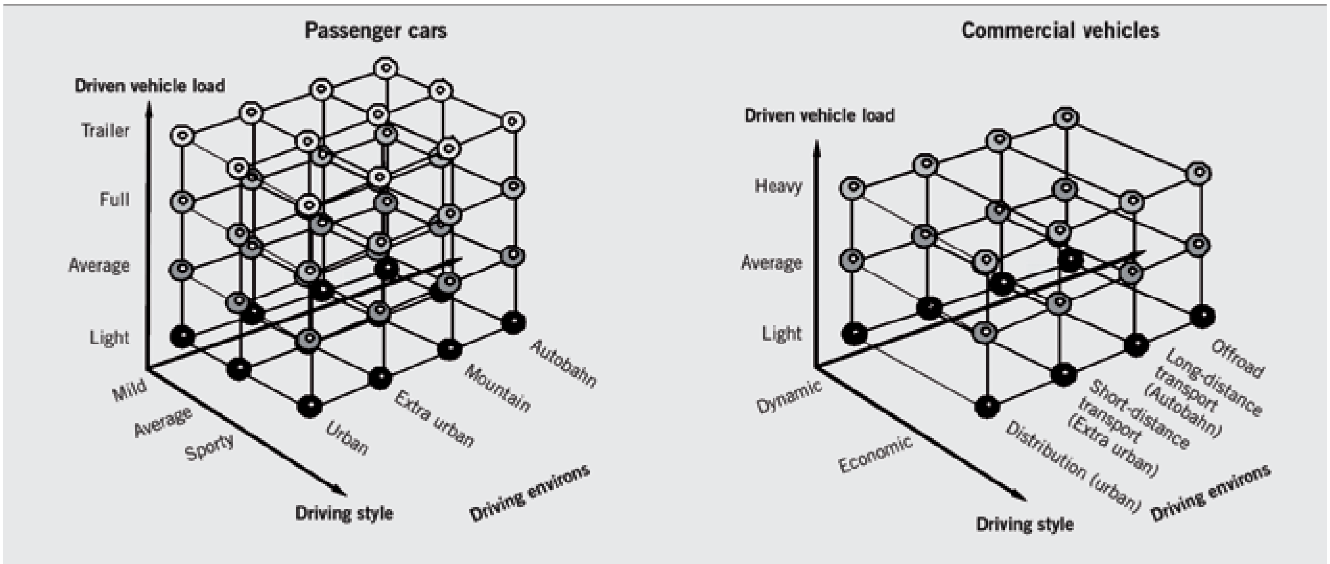
This paper describes the extension of the 3D-method [1, 2, 4-6, 8, 9], developed by the Institute of Automotive Engineering for passenger cars, to commercial vehicles in cooperation with Daimler AG. The first step of transfering the method from passenger cars to commercial vehicles was the definition of the 3D-parameter space for commercial vehicles, whose parameters are significantly different from those of passenger cars. Therefore the 3D parameter space with the axis "Driver", "Driven vehicle" and "Driving environs" is defined by relevant parameters of commercial vehicles. In terms of longitudinal dynamics, the driver is considered by means of an economic or dynamic style of driving, the vehicle by its total mass as "light", "average" or "heavy" load. The driving environs are differentiated according to the main application: distribution (city), short distance (extra urban), long distance transport (highways) and off road. The so defined 3D-customer use for commercial vehicles is the basis for the systematic investigation of customer operations. In the field of passenger cars, the 3D-parameter space for the driver is divided into three driving styles (mild, average and sporty), the driving environs into the four road types (urban, extra urban, Autobahn and mountain) and the vehicle into four types of load (light, average, heavy and with trailer) [7, 8]. The 3D-parameter spaces for cars' and trucks' powertrains are shown in ❷.

3 DETERMINATION OF REPRESENTATIVE DATA FROM FLEET TESTS

The input variables for the 3D-parameter space (vehicle load, speed profiles …) and component-related fatigue damage characteristics (e. g. load spectra) are systematically measured and evaluated as part of Daimler's CMC project monitoring the customers' vehicle use. The base of this project is a statistically selected fleet of several hundred commercial vehicles from different customers, which are equipped with data loggers on request. They record defined load spectra which are transmitted via the GSM mobile network. For privacy reasons, only load spectra are measured to document the vehicle's condition. Driver data or vehicle positions are not included. For example, the percentage distributions of traveled road gradients, temporal frequency distributions of the total vehicle mass or the acceleration behavior of the vehicles are derived from these load spectra.



❶ From the customer use to representative test tracks



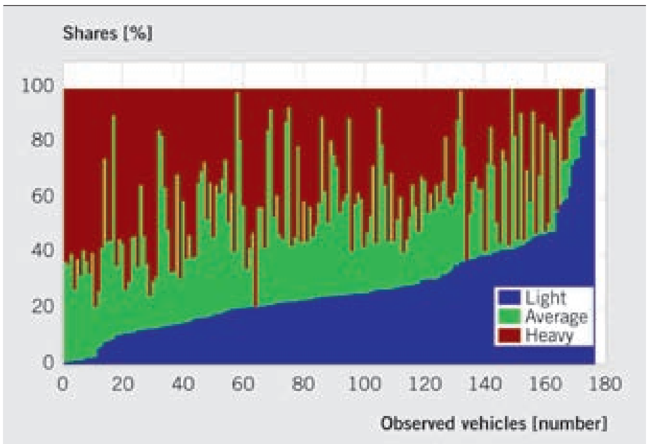
❷ 3D-parameter spaces for cars and commercial vehicle regarding drivetrain components

4 DATA ANALYSIS

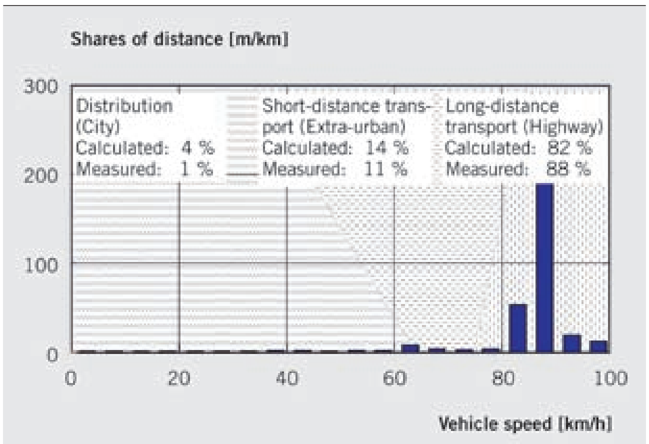
The percentage of customer use is determined by measured data. Regarding the vehicle mass, loading conditions below 50 % of the vehicle total weight is defined as light, masses between 50 % and 75 % "average", masses of above 75 % "heavy". Thus, the percentage distribution of the vehicle mass can be determined from the measurement data for each vehicle measured. Looking at the percentage of mass distribution the use and occupancy of a commercial vehicle can be estimated. ❸ shows the percentage of mass distribution for a selection of commercial vehicles.The observed vehicles are sorted by increase of "light" load shares.

The base for the allocation of the driving environs portions is the load spectrum of driven speed. Based on measurements on public road test tracks, an algorithm to identify the statistical distribution of the driving speeds on the route types "city", "extra urban" and "highway" was developed. This algorithm assigns the shares of driven environs of the customer vehicles by recorded velocity distributions, as shown in ❹. It assigns shares with velocities of under 35 km/h to "city", shares with 65 to 75 km/h to "extra urban" and shares with up to 85 km/h to "highway" routes. Velocity components between the identified speed ranges are assigned by means of a transfer function to the neighboring classes.

The distinction whether the driver drives dynamically or economically is derived from engine torque and gear-dependent load spectra. For this purpose this load spectrum is first converted into a load spectrum of retrieved power, depending on the vehicle speed. The driving resistance or constant speed was determined individually for each vehicle by taking the distribution of the road gradient and the vehicle mass into account. This driving resistance and the demand of engine power are plotted versus the speed for one vehicle as shown in ❺. The engine power demanded by the driver in addition to the power to overcome driving resistance can be interpreted as power for acceleration. From the



❸ Percentage load shares of the measured vehicles (sorted by shares of empty trips)



❹ Relative velocity components of a test track with the assessment areas of the identification algorithm and a comparison between measurement and estimation frequencies of demanding additional power a dynamic performance factor is calculated for each individual vehicle. Vehicles with a dynamic factor above average are assigned to the dynamic driving style; the remaining vehicles are assigned to economic driving style.

5 DETERMINATION OF THE 3D-PARAMETER SPACE USING ANALYSIS ALGORITHMS AND CUSTOMER DATA

To allow a classification of customer data in the 3D-parameter space, measured data from the CMC project of the Daimler AG are analyzed by presented algorithms. It is now possible to identify the customer's motion profile offline for each vehicle regarding the three axes of the 3D-parameter space. Assuming that the driving style of a driver is not influenced primarily by the vehicle or the driving environs the distribution of the customer types are directly derived from the offline detection of customer types as shown in ❻.

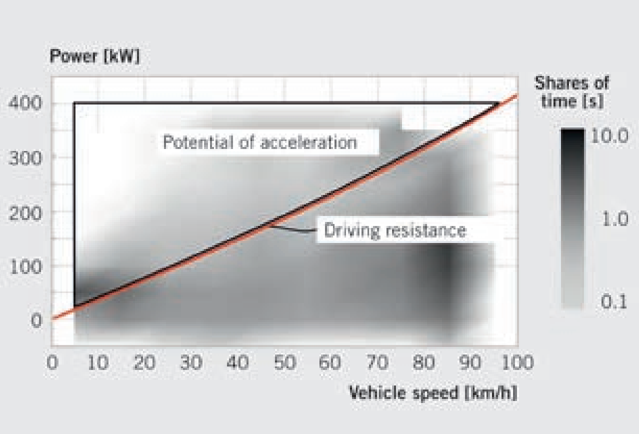
6 COMPONENT LOADS IN THE 3D-PARAMETER SPACE

The customer measurements of the CMC's fleet recorded not only the driver's action, but also load spectra, which relate to particular component loads. Thus, for each measured vehicle the customer use in the 3D-parameter space as well as the load of individual components are known.

Based on the obtained data the customer type in the 3D-parameter space which is relevant for the fatigue damage of a component can be identified. According to the linear fatigue damage accumulation component loads can be summed up (for example, doubling the appearing load frequency leads to a doubling of the fatigue damage) [3]. Thus, the entire load of component B is determined by the sum of the individual loads. Since each vehicle is driven with individual percentage of customer use A_{Kx}, a certain load is given for each customer within the 3D-parameter space. It can be determined by the product of driven distance A_{Kx} and by the distance normalized customer load B_{Kx}. This approach leads to Eq. 1.

EQ. 1

$$A_{K1} \cdot B_{K1} + A_{K2} \cdot B_{K2} + \ldots + A_{K18} \cdot B_{K18} = B$$



❺ Identification of customer's driving style by approximation of acceleration usage from collected CMC-data

The normalized customer loads B_{Kx} can be identified through a number of customer vehicles. Therefore Eq. 2 is used for all considered vehicles. This equation is derived for several vehicles from Eq. 1 adding an error vector E. This error vector is required since Eq. 2 must be considered to be an over determined system of equations in order to secure the statistical method, i.e. more vehicles must be measured than customers are defined in the 3D-parameter space.

EQ. 2

$$\begin{pmatrix} A_{K1,1} & \ldots & A_{K18,1} \\ \vdots & \ddots & \vdots \\ A_{K1,n} & \ldots & A_{K18,n} \end{pmatrix} \cdot \begin{pmatrix} B_{K1} \\ \vdots \\ B_{K18} \end{pmatrix} + \begin{pmatrix} E_1 \\ \vdots \\ E_n \end{pmatrix} = \begin{pmatrix} B_1 \\ \vdots \\ B_n \end{pmatrix}$$

Using a correlation analysis the strains of each customer within the 3D-parameter space can be determined by approximation with the aim of minimizing the error vector E. A constraint mapping of a drive train component like this is exemplarily shown in ❼. For this component it is noticeable that the distribution transport (urban) has a very stressful effect on the component considered here. Due to the special fatigue damage mechanism to this component, an average vehicle weight provokes a certain driver's behavior. This driver's behavior in combination with the gear shift behavior of the vehicle causes strong fatigue damage to the component. In this example no significant difference can be seen between the driver types. But this is generally not the case for other components with other fatigue damage mechanisms. The identified loads are pure customer loads. No vehicle will entirely be used with medium load, dynamic driving style and on short distances, but there will always be a mixing of driving styles or other 3D parameters. This mixing must be considered when determining the component load.

The customer causing the largest average load on a specific component is called the representative customer. The representative load or representative load spectrum caused by the representative customer has to be the requirement for representative testing.

7 DEFINITION OF REPRESENTATIVE TEST TRACKS

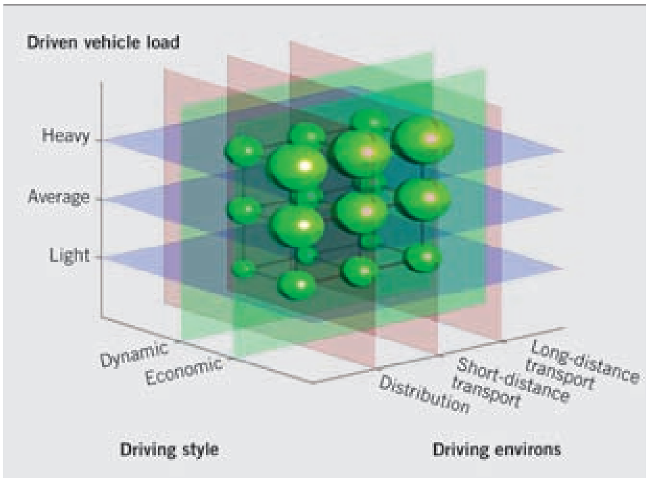
For efficient and simultaneous testing of several components in durability tests the order and frequency of tests on available test tracks have to be selected in such way that the resulting test route is as short as possible but a representative load is applied uniformly to all components as well.

Due to the characteristics of the test routes a natural accumulation of the load is ensured, i. e. individual components are highly stressed by the chosen routes. The individual routes show customer-orientated load spectra rather than a single-level load spectrum similar to test rig procedures. This allows significant loading on several components simultaneously within the same test procedure. Hence the condition may be established that the component load B_{Bx} caused by the representative customer is given by the product of the sum of all loads $B_{SX,x}$ of the partial test routes and the corresponding frequency of occurrence a_x:

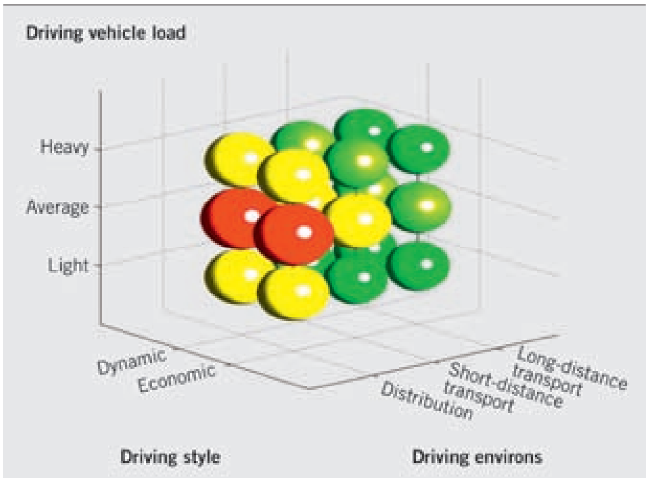
EQ. 3

$$\begin{pmatrix} B_{S1,1} & \ldots & B_{S1,n} \\ \vdots & \ddots & \vdots \\ B_{Si,1} & \ldots & B_{Si,n} \end{pmatrix} \cdot \begin{pmatrix} a_1 \\ \vdots \\ a_n \end{pmatrix} = \begin{pmatrix} B_{B1} \\ \vdots \\ B_{Bi} \end{pmatrix}$$

With: n: number of routes
i: number of components



❻ Profile of a commercial vehicle movement in the 3D-parameter space (the sphere size corresponds to the distance shares of each customer type)



❼ Load of customer types: the larger the sphere, the greater the distance based load of the customer

An exemple of the demand on a component is shown in ❽. It can be seen that various test sections are combined with each other, so that representative exposure can be modeled [7].

Through an optimization algorithm the required repetition of the individual test sections can be determined in a way that an efficient roadway plan is generated corresponding to the representative requirements. If certain parts are tested not at all or only incompletely (not representatively) on all test sections, separate testing in special test programs is necessary. Otherwise no optimum frequency of occurrence of the driven test tracks can be found.

8 OUTLOOK

The presented and implemented method is based on measurements of commercial vehicles in customer use. Aiming of frontloading within the development of commercial vehicles, a substitution of the measurements is possible by using a simulation model. This model must represent both the driver's behavior in the customer facility and the vehicle accurately. Thus, the burden on the test track optimization for the components can be determined in an early stage of development.

For simulation of the customer operation the simulation tool MOVE3D (Modular variable and effective platform for 3D-simulations) is used which was developed at the Institute of Automotive Engineering [1, 2]. This simulation environment includes a specifically created and verified vehicle model as well as statistical drivers and driving environs models. These models allow a long-term simulation of infinite length for all defined types of customers without repetition of the driving situations.

The statistical driving environs model generates target velocities and road gradients based on the measurements of identified speed curves and the measured height profiles which are summarized in multidimensional statistics.

The output of the driving environs model is used by the statistical driver model for selection of the appropriate driver actions corresponding to the respective driving conditions. Usually these are longitudinal accelerations, decelerations or constant speed requested by the driver's control of the accelerator pedals.

Within the simulation multidimensional statistical correlations concerning driven speed profiles and the operation of the driver-vehicle interfaces are used. Aim of future activities is to receive these statistical correlations in customer vehicles in order to obtain a parameterization base for the simulation model.

9 SUMMARY

In cooperation with Daimler AG and the Institute of Automotive Engineering of the Technische Universität Braunschweig a systematic approach for the analysis of component loads in customer use was established in the field of commercial vehicles. The presented development tools provide a broad basis for continuous improvement of the product quality by taking costumer requirements even more into account for the development of commercial vehicles of Daimler AG.

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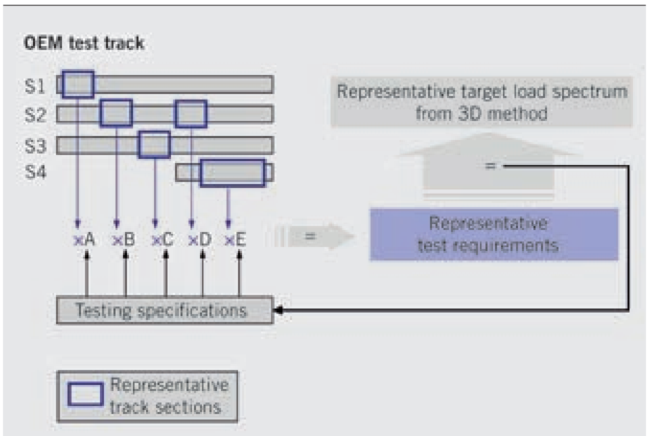

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